

**STATIC RESERVOIR MODEL UPGRIDDING AND DESIGN OF
USER INTERFACE**

A Thesis

by

SONG DU

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2009

Major Subject: Petroleum Engineering

**STATIC RESERVOIR MODEL UPGRIDDING AND DESIGN OF
USER INTERFACE**

A Thesis

by

SONG DU

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Approved by:

Chair of Committee, Akhil Datta-Gupta
Committee Members, Yalchin Efendiev
Behnam Jafarpour
Head of Department, Stephen A. Holditch

December 2009

Major Subject: Petroleum Engineering

ABSTRACT

Static Reservoir Model Upgridding and Design of User Interface.

(December 2009)

Song Du, B.S., Tsinghua University, Beijing, China;

M.Engr., Texas A&M University

Chair of Advisory Committee: Dr. Akhil Datta-Gupta

The development of fine grid geolgocial models has attracted great attention in the past decades. Meanwhile, the need for reliable upscaling and coarsening techniques is continuing. Besides the computational efficiency, upscaling can also offer other advantages. The desire for the assessment of risk and uncertainty in reservoir performance is another key issue that is attracting the researchers. Predictions are necessarily of a statistical character because uncertainty is involved in almost all the aspects of the reservoir characterization. Significantly upscaled models are desired when the full assessment of project risk and uncertainty are to be accomplished. The problem of upgridding fine scale models into the coarsened ones is still an attractive and challenging topic demanding much more effort in the reservoir simulation field.

We proposed a modified static coarsening algorithm that has better performance without introducing extra computation cost. This algorithm combines adjacent layers based on static calculations such that the heterogeneity measure of a defined static property is minimized within the layers. In addition, the geological model coarsening will also rely on preserving geological marker information. This combination of static calculation and geological information enables this algorithm to generate models more closely to the true ones. The power and utility of our approaches have been demonstrated using both synthetic and field examples.

To assist the optimal coarsening procedures, we developed and implemented a GUI (Graphical User Interface), named MARS. We focused on building up a C++ based user interface which enables users to handle access the upgridding simulation visually. This MARS software package is a general purpose GUI for applications that make use of graphs as an underlying data model. MARS, which allows user to create simulation cases, import and modify data, and generate graphical geological figures, is developed to facilitate the operation of this coarsening procedures and the interpretation of the results obtained by this model. The user of MARS will be graphically guided through the entire process of creating coarsening simulations.

DEDICATION

To my family and my friends for their love, support, and encouragement

ACKNOWLEDGEMENTS

I would like to thank my graduate advisor Dr. Akhil Datta-Gupta for his inspiration, thoughtful advice, academic guidance, financial support, time and efforts contributed to this project. This work couldn't have been done successfully without him.

To my committee members, Dr. Efendiev and Dr. Jafarpour, I would like to thank them for their contribution to my education and for their guidance, helpful comments and suggestions.

Also, I would like to acknowledge Chevron Energy Technology Company for providing me summer internship opportunity. William Milliken and Clair Jensen were wonderful mentors in the summer jobs and I learned a lot from them.

I would like to thank both Dr. Jong Uk Kim and Dr. Xianlin Ma for the friendship and guidance in the completion for my research and study. I would thank all my colleagues in Dr. Datta-Gupta's group for their generous help, encouragement and discussion.

TABLE OF CONTENTS

	Page
ABSTRACT	iii
DEDICATION	v
ACKNOWLEDGEMENTS	vi
TABLE OF CONTENTS	vii
LIST OF FIGURES	ix
LIST OF TABLES	xii
 CHAPTER	
I INTRODUCTION AND LITERATURE REVIEW	1
1.1 Introduction	1
1.2 Literature Review	2
1.3 Objective of Studies	6
1.4 Thesis Outline	7
II THEORY AND DEFINITION	8
2.1 Algorithm Description	8
2.1.1 Combine Adjacent Layers	8
2.1.2 Optimal Number of Layers	13
III DESIGN OF GRAPHICAL USER INTERFACE	15
3.1 Introduction to User Interface Design	15
3.1.1 Introduction	15
3.1.2 Definition	16
3.1.3 Brief History	16
3.2 GUI System Overview	18

CHAPTER	Page
3.2.1 Main Window	20
3.2.2 Project Management	22
3.2.3 New Project	23
3.2.4 Advanced Settings	35
IV CASE STUDY	39
4.1 Synthetic Case	39
4.2 Field Case 1	42
4.2.1 Reservoir Description	42
4.2.2 Upgridding Algorithm	43
4.2.3 Constraint Setting through MARS	55
4.3 Field Case 2	59
4.3.1 Reservoir Description	59
4.3.2 Upgridding Analysis	60
V CONCLUSION AND SUGGESTIONS	69
5.1 Conclusions	69
5.2 Recommendations	70
NOMENCLATURE	71
REFERENCES	72
APPENDIX	75
VITA	85

LIST OF FIGURES

	Page
Figure 2.1 Heterogeneity analysis	10
Figure 2.2 Flow chart of optiaml coarsening	11
Figure 3.1 Navigation of major work flow.....	18
Figure 3.2 Welcome message board	19
Figure 3.3 Main window of MARS.....	20
Figure 3.4 Status bar.....	21
Figure 3.5 Project management menus	21
Figure 3.6 Essential 5-Step guidance for beginners	22
Figure 3.7 Working directory setup.....	23
Figure 3.8 Dialog box of data files import	24
Figure 3.9 Data verification window.....	26
Figure 3.10 Simulation mode selection and launch window.....	27
Figure 3.11 Data visualization window	28
Figure 3.12 Layer definition table generated by MARS	28
Figure 3.13 Variation of within cell variation (W) and between cell variation (B) as a function of number of layers	29
Figure 3.14 Regression mean square error analysis	30
Figure 3.15 Permeability comparison window for fine and coarsen scale model.....	31
Figure 3.16 Permeability zoom in a single window	31
Figure 3.17 Advanced setting window	33
Figure 3.18 Window for defining coarsening number	34
Figure 3.19 Window for setting geological markers into reservoir model.....	35
Figure 3.20 Navigation map for MARS.....	36
Figure 4.1 Synthetic model in fine scale	37
Figure 4.2 Between layer variation (B) and within cell variation (W).....	38
Figure 4.3 Regression mean square error analysis	39
Figure 4.4 (a) Initial permeability field (b) its coarsened model (i.k plane)	39
Figure 4.5 Original permeability distribution of field and sub regions.....	41
Figure 4.6 Between layer variation (B) and within cell variation (W) for 81.layer	

	Page
mode	42
Figure 4.7 Regression mean square error analyses for 81 layer model.....	43
Figure 4.8 Sand A. optimal 35 layer model comparison of permeability distribution with original 81 layers.....	44
Figure 4.9 Sand B. optimal 35 layer model comparison of permeability distribution with original 81 layers.....	45
Figure 4.10 Main Sand. optimal 35 layer model comparison of permeability distribution with original 81 layers.	45
Figure 4.11 Field oil production rate for original (81 layers), optimal velocity model (25 layers) and optimal slowness model (35 layers)	47
Figure 4.12 Field water cut for original (81 layers), optimal velocity model (25 layers) and optimal slowness model (35 layers)	48
Figure 4.13 Oil production rate for individual well, S, with original model (81 layers) optimal velocity model (25 layers) and optimal slowness model (35 layers).....	49
Figure 4.14 Water cut for individual well, S, with original model (81 layers), optimal velocity model (25 layers) and optimal slowness model (35 layers)	49
Figure 4.15 Oil production rate for individual well, W, with original model (81 layers), optimal velocity model (25 layers) and optimal slowness model (35 layers).....	49
Figure 4.16 Water cut for individual well, W, with original model (81 layers), optimal velocity model (25 layers) and optimal slowness model (35 layers)	50
Figure 4.17 Over merging of Sand A and B with local velocity model (25-layer)	50
Figure 4.18 Field oil production rate for original (81 layers), optimal velocity model (25 layers and 35 layers) and optimal slowness model (35 layers w/o & w/ marker)	51
Figure 4.19 Field water cut rate for original (81 layers), optimal velocity model (25 layers and 35 layers) and optimal slowness model (35 layers w/o & w/ marker)	51
Figure 4.20 Comparison of merging with and without geological constraints	54
Figure 4.21 Field oil production rate for original (81 layers), optimal velocity model (25 layers) and general velocity model (35 layers) and velocity model (25 layers) with constraint.....	54
Figure 4.22 Field water cut for original (81 layers), optimal velocity model (25 layers) and general velocity model (35 layers) and velocity model (25	

layers) with constraint	55
Figure 4.23 Single well (BJ_S) oil production rate and water cut for original (81 layers), optimal velocity model (25 layers) and general velocity model (35 layers) and velocity model (25 layers) with constraint	55
Figure 4.24 Original permeability distribution of Field 2 in India.....	56
Figure 4.25 Permeability field of three typical layers: #4, #10 and #24	58
Figure 4.26 Between layer variation (B) and within cell variation (W) for 24.layer model.....	58
Figure 4.27 Field oil production rate for original (24 layers), optimal velocity mode (3 layers) and optimal slowness model (3 layers)	60
Figure 4.28 Field gas production rate for original (24 layers), optimal velocity mode (3 layers) and optimal slowness model (3 layers)	60
Figure 4.29 Field water cut for original (24 layers), optimal velocity mode (3 layers) and optimal slowness model (3 layers)	61
Figure 4.30 Single well oil production for original (24 layers), optimal velocity mode (3 layers) and optimal slowness model (3 layers)	61
Figure 4.31 Single well gas production rate for original (24 layers), optimal velocity mode (3 layers) and optimal slowness model (3 layers)	62
Figure 4.32 Single well gas production rate for original (24 layers), optimal velocity mode (3 layers) and optimal slowness model (3 layers)	62
Figure 4.33 Initial permeability field and coarsened permeability field in 3 and 9 layer model.....	63
Figure 4.34 Field water cut for original (24 layers), optimal slowness mode (3 layers) and improved slowness model (9 layers)	63
Figure 4.35 Well water cut for original (24 layers), optimal slowness mode (3 layers) and improved slowness model (9 layers)	64

LIST OF TABLES

	Page
Table 3-1 Data files required by MARS	25

CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

In the past decades, great effort has been put on developing the detailed geological models for gas and oil reservoir. Basically, the detailed models are trying to capture the heterogeneity in the rock properties that can affect the fluid flow and hence the oil and gas recovery. Due to the development of the computer technology, the complex models with large amount of grid blocks can be smoothly handled. Typically, current reservoir simulators are able to handle millions of simulation cells. Simulation type (dead oil, black oil, compositional) performed has great effect on the exact simulation number. However, by contrast, geological characterizations contain up to hundred millions cells. These fine grid models, which are known as the geostatistical models represent very fine scale in vertical direction, and relatively large scale in areal direction. A typical reservoir model may contain layers with thickness of 1 ft or even less and the cell may have a size of 100 ft in areal direction. The fine grid geological models are expected to grow further, so the need for reliable upscaling techniques will continue.

Besides the computational efficiency, upscaling can also offer other advantages. The desire for the assessment of risk and uncertainty in reservoir performance is another key issue that attracting the researchers. Predictions are necessarily of a statistical character because uncertainty is involved in almost all the aspects of the reservoir characterization.

Significantly upscaled models are desired when the full assessment of project risk and

This thesis follows the style of the *SPE Journal*.

uncertainty is to be accomplished. The problem of upscaling fine scale models into the coarsened ones is still an attractive and challenging topic demanding much more effort in the reservoir simulation field.

Different upscaling methods are available to be applied to reservoir properties after upgridding the geological models in different situations. On a specific case, the upscaling procedure is decided based on the simulation question addressed, the production mechanism and level of detail that is going to be reached. In 1996, Christie (Christie 1996) described the traditional upscaling problem as two parts. One part is single phase upscaling, and the aim was to preserve the gross features of flow on the simulation grid. Basically, it refers to upscaling of porosity and net-to-gross (trivially dealt with by volume averaging), and absolute permeability. Another part of upscaling is multi-phase upscaling which refers to the upscaling of the relative permeability curves. Multi-phase upscaling is much less well developed. Current works also show the emphasis on local and global solution based upgridding. They refer to the scale upon which the reservoir parameters are calculated. (Sablok and Aziz, 2005; Wu et al., 2007). Wu et al. also proved that the global scale up will lead to high accuracy and high cost results.

The first part of upscaling is upgridding of original geological models for further simulation. After the upgridding is finished, different upscaling methods are available to assign the reservoir properties to each of the grid block. The research of upscaling and development of coarsened reservoir simulation is always being an attractive area. Many methods and algorithm had been proposed in the literature ranging from flow based to static upgridding methods. (Li and Beckner 2000; Stern and Dawson 1999; Fincham et al. 2004; Durlofsky et al. 1996; King et al. 2005)

1.2 Literature Review

The process of upscaling is generally divided into two procedures. The first step is to determine the combination algorithm that can preserve characteristics for fine grid blocks. This is also called upgridding. The second step is to determine the effective properties that can preserve the flow characteristics.

Several papers have been published regarding the both upgridding and assign effective properties for coarsened grid block (Testerman 1962, Stern and Dawson 1999, Li and Becker 2000, Zhang et al., 2006). The most popular methods for upgridding would be static and flow-based approaches.

Statistical approaches applied to the layer coarsening use the geological reservoir properties to generate the new property. Early in 1963, Testerman first developed the application of statistical approach on zonation scheme. In his work, Testerman focused on how zone individual wells and how to build up a reservation zonation scheme from multiple wells. His approach is better described as a refinement method because he started with treating the reservoir as a single layer and sequentially separated this reservoir into layers based on calculation of “Between” and “Within” variation. His ideas about grouping layers based on the permeabilities, minimizing the variance within each layers and maximizing the variance between layers are later used by Li and Beckner.

Li and Beckner basically followed the refinement method and focused directly on grouping fine scale layers into coarsen scale for reservoir simulation. Rather than using permeability only, they proposed a new uplayering (upgridding) property, which is the combination of porosity, permeability and facies (in term of relative permeability, endpoint saturation and various facies rules), as a static measure. Worth mentioning that, a residual curve as a function of the number of simulation layers from a given initial

number of layers to the number of geologic layers will be generated. The residual cures is able to show all potential upgridding scenarios for a given geological model and it provides reservoir engineers with quantitative knowledge on the amount of the loss of reservoir heterogeneity which will be used for optimal layer determination.

From Darcy's steady state equation, Hosseini et al. (2008) derived a criterion that can incorporate thickness and size of the grid blocks into account for upgridding. They used pressure profile as a way to combine layers while maintaining the variation in permeabilities and introduced a total error term which is the multiplication of various errors terms, including the effect of cross flow, adverse mobility ratios and so on. Besides that, Hosseini et al. provided two different parameter for choosing the optimum number of layer. The first one a design factor showing the information about the quality of the layering design and reservoir and the second one is change of error per layer calculated at each step of coarsening. These parameters are able to provide information about the level of the heterogeneity preserved in the reservoir and propose possible optimum layer combinations. Instead of proposing one optimal number of layer, they suggested various numbers for users to choose.

Another important approach applied to optimal coarsening is flow-based method in which the pressure equation will be solved for each cell and flux properties will be determined later.(Stern and Dawson 1999; Efendiev and Durlofsky 2004; Zhang et al. 2006; Wu et al. 2007)

Based on the idea of careful choosing coarse grid used in simulation with accurate results, Durlofsky et al. (Durlofsky et al. 1994 a; Durlofsky et al. 1994 b) proposed alternative method to overcome the limitation of multiphase upscaling techniques. The method is also based on nonuniform coarsening approach in which the portions of the reservoir,

specifically those regions potentially leading to high flow velocities, are particularized modeled.

In their model, the solution from single phase flow problem with fine grid was used for coarsening. Grid size will remain fine when flux was large and become coarse when flux is small. This algorithm was accepted and widely used later. Fincham and his coworkers (Fincham et al., 2004) developed software package with quality control based on Durlofsky's method and its derivative methods. They noticed that the algorithms were working fine for displacement problems where the flow patterns are dominated by heterogeneity rather than gravitational or capillary effects.

In 1999, Stern and Dawson, 1999, developed a sequential coarsening algorithm which includes selecting optimal locations for simulation model layer boundaries and determining the number of layers required. Starting from the bottom of a geological model, they sequentially combine the layers in such a way that can minimize the changes in geological model properties. Put it in detail, they defined two types of objective functions which are combinations of permeability, porosity and thickness of the fine grid cells: 1) the change in time required for single-phase breakthrough in both fine and coarse grid 2) the difference of flux between fine and coarse grids. The adjacent layers are combined so as to minimize the increase in objective function.

To determine the optimal number of layers that preserved, they calculated sweep efficiency for unit mobility displacements. This iterative method is able to provide a quantitative way selecting optimal layer number,

Zhang (Zhang et al., 2006) introduced a new upscaling method, Well Drive Upscaling, which utilized the actual reservoir boundary condition to preserve the dominant flow paths. Zhang focused on solving two major problems: 1. the inappropriate usage of boundary conditions for pressure solution method. 2. the lost of effects of two-phase

dispersion when apply single-phase upscaling to a two-phase flow system. The most obvious advantage is the single phase upscaling may become as accurate as possible after using the global well drive and actual boundary conditions.

To solve the subgrid effects which have a strong influence on flow and transport in oil reservoir, in 2004, Efendiev and Durlofsky (Efendiev and Durlofsky, 2004) investigated a new model for two-phase reservoir flow. Their research partially based on the volume averaging and homogenization. Because this method involves using modified coarse-scale convective flux function and coarse-scale diffusivity, it naturally has the advantage representing both large-scale effects (by modified convective flux) and small scale effects (by the coarse-scale diffusivity).

1.3 Objective of Studies

The objectives of this study include two parts:

The first part is to update the FORTRAN code of our modified algorithm, making it more robust and solving the problem of over combination of adjacent layers (vertically) (Ma, 2008). The original algorithm has a problem of over combining adjacent layers without consider the geological markers. By the help of setting geological constraints into the model, our goal is to improve the algorithm performance without introducing extra computational cost. Instead, we are going to upgrid the geological model based on preserved geological marker information and static heterogeneity calculation of defined static property. This combination of static calculation and geological information enables this algorithm generate models more close to the true ones. The power and utility of our approaches have been demonstrated using both synthetic and field examples.

The second part focused on building up a C++ based user interface which enables users

to handle the upgridding simulation visually. In order to facilitate the operation of this coarsening procedures and the interpretation of the results obtained by this model, this user-friendly graphical user interface for upgridding/coarsening modeling, named MARS, was created. This MARS software package is a general purpose GUI for applications that make use of graphs as an underlying data model. MARS, which allows user to create simulation cases, import and modify data, and generate graphical geological figures, makes the coarsening application easy, practical, and efficient to use.

1.4 Thesis Outline

In Chapter II we describe an optimal coarsening algorithm of 3D reservoir models for flow simulation. The advantages and disadvantages of this approach are discussed and a method of obtaining a better “optimal” number of layer combinations is proposed and analyzed.

In Chapter III, a GUI (Graphical User Interface) for geological coarsening application is presented. This GUI is a high performance data visualization and analysis platform that provides researchers with a highly interactive and extensible data exploration environment. It offers users the ability to visualize manipulate and interact with millions of data in a short period of time. Our GUI is constructed using C++ under Borland Builder IDE. Detailed GUI elements are introduced and exhibited thoroughly in this chapter.

In Chapter IV, we are going to discuss application of upgridding algorithm and test the performance of MARS, the upgridding assist tool and GUI. We start with a synthetic example to illustrate the steps in our approach and demonstrate the visualization workability of MARS. Then, two field cases will be used proving the applicability of our approach to high resolution and geologically complex field cases which was from

offshore South America and from India near Bombay High field. The results are compared to a full field simulation using both field and well responses.

CHAPTER II

THEORY AND DEFINITION

The most obvious advantage and interesting point of static upgridding method is its computation efficiency. However, they have the limitation choosing the optimal number of layers, though many researchers have proposed different ways (Stern and Dawson, 1999) predicting this optimal number. Followed Testerman (1962), Li and Beckner (2000), King et al. (2005), we utilize a static analysis and a sequential approach which is a recursive coarsening algorithm and much faster than the sequential refinement. In this chapter, the algorithm and definitions will be discussed in detail.

2.1 Algorithm Description

There two major parts in our algorithm. First part is to determine which two adjacent layers should be combined together and second part is to find the optimal number of layer that can preserve the maximum heterogeneity.

2.1.1 Combine Adjacent Layers

In the first part, merging of neighbor layers will be based on the variation of static property which is a combination of porosity, permeability and Buckley-Leverett Speed.

This static property, denoted as p , is defined by: $p = \frac{k}{\phi} f'$, where $\frac{k}{\phi}$ is the interstitial

velocity and f' is the Buckley-Leverett Speed which includes the facies and saturation dependent relative permeability terms. Our upgridding algorithm relies on the analysis of “total variation”, as a measure of heterogeneity during coarsening. This is “total

variation” is shown in two parts: “within cell variation (W)” and “between cell variation (B)”.

The “within cell variation (W)” and “between cell variation (B)” are defined as:

$$W = \sum_{i,j,k=1}^{NX,NY,NZ} n_{i,j,k} (p_{i,j,k} - p_{i,j,k}^C)^2$$

$$B = \sum_{i,j,k=1}^{NX,NY,NZ} n_{i,j,k} (p_{i,j,k}^C - \overline{p_{i,j}})^2$$

where:

$n_{i,j,k}$ is the bulk rock volume of each cell

$p_{i,j,k}$ is static property at fine-scale

$p_{i,j,k}^C$ is the transitional static property calculated after every merging of adjacent layers.

$\overline{p_{i,j}}$ is the column based average of the static property and defined as :

$$\overline{p_{i,j}} = \frac{\sum_{k=1}^{NZ} n_{i,j,k} p_{i,j,k}}{\sum_{k=1}^{NZ} n_{i,j,k}}$$

The “within cell variation (W)” represents heterogeneity that removed from the entire reservoir model after coarsening. $n_{i,j,k}$ is used to weight this summation through the whole model and guarantee the variation value keeps constant under numerical refinement of the grid. Meanwhile, “between cell variation (B)” shows the heterogeneity that preserved in the geological model after upgridding. The total variation that preserved in the coarsened geological model was defined as the summation of “Within cell variation” and “Between cell variation”:

$$H = W + B$$

Our algorithm is to minimize the variation removed from geological model and maximize

the variation preserved in this model while honoring the geological model marker during upgridding.

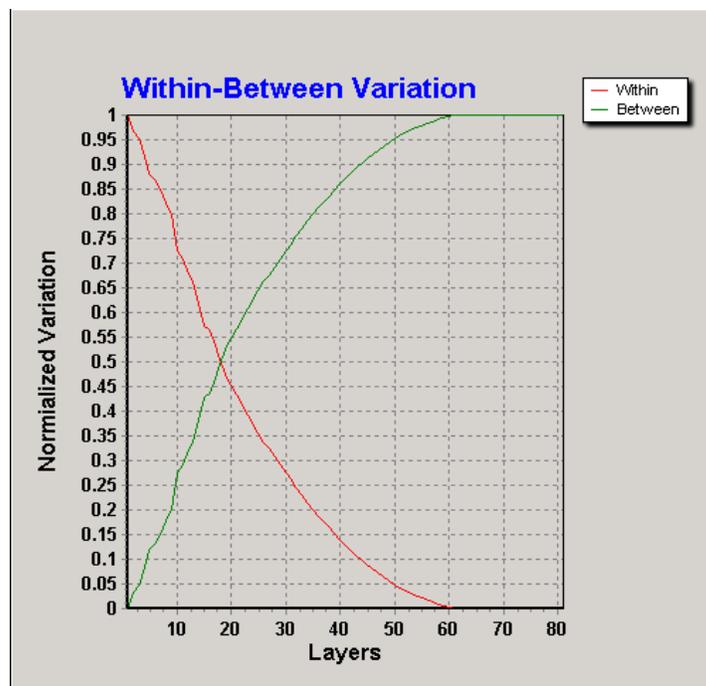


Figure 2.1 Heterogeneity analysis

Figure 2.1 presents the relationship between the “Within cell variation”, “Between cell variation” and the layer numbers. This figure was generated by the upgridding tool, MARS, which was designed to facilitate the operation of these coarsening procedures and for data visualization purpose. Based on this chart, the optimal upgridding number will be determined in such a way that the W , representing the loss of heterogeneity, is minimized or B , representing the conservation of heterogeneity, is maximized. Figure 2.2 describes our procedures generating the coarse grid model. We start from the fine grid geologic models in which the attributes, such as permeability, porosity and et al., will be extracted. Shown in Figure 2.2, the model is coarsened in following steps to minimize the heterogeneity removed from the model.

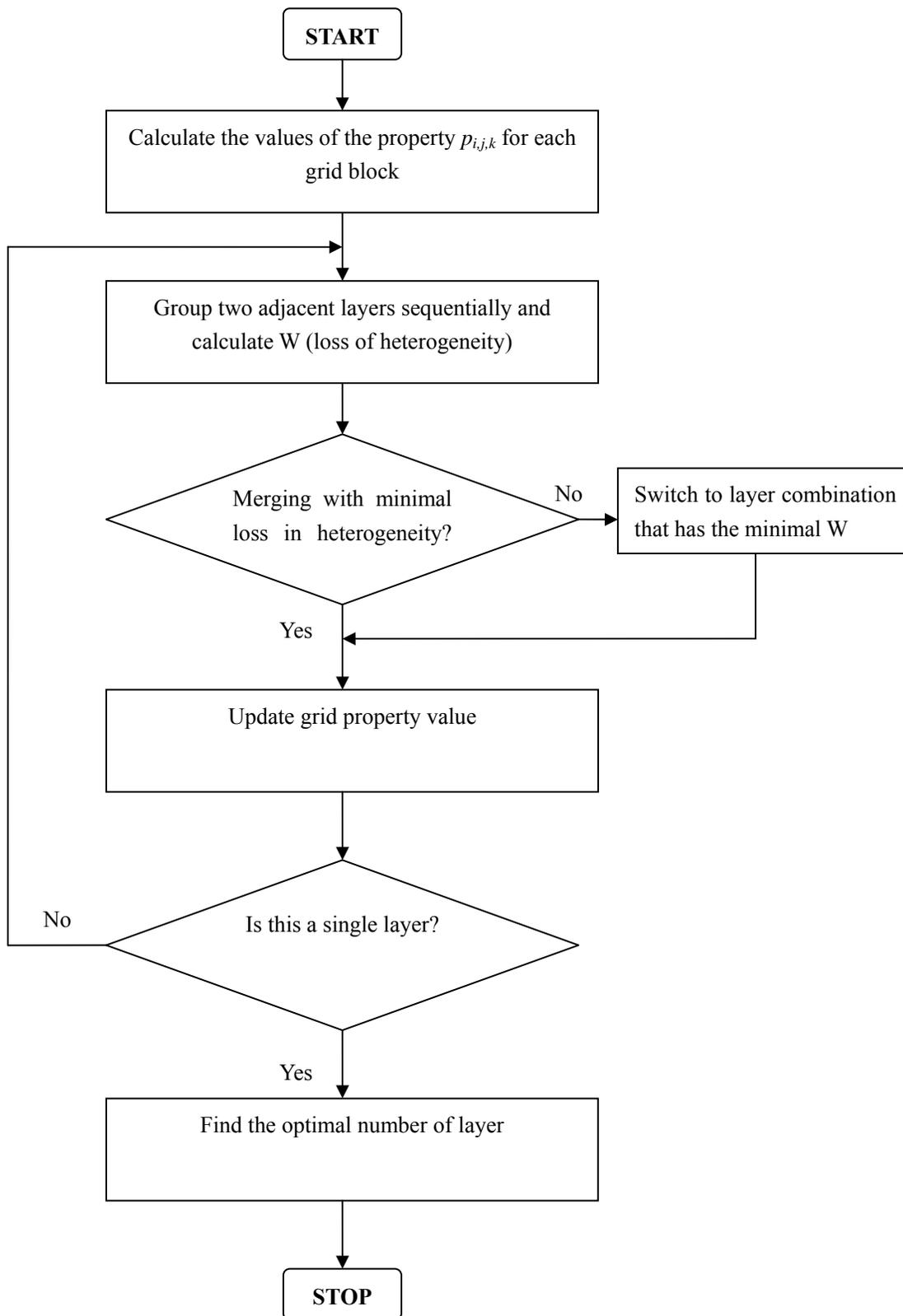


Figure 2.2 Flow chart of optimal coarsening

Starting from the fine grid model, the change in “within cell variation (W)” and “between cell variation (B)” is recorded at each combination. For example, we have a file with 100 layers and the first step of merging may have up to 99 possible selections. From these 99 choices, we are going to choose the combination that has the minimal “within cell variation (W)”, or alternatively, the maximum “between cell variation (B)”. For the coarsened 99-layer model (originally, 100-layer), we will find out the optimal combination from 98 choices and keep repeating these procedures. Meanwhile, the “within cell variation (W)” and “between cell variation (B)” will also be recorded until the geologic model is combined into a single one.

2.1.2 Optimal Number of Layers

In addition to the finding a criterion for coarsening the geological model, another serious question that we should answer is that: how we decide the “Optimal” number of layers. We have different choices to get this “optimal” number for combining geological models.

From the variation chart (Figure 2.1), we noticed that the optimal layer can occur at the point having maximum curvature. At the curve of “within cell variation (W)”, this point represents a start of slow decrease of heterogeneity. In other words, after this point, keeping more layers won't help us much on preserving heterogeneity. For instances, this maximum curvature shows up at a number of 35 in an 81 layer model. Clearly, the heterogeneity will decrease a lot if we reduce this layer number and won't increase much if keep more than 35 in coarsened model.

Another way available for retrieving the “optimal” number of layer is to calculate the root mean square error (RMSE) for a series of a regression lines. This method was proposed by Xianlin Ma (2008). Basically, in the variation analysis chart, two linear regressions that fit the two sides of the curve will be generated. Weighted mean square error of these

regression lines will be calculated for each of the layer number. The optimal choice is the one with minimum mean square error. Detailed description about RMSE method can be found in Chapter III and Chapter IV.

So far, the “optimal” number of layers is determined on the trust of the static calculation results. In other words, we believe this combination can conserve the maximum heterogeneity. However, the most obvious drawback of this calculation is that it may not follow the geological constrains which have great effect on the simulation results. So, we take the geological constraints into consideration that the model is coarsened with respect to the true model barriers. Geological markers will be insert into the models to prevent the over coarsening between different sands. The mechanism is verified with synthetic and field cases in later chapters.

CHAPTER III

DESIGN OF GRAPHICAL USER INTERFACE

In this chapter, we will focus on the design and implementation of MARS GUI graphical objects. This MARS software package is a general purpose GUI for applications that make use of graphs as an underlying data model. This GUI, which allows user to create simulation cases, import and modify data, and generate graphical geological figures, is developed and implemented for the upgridding system.

3.1 Introduction to User Interface Design

3.1.1 Introduction

GUI is short for Graphical User Interface, which allows a computer user to move from application to application (Winograd, 1995). A good GUI makes an application easy, practical, and efficient to use, and takes up more the market share of today's software programs.

The development of new software is extremely expensive. A professional GUI design is important. The entire company may depend on the application's GUI reception in the marketplace, which decides the corresponding software a success or failure. However, it is not easy to define if an application's GUI confines the three standards: easy, practical, and efficient. Although GUIs take a large portion of market in the software industry today, people still do not clear what the exact definition of a GUI is.

3.1.2 Definition

A GUI is a type of computer human interface on a computer. Don Norman (1988) said in his book *The Psychology of Everyday Things* "It solves the blank screen problem that confronted early computer users". In the early days of computer era, the machine gave the user no indication what the user was to do next, and user sat down in front of the computer with no prompt. GUI is an attempt to solve this blank screen problem.

Bonsiepe (1993) defines that a computer human interface is a "means by which people and computers communicate with each other". A good GUI design removes the impediment of communication with the computer system and allows the user to work directly on the problem at hand (Don Norman, 1988).

In computer science terms, the GUI is a visual operating display that the monitor presents on the monitor to the computer operator (Harding, 1989). Logically speaking, three major components consists a GUI: a windowing system (Windows 3.0 and above, Fedora Linux series, Ubuntu Linux series, MAC OS and etc.), an imaging model, and an application program interface (API).

The windowing system presents the frame of the appearance of the software: windows, menus, and dialog boxes that users can observe on the screen. The imaging model defines the fonts and graphics that appear on the screen. The API is the interface in which the user can specify how and what windows and graphics appear on the screen.

3.1.3 Brief History

When talking about history of GUI, Douglas Englebart, the GUI father, can never be ignored. He had two greatest contributions: inventing the computer mouse, and a pioneer of human-computer interaction (HCI) (http://en.wikipedia.org/wiki/Douglas_Englebart). He had his PhD from EECS department, UC Berkeley. Then Englebart settled down in

NASA Institute (the forerunner of NASA) with a decent job (<http://arstechnica.com/old/content/2005/05/gui.ars>). Englebart's idea was published in his report: *Augment Human Intellect: A Conceptual Framework* (Englebart, 1962).

In this technical report, Englebart first introduced the concept: "augmenting human intellect", when was only 16 year after the first computer "ENIAC" was invented in University of Pennsylvania. This report offers a detailed conceptual framework, exploring the nature of the system composed of the individual and the tools, concepts, and methods that match his basic capabilities to his problems. Then the author classified four major human abilities to solve problems (in the paper, it is regarded as "augmentation mean"): artifacts, language, methodology and training. The paper described the conceptual system: H-LAM/T System, to do the interaction of human and machine, letting computer to "know" what user want to. In this paper, Douglas argued that digital computers could provide the quickest method to "increase the capability of a man to approach a complex problem situation, to gain comprehension to suit his particular needs, and to derive solutions to problems." He envisioned the computer not as a replacement for human intellect, but a tool for enhancing it [6].

Then in 1977, the first application with GUI, the Xerox Star, was designed at the Xerox Palo Alto Research Center. Unfortunately, the Xerox Star was too slow, and it was not commercially successful.

However, this inspired Steve Jobs, who is the founder and chairman of Apple Computer. He happened to visit the Palo Alto Research Center and saw Xerox Star. He returned to Apple Computer and subsequently hired several of the original designers of Xerox Star, and then they first produced the Apple Lisa. Apple Lisa met the same situation as Xerox Star: was not commercially successful. But they did not give up. In 1984, they developed the commercially successful Apple Macintosh, whose GUI became the standard of all GUIs today.

3.2 GUI System Overview

The layout and design of the GUI (MARS) is simple and intuitive. MARS basically works as the communicator between the user and optimal coarsening (upgridding) application. It has no pre-information from either the application or the actions performed by users. It plainly interprets user's actions into computer input and notifies the upgridding application. However, beyond that, MARS is also a high performance data visualization and analysis platform that provides researchers with a highly interactive and extensible data exploration environment. It offers users the ability to visualize manipulate and interact with millions of data in a short period of time. Our GUI is constructed using C++ under Borland Builder IDE.

The MARS, a upgridding and visualization tool, consists of five basic stages: 1) working directory setup, 2) data file import, 3) data verification and advanced adjustments, 4) simulation (Upgridding) and 5) output visualization. The program flow and user actions are illustrated in the following figure:

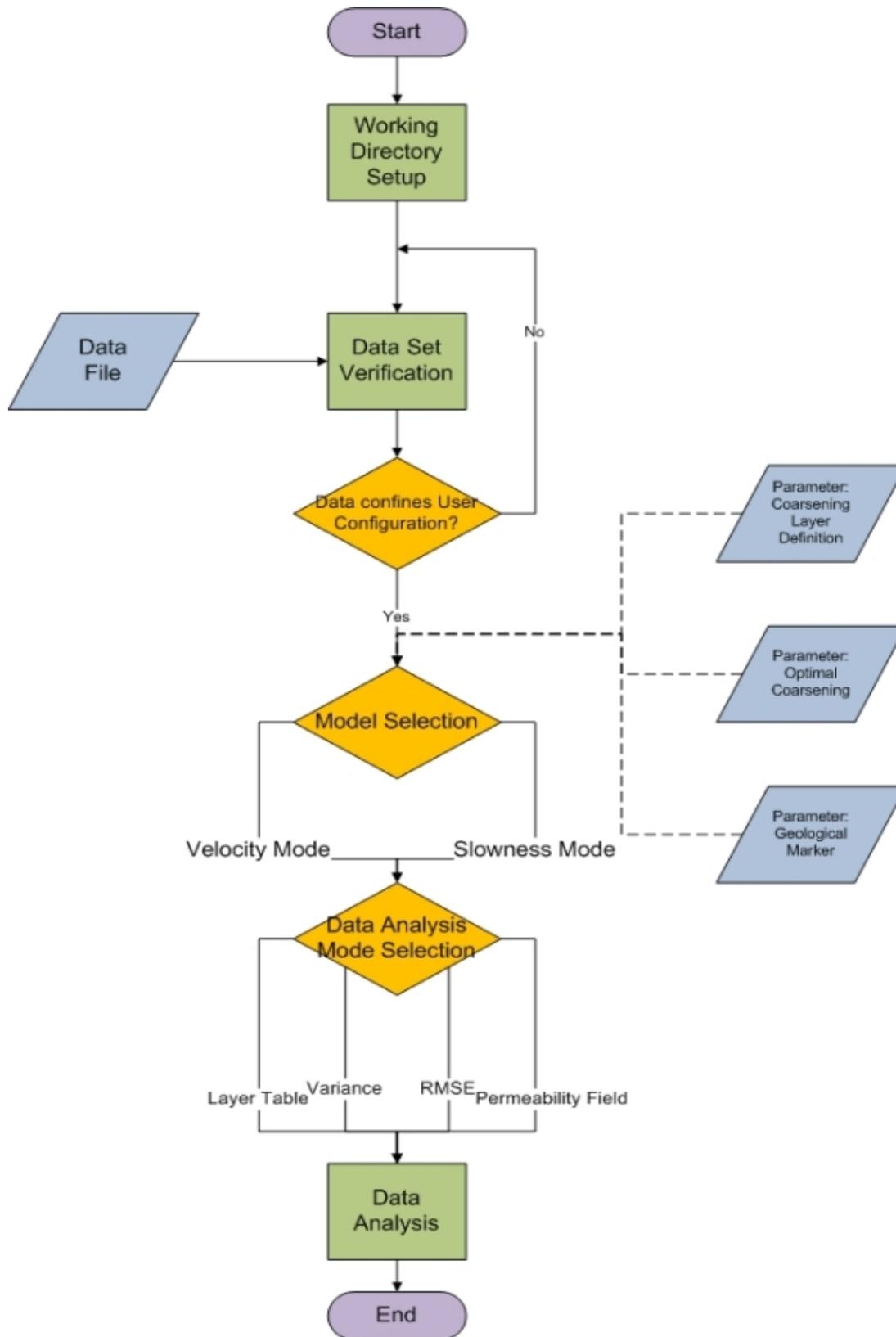


Figure 3.1 Navigation of major work flow

When MARS starts up, a welcome message board, as shown in Figure 3.2, will present version information and the major editor. The current GUI and upgridding assistant tool package is at version 1.1 and technical support would be provided by MCERI, Texas A&M University. After displaying the welcoming information, Main Window will be launched and is going to lead users for project management.

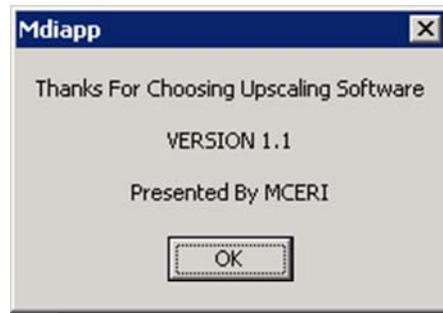


Figure 3.2 Welcome message board

3.2.1 Main Window

The main window is created when the process is started and will lead users to the whole view of this fully functional upgridding assistant tool and visualization platform which allows a user to construct, modify and visualize the results of a new or existing optimal coarsening project. Figure 3.3 shows the main window.

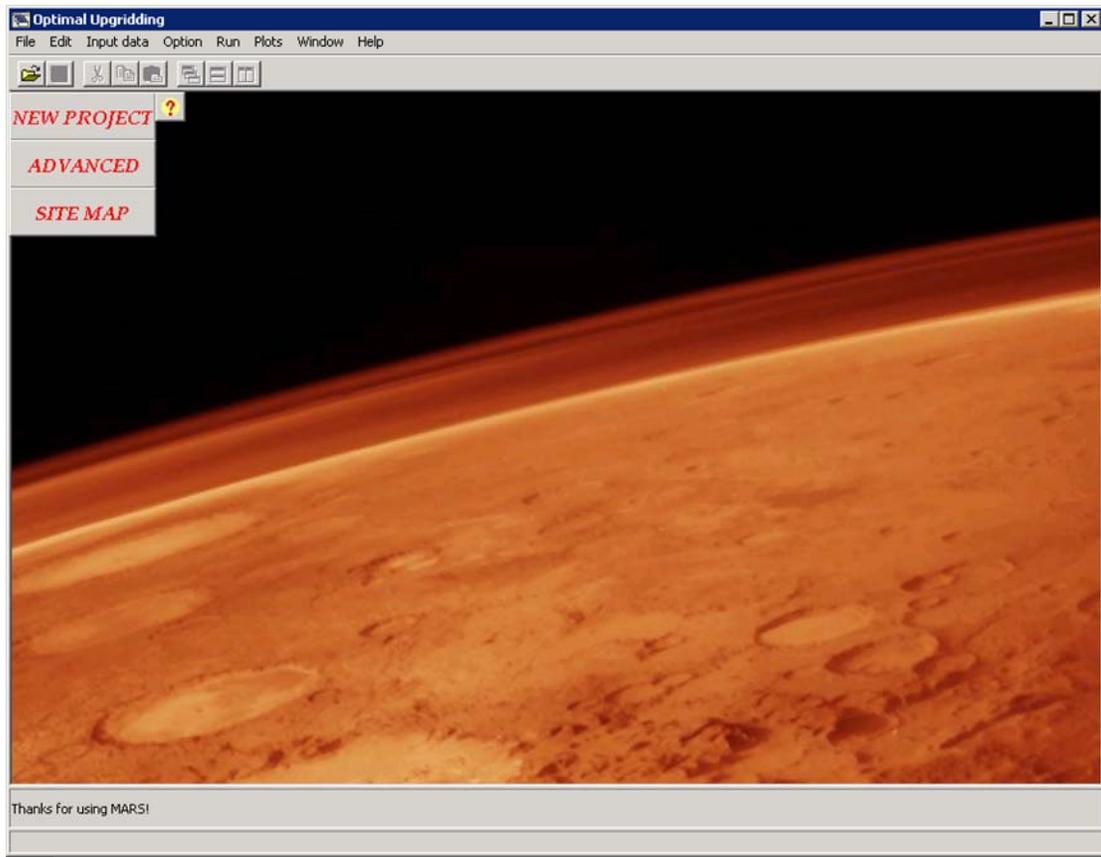


Figure 3.3 Main window of MARS

It consists of two areas, a project management area, in which the user can directly interact with project elements and pull-down menus by which users have the access to various functions. The main functions of the program such as loading files, starting optimal coarsening application, and visualizing results are accessible through either project menus or the toolbars across the top of the window. The optimal coarsening application is assumed to have a number of input files for different geological properties and reservoir information. All of those data files and geological properties could be imported, modified and transferred through the main window platform.

At the bottom of the main window, a text-based status bar (seen in Figure 3.4) is

accessible and kept activated all the time to provide the essential but necessary information. One of the most popular techniques and design thoughts to make applications easier is to providing short but important hints about each essential features of the GUI. This often overlooked feature of the window provides important information about the elements in the GUI screen, in addition to offering functionality. The purpose of this hint shown in status bar is to give the user a basic idea of that what the component does, how to use it, or whatever information the user may need. The status bar is able to provide various button function information when mouse move to a specific button or to show information relating to current program status (e.g.: file opened, window closed, et al.) of current window or an action. Status bar text is correctly restored when leaving a control, closing a form, switching between forms, and when entering or exiting a menu.

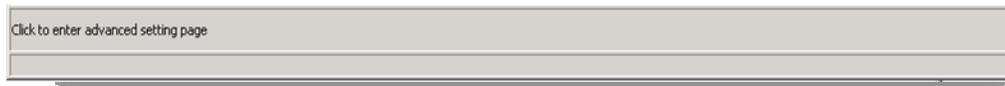


Figure 3.4 Status bar

3.2.2 Project Management

Project management provides direct links for users who may or may not have basic knowledge about setting up data files for optimal coarsening application. All the buttons are located at the left upper area in the main window, as shown in Figure 3.5.



Figure 3.5 Project management menus

3.2.3 New Project

The first button is the “New Project” for users to create a new project. After clicking “New Project”, a new popup window (Figure 3.6) will show up and help user activate a project from beginning to the very end (visualization of results).

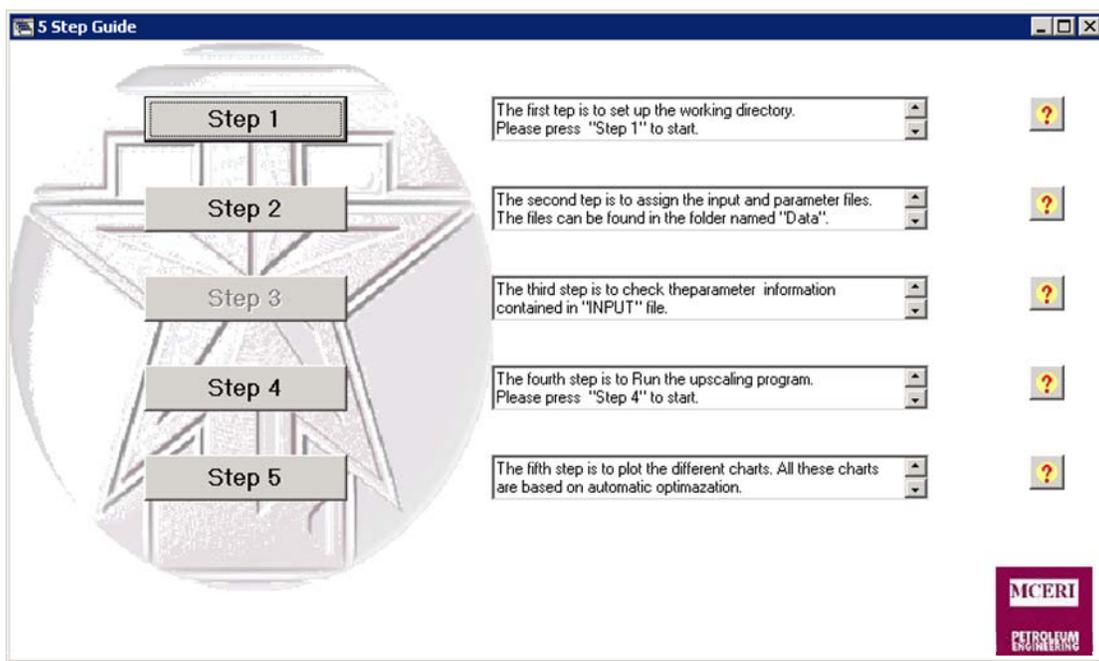


Figure 3.6 Essential 5-Step guidance for beginners

Divided into three main areas, the “5-Step Guide” popup window supports essential

button control for basic coarsening procedures and supplies fundamental introduction information for each of the step. Following the elementary user interface design rules, the related components are kept together and procedures are maintained in a simple way. In the left control panel, five control buttons bring the most important and necessary operations for optimal coarsening, which include: working directory setting, data file import, data verification, coarsening mode choosing and results visualization. This control panel supplies only the fundamental command with default settings, meaning the experienced user will reply on “Advanced Setting” menu for more options. The detailed settings will be available in the “Advanced Setting” panel which will be introduced later in this chapter. The second (middle) area shows crucial descriptions for each of the button. These descriptions would be very helpful for new users who have no knowledge about how this interface works. More particularized information and HELP files can be found by clicking the question buttons beside the description boxes.

Five-step Procedures

The most important and crucial ideas of graphical user interface (GUI) design should pay attention to the following design principles: simplicity, visibility, functionality, error tolerance and user friendliness. For this purpose, a careful design is necessary to guarantee a smooth working flow of the application through all stages from setting up a scenario to running, generating and finally examining the output. Therefore, MARS provides an easy-use environment for users. The basic routine procedures include only five steps from the beginning to the end. Each of the steps can be accessed by clicking the buttons in the “5-Step Guide” popup window.

The very first step was to set up the working directory. Clicking “STEP 1” opens the Working Directories dialog box (shown in Figure 3.7). Since multiple working directories are possible, this box allows users to create a new working directory. By default, MARS

is able to search the correct working directory automatically and it is also the recommended working directory we suggested. This default working directory would be linked to the folder containing the executable file of optimal coarsening FORTRAN code. This executable file will be executed later after the coarsening mode was decided. When specifying a new working directory, the path can be typed directly into the directory name field.

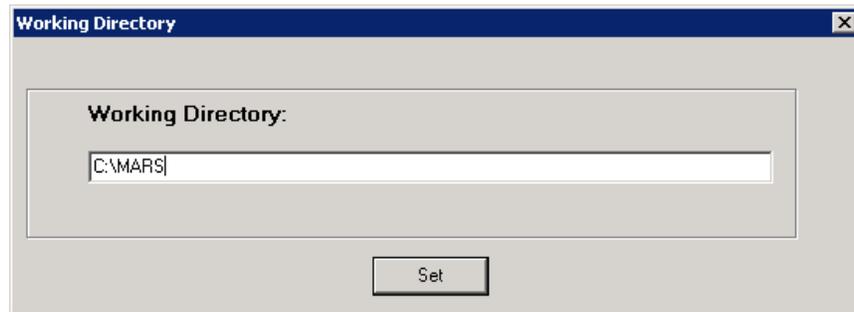


Figure 3.7 Working directory setup

The second step is to configure the data files for optimal coarsening. By clicking “STEP 2” button in the window of “5-Step Guide”, a new dialog window, as shown in Figure 3.8, will popup. Data files loaded in this step include a general parameter file, bulk volume file, permeability file, porosity file and saturation number file. The parameter file basically contains geological model information. MARS will automatically create indexes for file names and paths which will be recorded in a txt file for reuse purpose. An overview of the different files used by MARS is given in TABLE 3.1

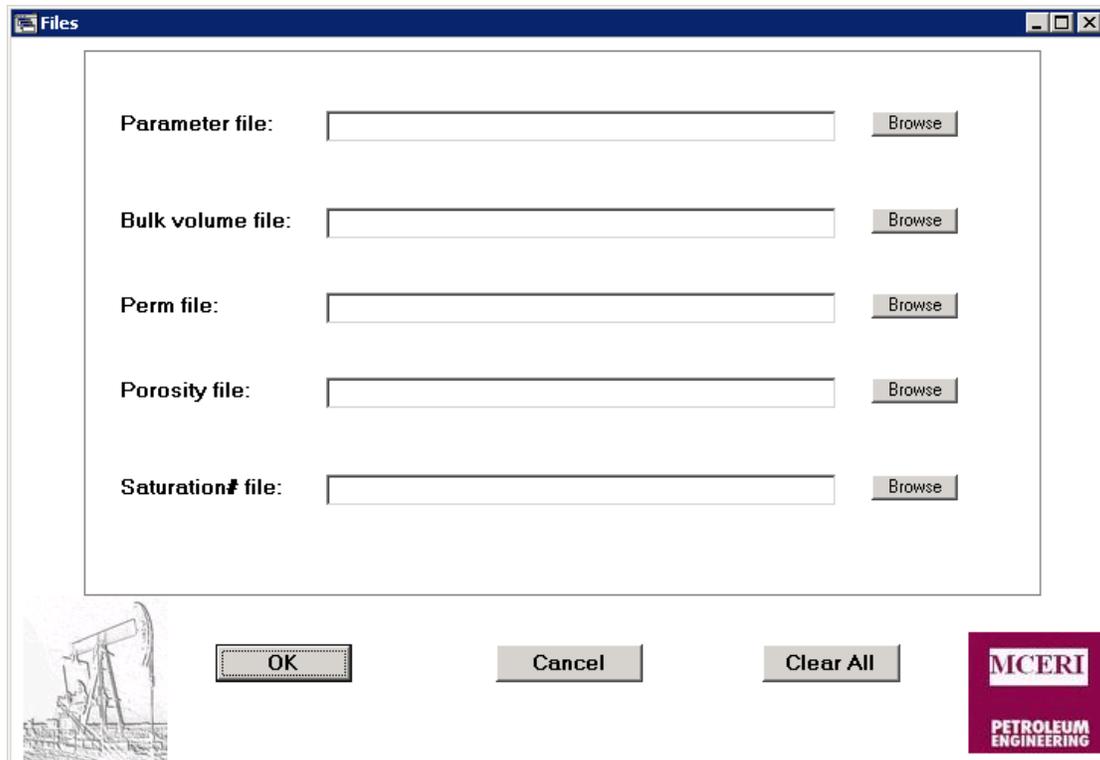


Figure 3.8 Dialog box of data files import

Table 3-1 data Files Required by MARS

File	Description
Parameter File	A text file with a .dat extension (data file), containing relative permeability tables, oil viscosity, water viscosity, grid size, and minimum target number of coarsened layers.
Bulk Volume File	A text file with a .dat extension (data file), containing a keyword "BULKVOL" followed by one real number for every grid block specifying the bulk volume. The values must be non-negative. Any negative value will be transferred to zero. Data will be terminated by a slash (/). Grid blocks are ordered with the X axis index cycling fastest, followed by the Y and Z axis indices.
Permeability File	A text file with a .dat extension (data file), containing a keyword "PERM" followed by one real number for every grid block specifying the permeability. Permeability values must be non-negative and data will be terminated by a slash (/). UNITS: mD. Grid blocks are ordered with the X axis index cycling fastest, followed by the Y and Z axis indices.
Porosity File	A text file with a .dat extension (data file), containing a keyword "PORO" followed by one real number for every grid block specifying the porosity. Permeability values must be non-negative and data will be terminated by a slash (/). Grid blocks are ordered with the X axis index cycling fastest, followed by the Y and Z axis indices.
Saturation number File	A text file with a .dat extension (data file), containing a keyword "SATNUM" followed by one integer for every grid block specifying the saturation function region to which it belongs . The region number should not be less than 1. Data will be terminated by a slash (/). Grid blocks are ordered with the X axis index cycling fastest, followed by the Y and Z axis indices.

The third step is to check and verify the imported parameter file, as seen in

Figure 3.9. “STEP 3” button is grayed out and inactive when it is not available and it also an indicator showing whether the parameter files have been properly transported. This enforcing protection mechanism ensures that operations and actions are performed in a correct sequence and that it is almost not possible to perform illegal operations which may cause erroneous results or deadly error to the program. Most parameters for defining the geological model are set in this parameter file. Those values should be checked before optimal coarsening is running. Invalid values will results in unexpected stop.

```

Optimal Upgridding - [Parameter File]
File Edit Input data Option Run Plots Window Help
TABLEDIM
1
MAXRPERMDIM
50
RPERM
'table1
42
Sw KRW KRD -Attention: Second Sw has to be Swi-
0 0 1
0.475 0 0.388
0.489 0.0005 0.326
0.502 0.002 0.272
0.515 0.0045 0.225
0.528 0.008 0.185
0.541 0.0127 0.15
0.554 0.0183 0.12
0.567 0.0251 0.0954
0.58 0.0329 0.0745
0.593 0.0418 0.0573
0.607 0.0518 0.0433
0.62 0.0629 0.032
0.633 0.0751 0.0231
0.646 0.0884 0.0162
0.659 0.103 0.011
0.672 0.118 0.0071
0.685 0.135 0.0044
0.698 0.152 0.0028
0.712 0.171 0.0014
0.725 0.191 0.0006
0.738 0.212 0.0003
0.751 0.234 0.0001
0.764 0.258 0
0.777 0.282 0
0.79 0.307 0
0.803 0.329 0
0.816 0.352 0
0.83 0.376 0
0.843 0.401 0
0.856 0.426 0
0.869 0.453 0
0.882 0.481 0
0.895 0.511 0

```

Figure 3.9 Data verification window

The fourth step is to run the optimal coarsening application, as shown in Figure 3.10. After a project has been set up (i.e. data files are properly loaded), the simulation is ready to run. At this moment, it is possible for users to save the current data file information via the “SAVE” function in the main menu bar. Here, we allow user to pick up two different static properties, ‘local velocity’ and ‘local slowness’, that we

are going to preserve during the coarsening.

While application is running:

1. Menus, toolbars and buttons are grayed out avoiding actions being performed.
2. A new DOS command window appears presenting the simulation status
3. UpScale Connection (.USC) file for each upscale step is being generated

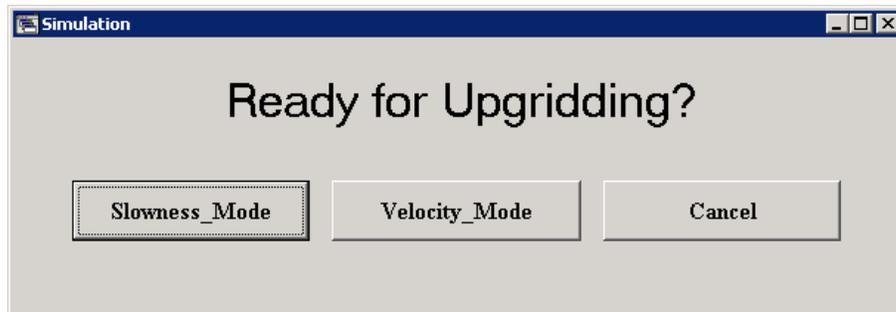


Figure 3.10 Simulation mode selection and launch window

When the optimal coarsening procedure is finished, the output is ready for visualization and analysis. By clicking on the “STEP 5” button, a new popup window with four buttons, as shown in Figure 3.11, appears. The software will now perform calculations based the on the coarsening output to get the variation of “within cell variation (W)” and “between cell variation (B)” as a function of number of layers through the coarsening process and the relationship between the normalized square error and the number of layers. Also, it’s able to compute corresponding comparison measure for the fine and coarse grids. Simultaneous comparison of fine and coarse grid permeability filed in x-y, y-z or x-z direction is available in this version (1.1). In the “Data Visualization” popup window, four different types of chart, figure or tables, including: layer combination table (through “Layer Definition”), SSW and SSB chart (through “Variation”), Root mean square error chart (through “RMSE”) and final permeability field for both fine and coarsen grid in each direction (through “Permeability”), are ready for analysis.

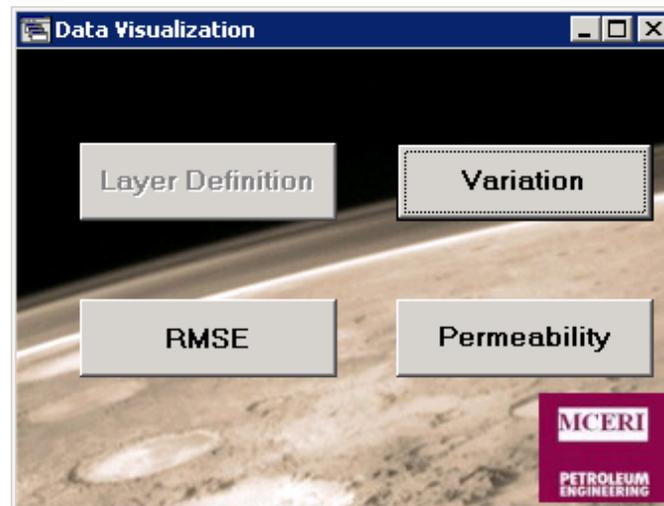


Figure 3.11 Data visualization window

Layer Definition

This function will show a table, shown in Figure 3.12, containing layer combination information. The first column shows the original layer number before coarsening and the second column presents the coarsened layer number for each of the original layer.

 A screenshot of a software window titled "Defining Upgrading - [Parameter File]". The window displays a table titled "Layer Definition Table". The table has two columns: "Fine Layer" and "Coarse Layer". The data shows a mapping from 14 fine layers to 2 coarse layers.

Fine Layer	Coarse Layer
1	1
2	1
3	1
4	1
5	1
6	1
7	2
8	2
9	2
10	2
11	2
12	2
13	2
14	2
15	2
16	2
17	2
18	2
19	2
20	2
21	2
22	2
23	2
24	2
25	2
26	2
27	2
28	2
29	2
30	2
31	2
32	2
33	2
34	2
35	2
36	2
37	2
38	2
39	2
40	2
41	2
42	2
43	2
44	2
45	2
46	2
47	2
48	2
49	2
50	2
51	2
52	2
53	2
54	2
55	2
56	2
57	2
58	2
59	2
60	2
61	2
62	2
63	2
64	2
65	2
66	2
67	2
68	2
69	2
70	2
71	2
72	2
73	2
74	2
75	2
76	2
77	2
78	2
79	2
80	2
81	2
82	2
83	2
84	2
85	2
86	2
87	2
88	2
89	2
90	2
91	2
92	2
93	2
94	2
95	2
96	2
97	2
98	2
99	2
100	2

Figure 3.12 Layer definition table generated by MARS

Variation

This function will generate a chart, seen in Figure 3.13, showing the normalized static measure during and after upgridding. Green curve presents the static measure between layers (SSB) that we are going to preserve and red curve exhibits the static measure within layers (SSW) that is going to be removed from the model.

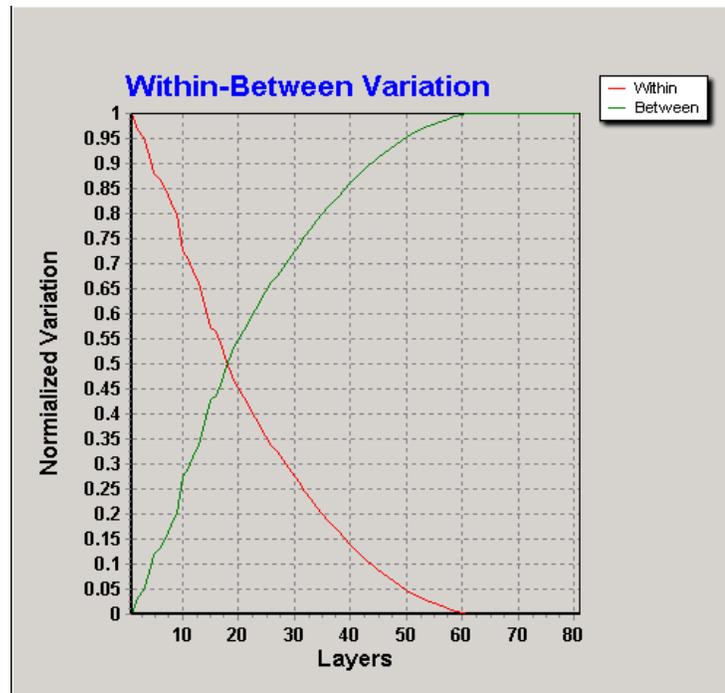


Figure 3.13 Variation of within cell variation (W) and between cell variation (B) as a function of number of layers

RMSE

This function provides a squared error chart, seen in Figure 3.14, revealing the optimal number of layers that should be preserved in the coarsen model. Recall that, the basic idea of selecting optimal number is that two linear regressions fitting on the two sides of the curve are generated, and then the weighted mean square error of the regressions is calculated by varying the number of points used in the regressions. The optimal number of layers is the one with the minimal mean square error.

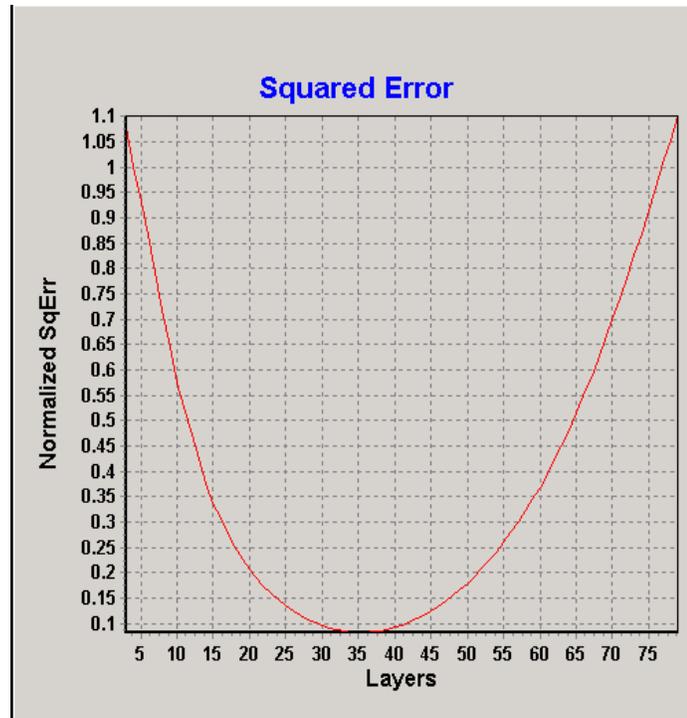


Figure 3.14 Regression mean square error analysis

Permeability Field

This function will bring a new popup window, seen in Figure 3.15, containing permeability fields for both fine and coarse grid blocks. In the left upper area, a figure of fine (original) scale permeability field is shown. And in the left lower area, a figure of coarse (upgridded) scale permeability field is presented. MARS is able to display two fields simultaneously for users to compare. A control panel is placed on the right side of the screen. At the top of this area, the minimum and maximum values of current permeability field are given. Users are allowed to adjust the legend scale in the middle part by inputting the minimum and maximum number and also the number of levels. For a general geological model, the total number of original layers may vary from ten to thousands. The third part of the control panel provides control buttons for change the layer that shown in the left area.

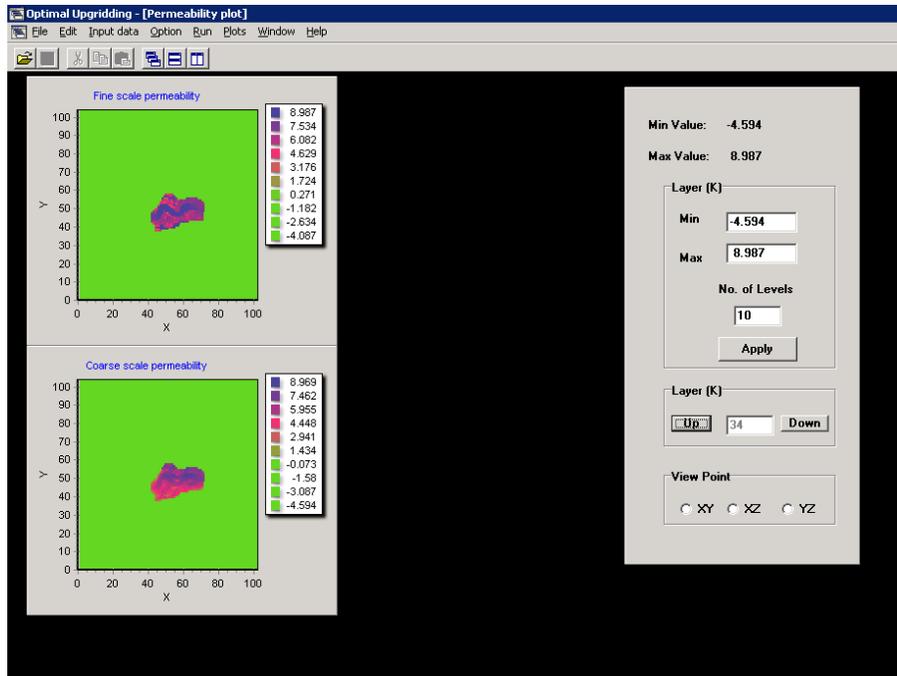


Figure 3.15 Permeability comparison window for fine and coarsen scale Model

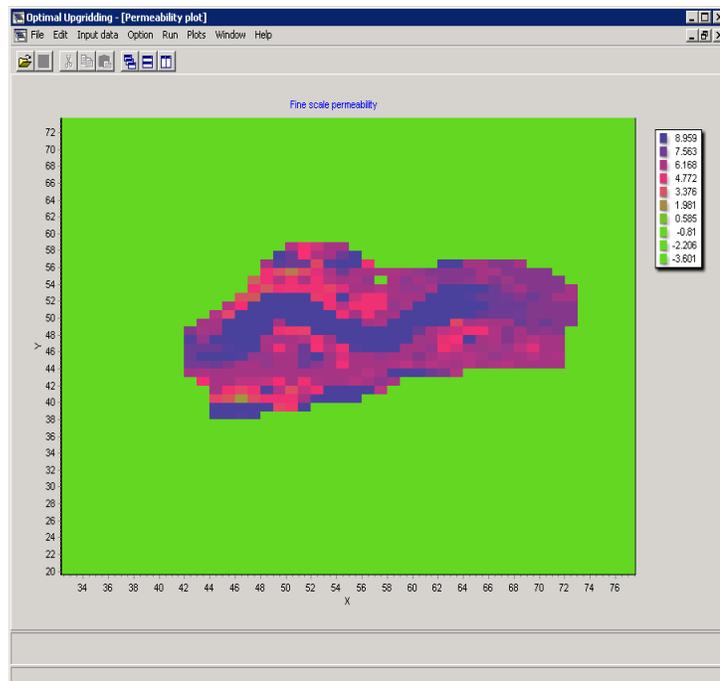


Figure 3.16 Permeability zoom in a single window

The viewpoint for x-y, x-z or y-z views can also be adjusted manually by specifying the checkbox in a dialog box which located at the bottom of the control panel. While TeeChart is a very powerful add-in of C++ builder for displaying and manipulating data, there still are some problems existing due to the large size of the data utilized in the upgridding procedure. The most important one is that displaying scene and output data are the memory required and processing time.

The GUI designed under C++ builder IDE is a functionalized visualization tool that allows user to zoom in/out on specific area of a figure. Also it has the function of pan crossing the screen. These functions are implemented with mouse control. To dynamically zoom in/out using the mouse, user needs to click and hold the left mouse button anywhere in the display window and drag to an interested area in a direction of left upper to right lower point. More than that, we designed interactive window with allows user to pick up one figure from the fine and coarse model and visualize the permeability in a single window, as shown in Figure 3.16. Double click on the interested window in Figure 3.15, a new window will replace the previous one; to go back to the comparison mode, user can simply double click on the enlarged single window. All these actions can also be finished through right-click popup menu. Similarly, to pan across the screen, users can simply click and hold the right mouse button anywhere in the display window and dray. One limitation with the current implementation of the zoom and pan controls is that user can access to any position of the canvas, which means, when user pan across the screen, area out of data range are expected to occur if user moves too far way from the original place. To avoid this, users are suggested to click and drag left mouse button in the opposite direction (right lower to left upper) on anywhere in the screen to go back to the original view. Functionality has been implemented in MARS to ensure a height-width threshold to be applied to the output images. This is particularly helpful in visualizing where we

are interested in specific number of layers. (like the zoom)

3.2.4 Advanced Settings

The second button in the main window is “Advance Setting” which will lead to a new popup window for advanced users and for specific geological model constructions.

In this new setting window, shown in Figure 3.17, three choices for defining target coarsening layer, using optimal layer definition, or inserting geological markers are accessible.

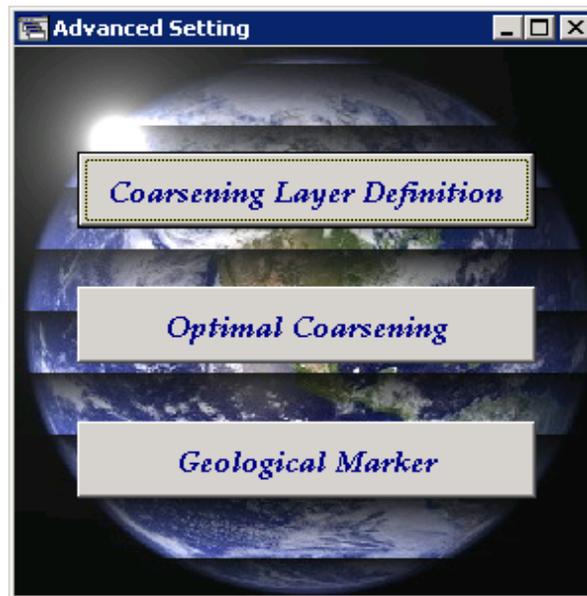


Figure 3.17 Advanced setting window

Clicking on “Coarsening Layer Definition”, a new dialogue window, as seen in Figure 3.18, pops up. User is asked to type his target coarsening layers instead using the optimal ones. This function enables users to have a slightly conservative or an arbitrary number of combining target to prevent or reduce the happening of over coarsening. Over coarsening is one of the most serious problems because it may results in fake subsurface fluid flow features. For example, a fault may be in a wrong location due to improper coarsening. This mechanism allows users to define how many layers are desired to represent their

models and if the upgridding results are not satisfied, users can always reconstruct a new one.

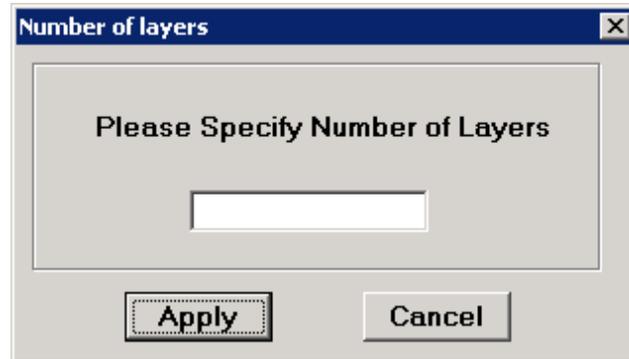


Figure 3.18 Window for defining coarsening number

Optimal Coarsening” is the default coarsening setting for our coarsening algorithm. This button should be clicked after setting user’s private target coarsening number. After clicking this button, a message board will popup and confirms the entry. Here, the ‘optimal’ number of layers is determined based on a bias-variance trade-off criterion. Theoretically, reservoir model with the ‘optimal’ number of layers has minimum loss of static measures which means, minimum ‘SSB’ or maximum ‘SSW’. Our approach used for finding the ‘optimal’ layer is to calculate the RMSE (root mean square error) for a series of regression lines as discussed by Ma (2008). Detailed discussion about how to find the “optimal” layer based on static calculation and geological reality observation will be shown in Chapter IV.

“Marker Layer Setting” enables users to insert geological markers into reservoir models, therefore better grouping layers into a model which is closer to the true one. The marker layers will be preserved thoroughly without combination with neighbor layers and it can be used for identifying different sands. The window is shown in Figure 3.19. There are two main parts in this window. The first part locates in the top area and contains marker

layer inset dialogue boxes. User is requested to select a marker layer on the right hand side dialogue box and then import the layer number into the left box by clicking the “Apply” button. The left top box shows the total number of marker layers has been inserted into the model and the lower box presents the layer numbers. MARS 1.1 allows user to insert as many layers as possible, unlike version 1.0, which can hold only up to 10 layers. Also we provide “Auto Search” function for users searching the possible positions automatically. This search function will identify the i and j positions for each grid block and compare the adjunct layers.

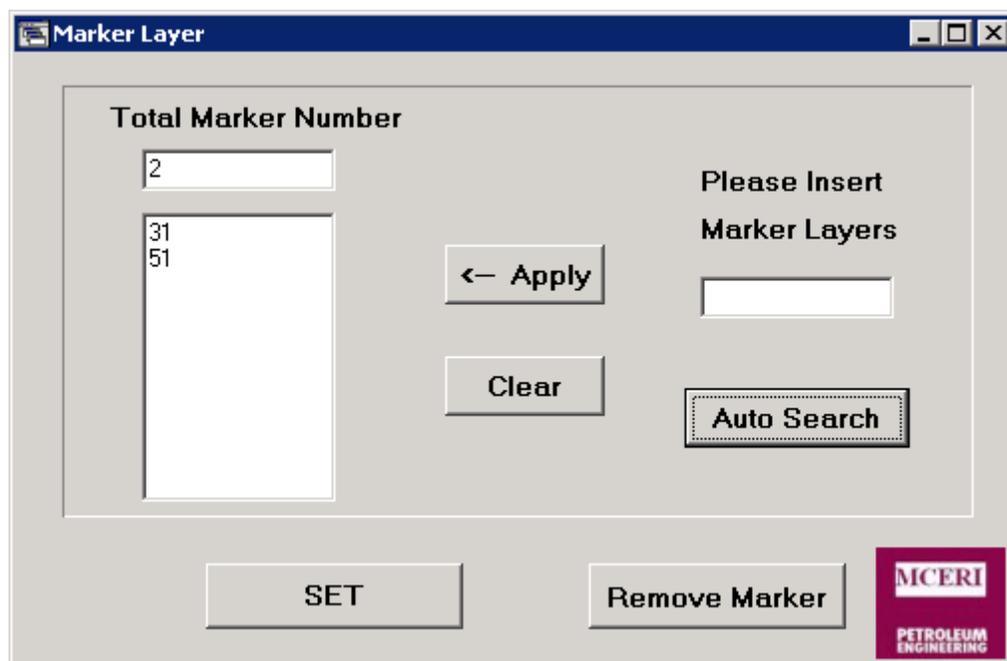


Figure 3.19 Window for setting geological markers into reservoir model

Flow Navigation

We realized the navigation on our program is crucial and we need to define our program information architecture. Along with the “New Project” and “Advanced Setting”, a “Site Map” is located in the main window presenting a list of processes from the beginning to the end including major sub-functions, such as setting target coarsening layer number or geological marker layers. This navigation chart improves the usability and friendliness to

consumers by making sure that all the major and optional functions and capacities can be easily found and are accessible. In addition to that, it also provides an overview of this software's major content at a single glance. Site navigation map can be seen in Figure 3.20. Each part in this navigation map is accessible. By double clicking on the chart element, the correlated window or figures will popup.

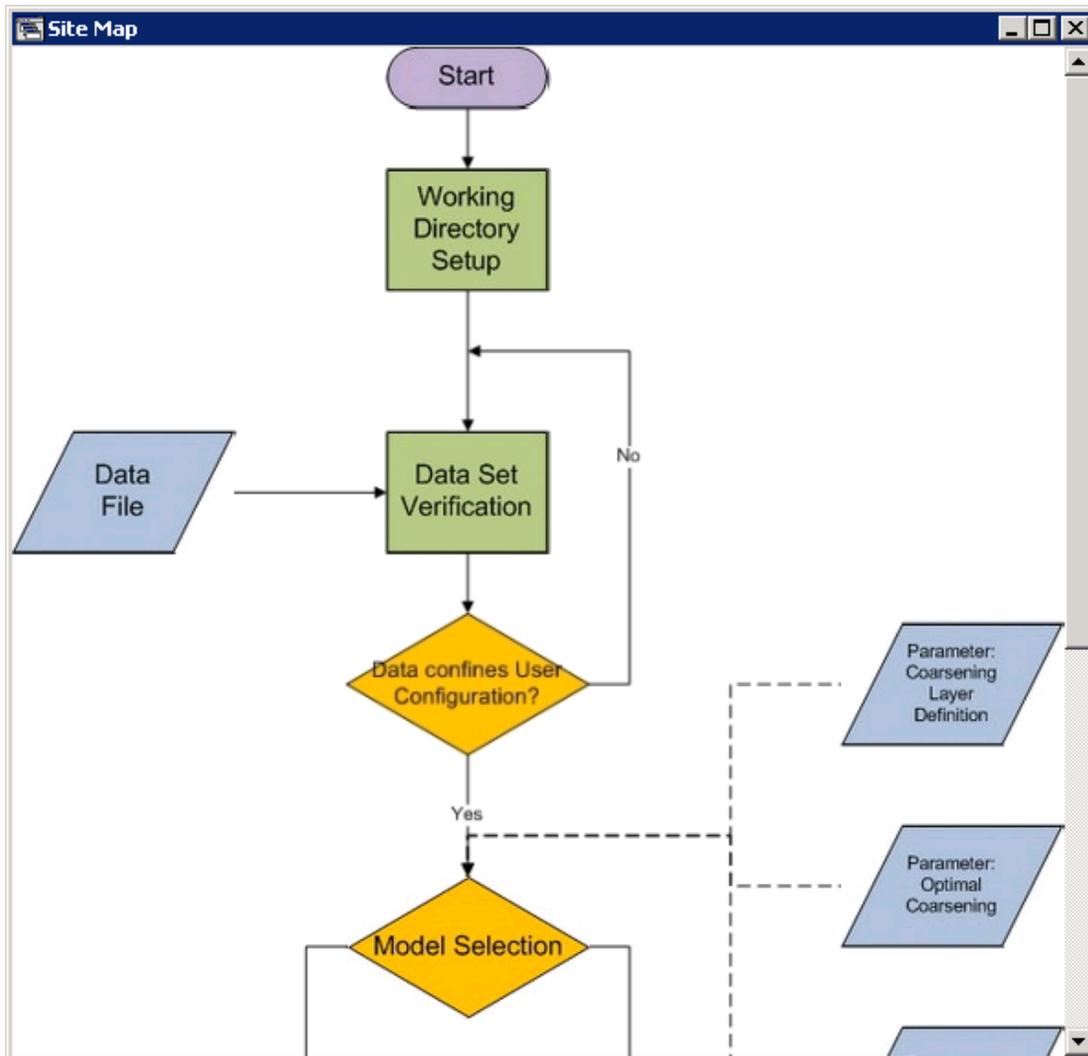


Figure 3.20 Navigation amap for MARS

To make it as simple as possible, meanwhile maintaining its accessibility, we avoided using any distracting elements, such as non-descriptive images. At the same time, we

keep this navigation site meaningful to make sure someone who has never been use this visualization tool before can know immediately where the link will take them. This navigation site gives user a quick visualization without requiring further interaction. Also, the navigation menu is one of the design elements that can provide users with some sense of orientation and guide them through the software. Users should be able to rely on it. To communicate navigation options in a more effective way, we made use of text buttons which are easily recognizable, precisely conveys the message and corresponds to the link it stands for and aren't too small.

CHAPTER IV

CASE STUDY

In this chapter, we are going to discuss application of upgridding algorithm and test the performance of MARS, the upgridding assist tool package. We start with a synthetic example to illustrate the steps in our approach and demonstrate the visualization workability of MARS. Then, two field cases will be used proving the applicability of our approach to high resolution and geologically complex field cases which was from offshore South America and from India near Bombay High field.

4.1 Synthetic Case

To illustrate our algorithm and procedures, we will show a simple synthetic example. This is a 3D 9-spot case containing $21 \times 21 \times 10$ grids and it has a water injection well in the center with 8 producers in the perimeter of the model. The original model is shown in Figure 4.1.

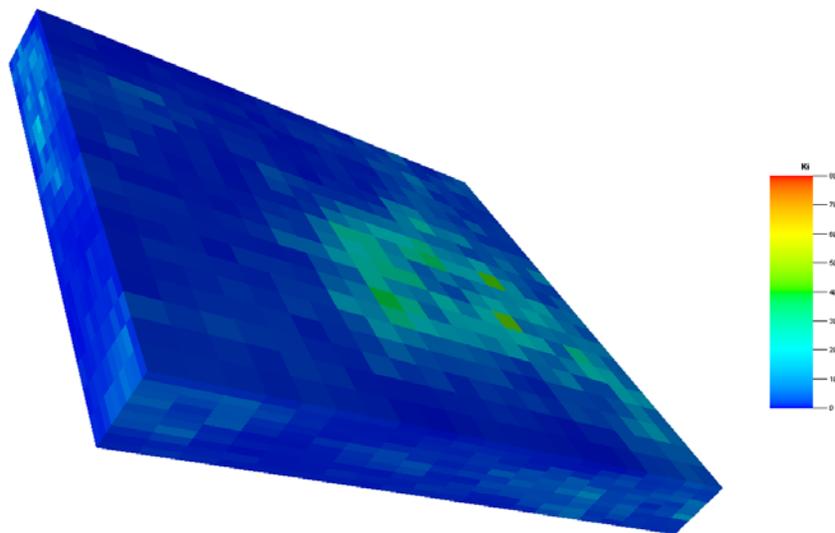


Figure 4.1 Synthetic model in fine scale

The upgridding procedures were accomplished using MARS, which also generated other

data figures, charts and tables like the permeability distribution and variance chart. The variation results with MSRE (Mean Square Root Error) calculation give a 4-layer model as an optimally coarsened one. Here, we followed Ma's (2008) method to retrieve the optimal number which was selected by analyzing the relationship between the 'within cell variation (W)' and the number of layers (Figure 4.2). In Figure 4.2 we present a chart generated by MARS showing the normalized heterogeneity that preserved and removed from the geological model, known as 'between the cell variation (B)' and 'within the cell variation (W)'. From this chart, we noticed that, with 4 layers remaining, we are able to preserve the major features of the initial model and capture 65% of heterogeneity which will be used performing history matching. The basic idea of selecting optimal number is that two linear regressions were fit on the two sides of the curve, and then the weighted mean square error of the regressions is calculated by varying the number of points used in the regressions.

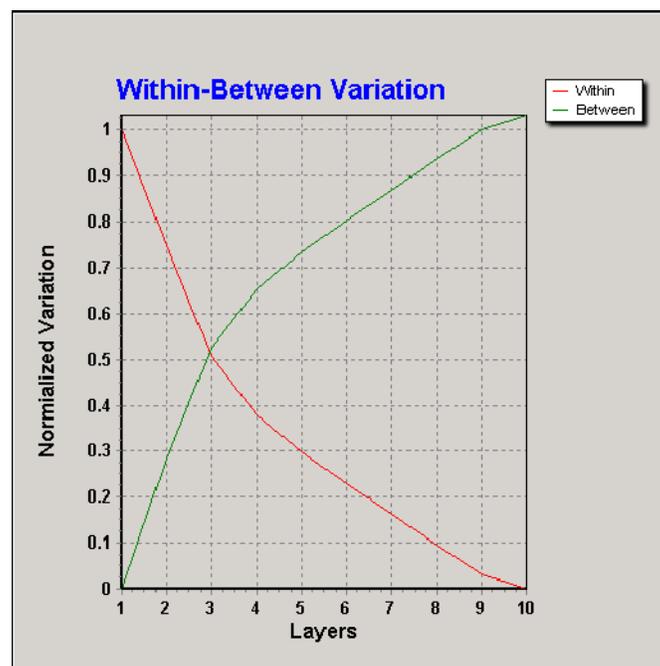


Figure 4.2 Between layer variation (B) and within cell variation (W)

Fig. 4.3 reveals the relationship between the mean square error and the number of layers. The optimal number of layers is the one with the minimal mean square error. In this case, it is 4 layers as the optimal, which preserves 65% heterogeneity of the fine scale model.

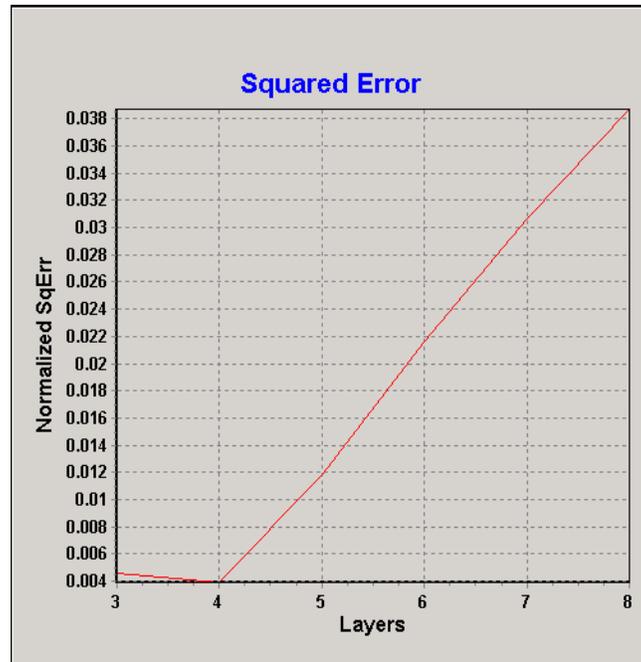


Figure 4.3 Regression mean square error analysis

In other words, the grid block number is reduced to 40% of original one, therefore reducing computer time. Figure 4.4 presents selected layer cross sections of both fine scale and coarsened scale model. The high and low permeability areas are preserved and the coarsened area will use the average value instead the original ones.

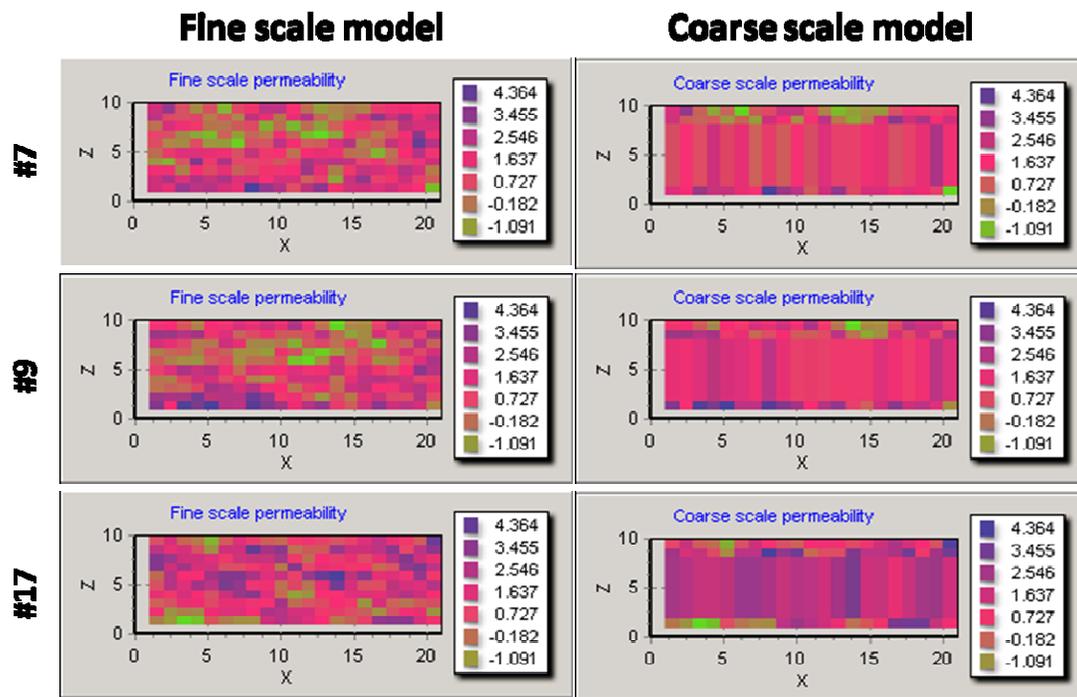


Figure 4.4 (a) Initial permeability field (b) its coarsened model (i-k plane)

4.2 Field Case 1

4.2.1 Reservoir Description

Here we are going to use a 3D channelized reservoir to prove our algorithm and also test our upgridding tool, MARS. This field (Hohl et al. 2006) is a South American offshore Eocene reservoir in water depths of 400 to 800m containing an estimated 500 MMSTB of oil at pressures of 4000 psi. This field consists of three distinctive regions, Sand A, Sand B and the Main Sand, as shown in Figure 4.5, with a k_v/k_h ratio of 0.01. Initially, this field was produced under natural depletion from two wells with field management relying on oil productivity and water cut for 6 years. Six new producers and 4 water injectors were added into this field in a time frame of three years later. The reservoir model was developed an 81 layer structurally complex and faulted turbiditic oil reservoir with more than 850,000 grids (200,000 of which are active cells). This geological model has high quality sands with high permeability, excellent porosity and distinctive transitions

between low and high quality sands. Figure 4.5 presented the 3D perspective view of the 81 layer model, sand A, sand B and main sand permeability distribution, in which numerous channels can be identified easily.

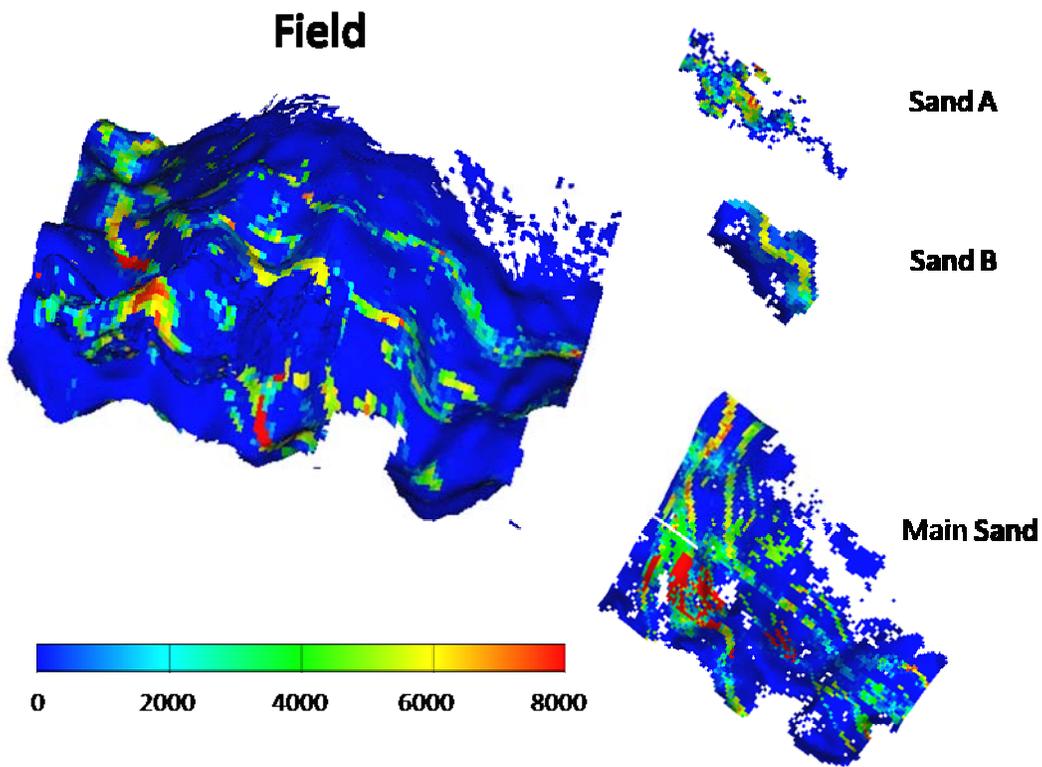


Figure 4.5 Original permeability distribution of field and sub regions

4.2.2 Upgridding Algorithm

We applied the optimal coarsening algorithm to this 81-layer geological model and visualized the results (layer combination, variation chart, permeability fields and et al.) using MARS. All the figures are generated by MARS and the simulation mode was “Slowness” which means we used local slowness as our static measure. Figure 4.6 shows the variation of “within cell variation (W)” and “between cell variation (B)” as a function of number of layers through the coarsening process.

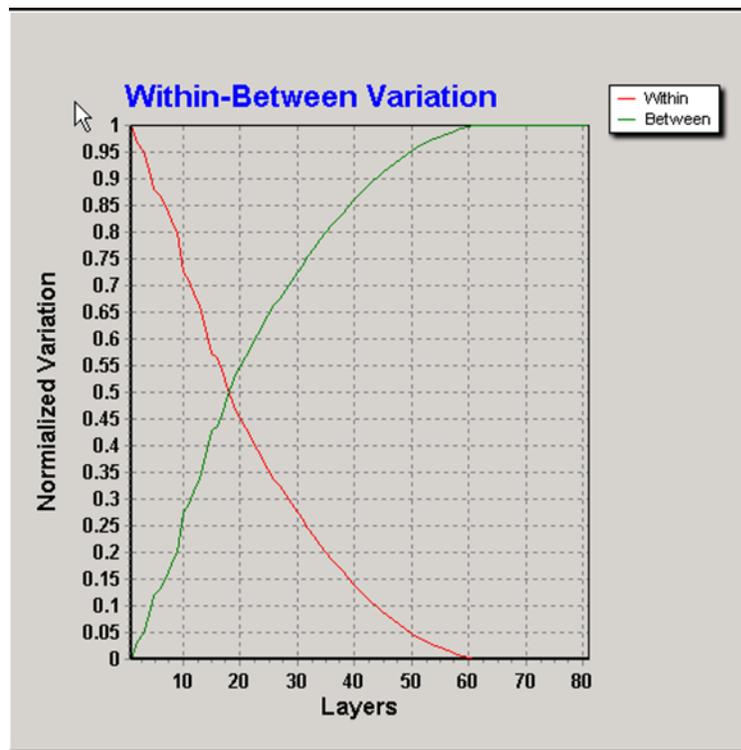


Figure 4.6 between layer variation (B) and within cell variation (W) for 81-layer model

In this 81 layer model, we noticed that the slope of “between cell variation (B)” decreased clearly after 30 (layer number), alternatively, it reveals an upward trend below around 30 layers of “within cell variation (W)” curve. To get the accurate “Optimal” number for layer merging, we calculated the MRSE (Mean Root Squared Error) to find the minimum value thus identifying the optimal number.

Figure 4.7 shows the relationship between the normalized square error and the number of layers for this 81-layer model. From this figure, we claim that optimal number of layer would be 35 with static measure of local slowness. With a layer of 35, the coarsened model is able to preserve 80% heterogeneity as seen from Figure 4.6. Comparing with this calculation, using local velocity as static measure will engender a combination of 25 layers. As mentioned by Telbert et al. (2008) and Ma (2008), the coarsened 25 layer

model has a problem of over coarsening and loss of geological reality. Worth mentioning, the 25 layer model violates the geologic markers. In other words, the geological marker, which should be preserved as it is, is merged with neighbor layers. Obviously, using local slowness instead of local velocity as the static measure will lead to a conservative and more reliable coarsened model. The particularized information about optimal layer selection will be discussed in later chapter.

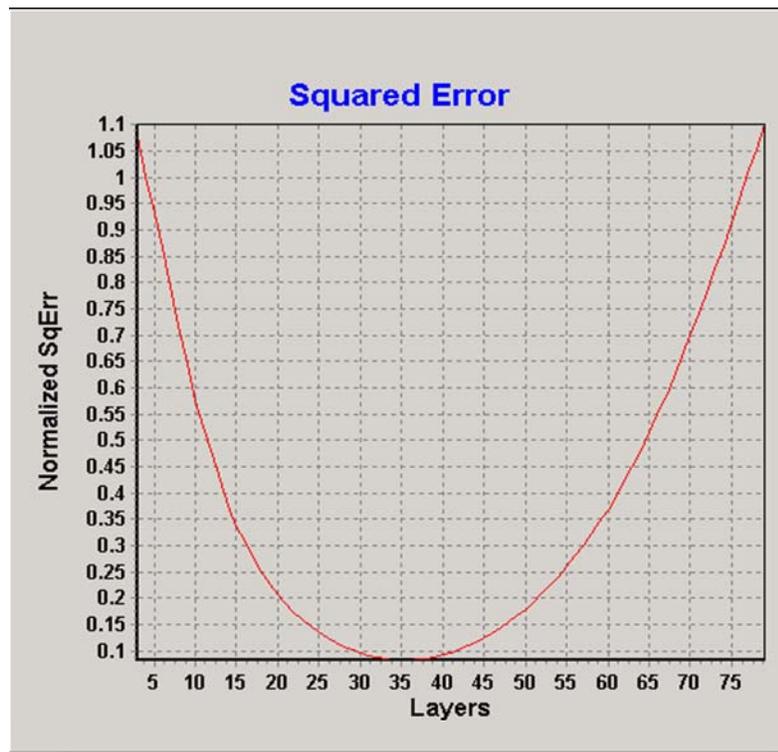


Figure 4.7 Regression mean square error analyses for 81-layer model

The detailed permeability field information for sand A, sand B and main sand can be seen through Figure 4.8 to Figure 4.10, which are going to compare the fine and coarsened models. From those figures, we can see that the coarsened geological model has successfully preserved major characters. Figure 4.8 presents the merging of sand A in optimal (35-layer) model in which the high permeability filed are conserved, though in some area coarse scale model shows a decrease in the permeability value. In this figure,

the 16th layer was combined with other layers resulting in a shape change. Check the output file of MARS, we find out that the 16th (originally) layer was combined with layer 13, 14 and 15 making the new 3rd layer in the optimally coarsened 35-layer model. Figure 4.9 reveals the features of three typical channelized layers in Sand B. In the coarsened model, layer 32 to layer 39 is combined together into a single one with a perfect conservation of high permeability field. Also, the channels are captured as well.

Thought there is a little bit smearing, the majority of the shape and distribution are still recognizable and apparent. For the rest of the area, we updated the value with a volume weighted average value instead for further calculation and history matching. In Figure 4.6, selected layers from the Main Sand are shown. Numerous channels are maintained as the original ones. Actually, for the main sand, based on the “Layer Definition Table” which generated by MARS showing specific combination group, our algorithm shows very limited merging. Important combining appears in the region of Sand A and B.

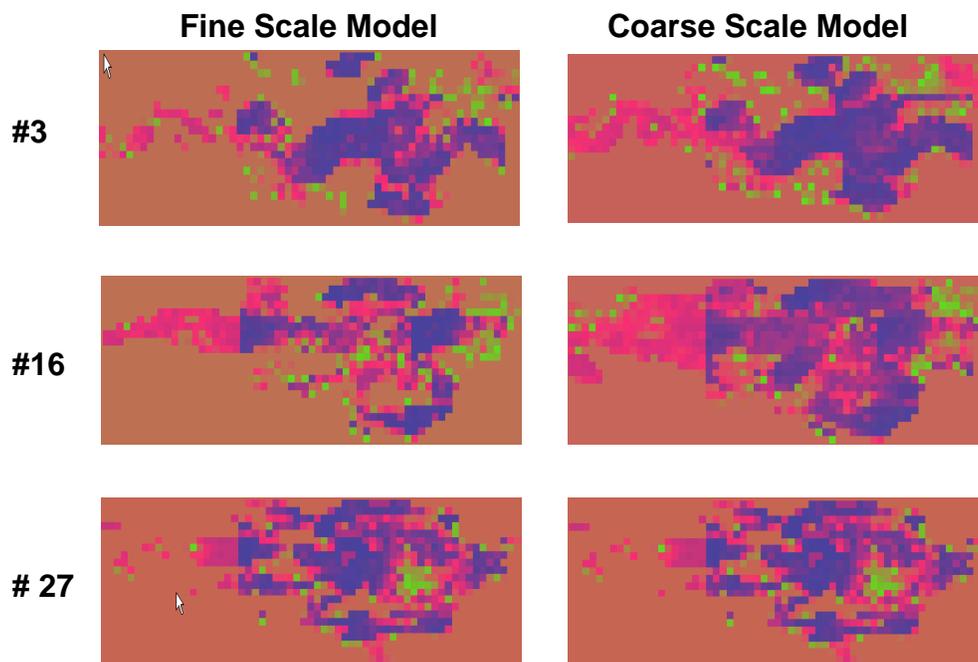


Figure 4.8 Sand A. optimal 35 layer model comparison of permeability distribution with original 81 layers.

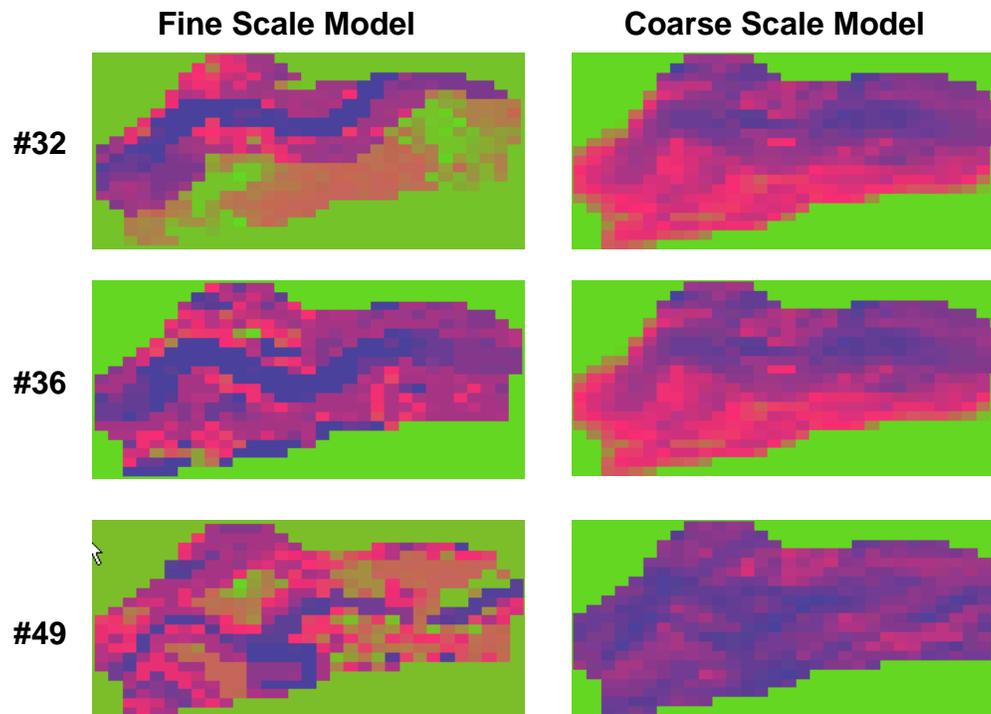


Figure 4.9 Sand B. optimal 35 layer model comparison of permeability distribution with original 81 layers.

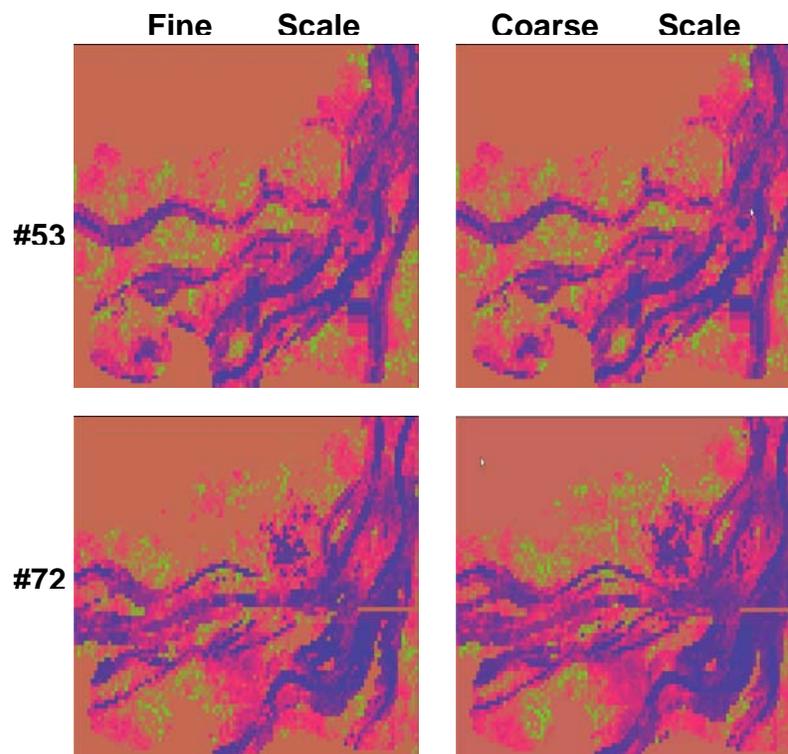


Figure 4.10 Main Sand. optimal 35 layer model comparison of permeability distribution with original 81 layers.

Figure 4.11 to Figure 4.16 reveal the oil production rate and water cut response for the field and for two individual wells. In each of the figure, there are three lines: blue, green and red representing response from original (81-layer) model, optimal coarsened model using local velocity as static measure (25-layer) and optimal coarsened model using local slowness as static measure (35 layers) respectively. Figures 4.11 and 4.12 show the field response for oil production and water cut. Using local slowness as the static measure, we get a 35 as the optimal geological number rather than 25 from using local velocity. Apparently, with minimum deviation from the fine model response and more heterogeneity preserved, the relatively conservative “optimal” model (35-layer) matches much better than using local velocity. We also inspected individual well response for both velocity and slowness mode. Figure 4.13 to Figure 4.16 present selected well responses in terms of oil production rate and the water cut for two wells. From those figures, the local slowness algorithm performs better than the optimal velocity with an excellent match of original model. As mentioned previously, our “optimal” number of layer is obtained based on analysis of “within cell variation (W)” curve. In reality, another important determinant is the concern about geological boundaries or facies distinction. In this model, a geological marker lays on layer 31. This 25-layer mergence significantly smeared the geological properties compared to the original 81 layer model, even to the 35-layer model. This upgridding will results in the loss of facies distinction between Sand A, Sand B and top layer of Main Sand, as mentioned by Talbert et al. (2008) and Ma (2008). In point of fact, with a number of 25, the model layers are merged cross geological boundaries causing a loss of channels and lowering of geological properties. For example, the marker layer, which should be isolated, merged with the adjacent layers in the 25-layer model and therefore combined with other layers step by step. What’s more important, there should be an apparent distinction between sand A and B in the coarsened model. However, from Figure 4.17, the Sand A and B was incorrectly combined due to the over merging of initial model with a static measure of local velocity. This over coarsening

can also explain the serious deviation in water cut therefore in the oil production rate as seen in individual wells and field wide. Ma (2008) suggested a 36-layer model as the optimal choice based on a combination of geological insight and statistical calculation. To compare with our 35-layer model, we choose another 35-layer model with local velocity as the static measure. Figures 4.18 and 4.19 didn't show much difference in field response concerning water cut and oil production rate. Both the static measures can match the initial model with limited deviation regarding water cut and oil production rate. Notice that, though have the same layer number, using local velocity and local slowness as static measure will not and don't have generate the identical layer grouping. A conservative number of coarsening acts better due to its capability of persevering heterogeneity therefore keeps close to the true model. Worth clarifying that, same optimal layer selection method may need further adjustments to generate an acceptable number. It is obviously shown in our case comparison that, for different static measures, Ma's (2008) method gives a 35 as "optimal" number for local slowness and gives a 25 instead for local velocity. Again, using local slowness as the static measure (with same optimal number choosing method) can perform better with minimum loss of geo realistic.

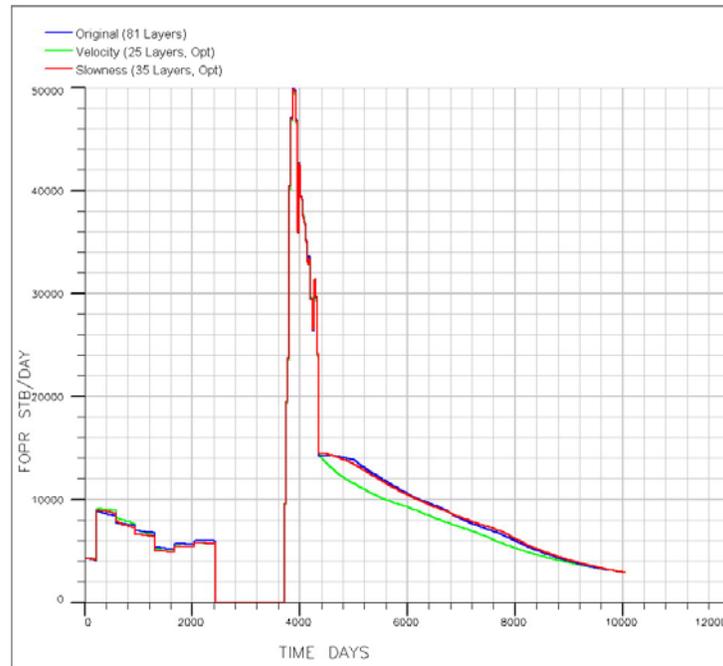


Figure 4.11 Field oil production rate for original (81 layers), optimal velocity model (25 layers) and optimal slowness model (35 layers)

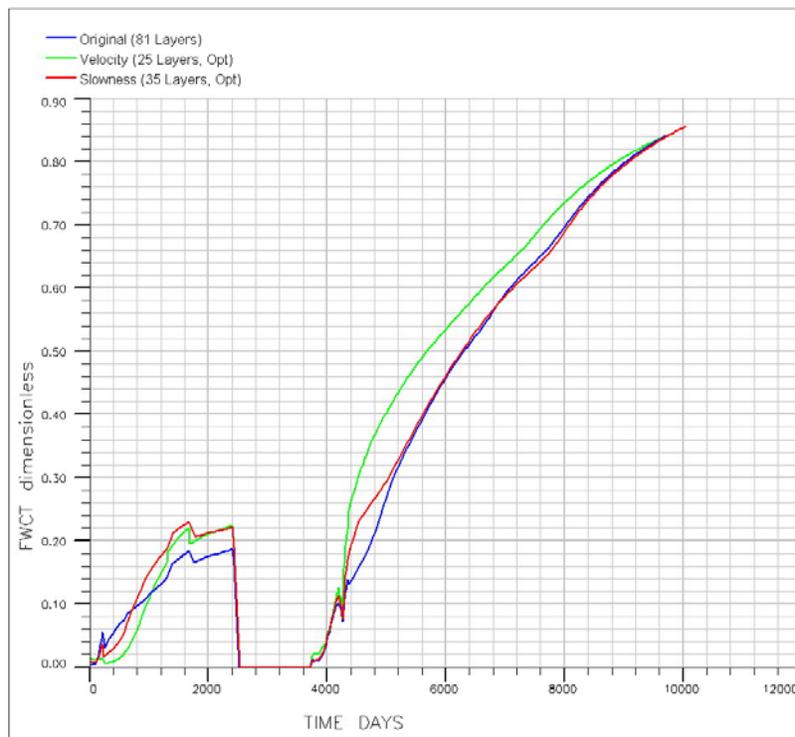


Figure 4.12 Field water cut for original (81 layers), optimal velocity model (25 layers) and optimal slowness model (35 layers)

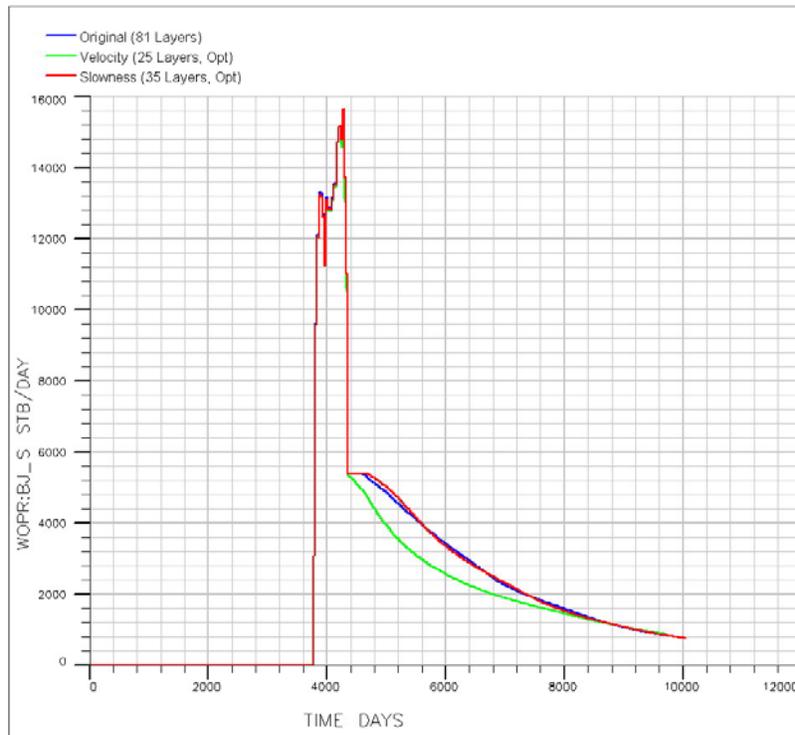


Figure 4.13 Oil production rate for Individual well, S, with original model (81 layers), optimal velocity model (25 layers) and optimal slowness model (35 layers)

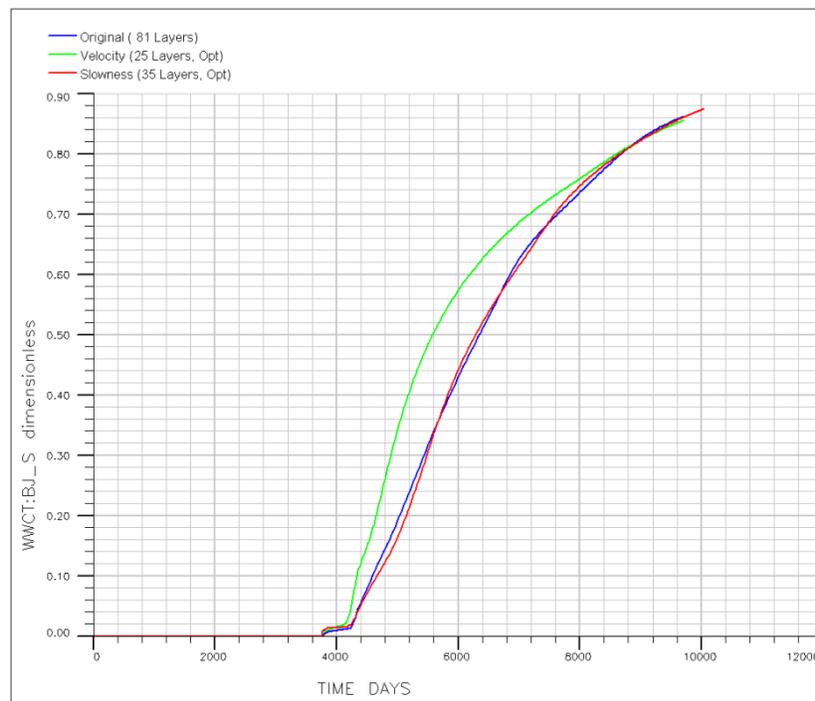


Figure 4.14 Water cut for individual well, S, with original model (81 layers), optimal velocity model (25 layers) and optimal slowness model (35 layers)

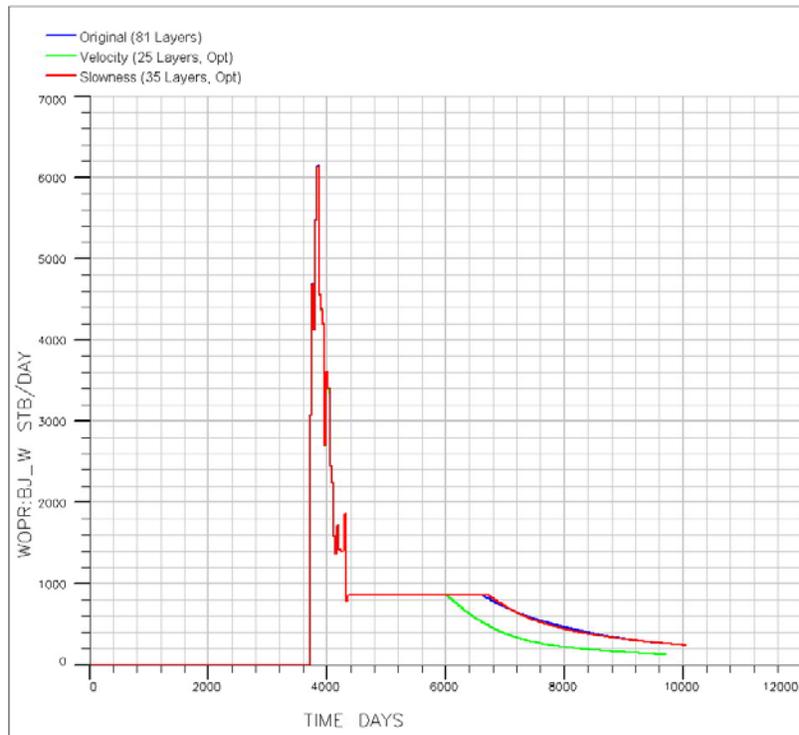


Figure 4.15 Oil production rate for individual well, W, with original model (81 layers), optimal velocity model (25 layers) and optimal slowness model (35 layers)

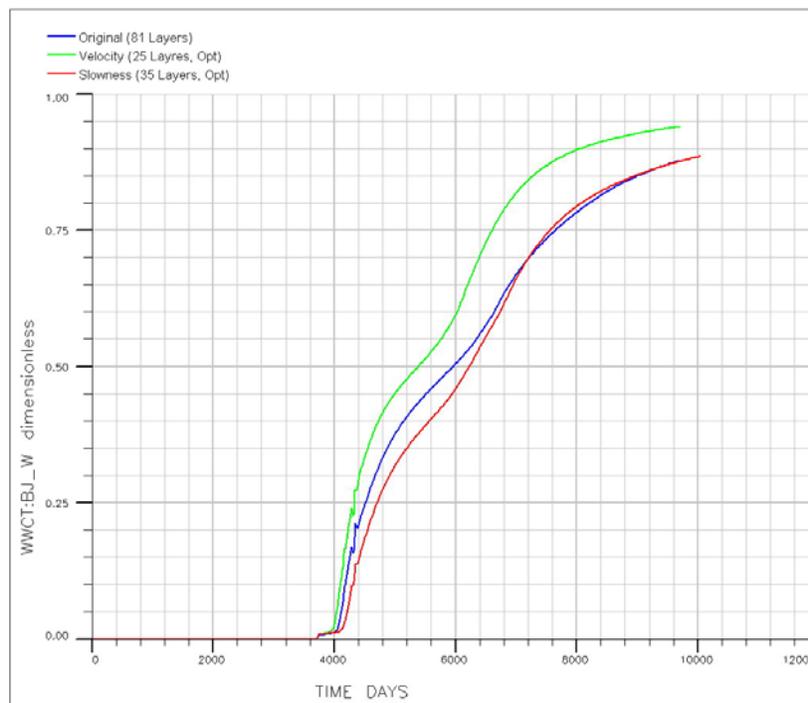


Figure 4.16 Water cut for individual well, W, with original model (81 layers), optimal velocity model (25 layers) and optimal slowness model (35 layers)

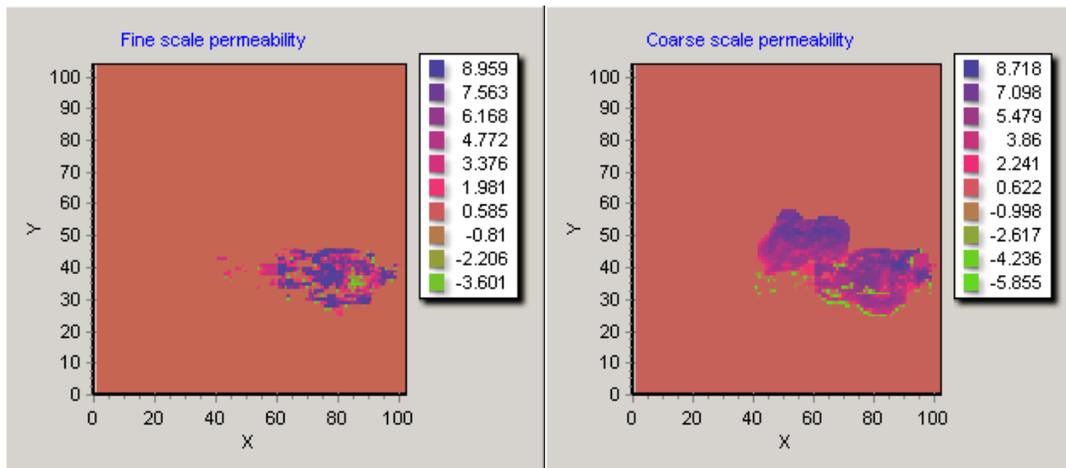


Figure 4.17 Over merging of Sand A and B with local velocity model (25-layer)

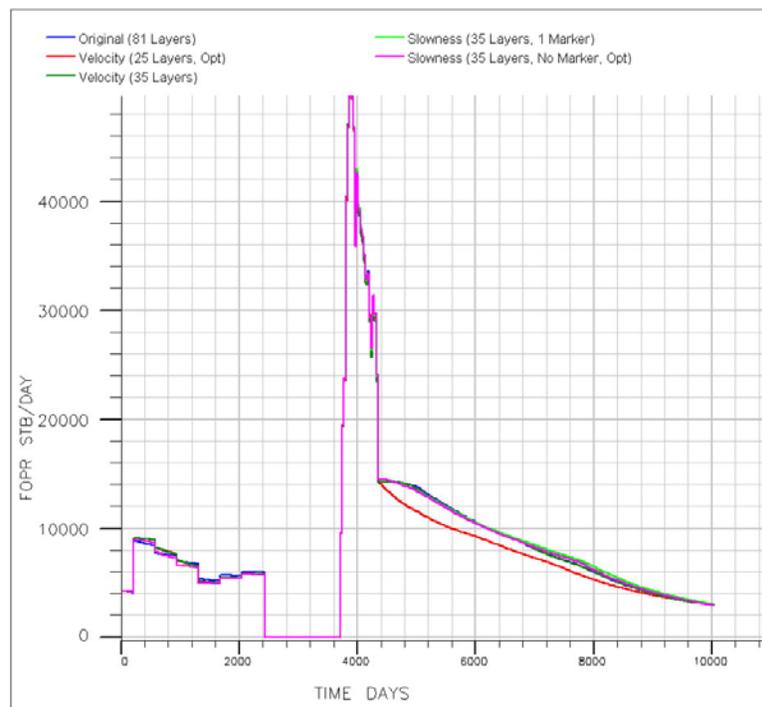


Figure 4.18 Field oil production rate for original (81 layers), optimal velocity model (25 layers and 35 layers) and optimal slowness model (35 layers w/o & w/ marker)

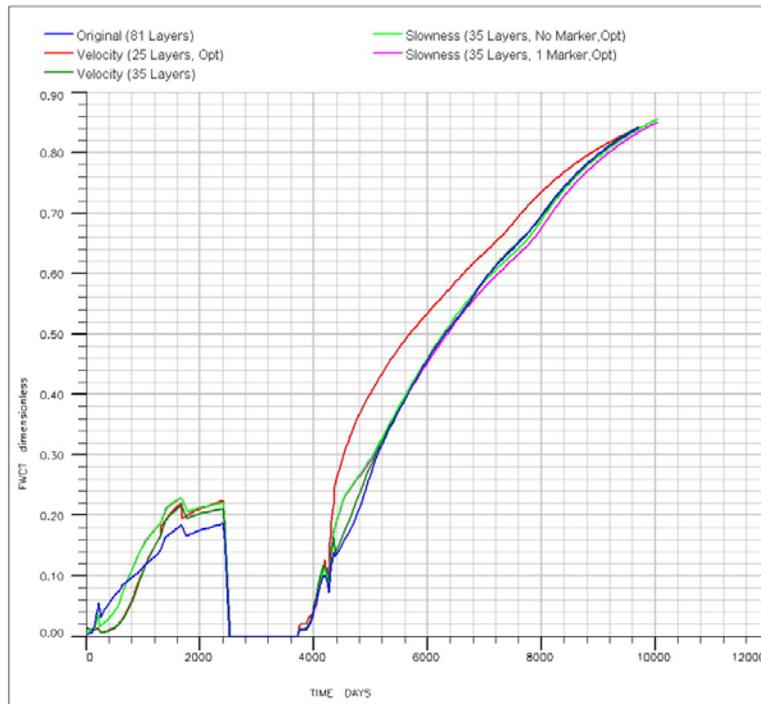


Figure 4.19 Field water cut rate for original (81 layers), optimal velocity model (25 layers and 35 layers) and optimal slowness model (35 layers w/o & w/ marker)

4.2.3 Constraint Setting through MARS

Recall the fact that, the ‘optimal’ number of layer was basically based on an analysis of the ‘within the cell variation (W)’ curve. The fundamental idea is to find the layer that preserves as much heterogeneity as possible with reduced total layer number. Here comes a problem: with too small layer number, the model layers are merged cross geological boundaries causing a loss of channels and lowering of geological properties.

To solve this problem, we have two possible choices: 1) Switch to other method finding the optimal number or use a more conservative number 2) With same target combination number, take geological barrier into consideration and reconstruct coarsen model. Miscellaneous methods had been proposed by previous researchers. Here we will focus on the second way to improve the algorithm by providing geological constraints. MARS provide a mechanism setting the constraints for the geological model to help generating

the “optimal” coarsening while honoring the true model at the same time. As mentioned the previously, the most serious problem in the 25-layer model is over combining of Sand A, Sand B and top 4 layers of Main Sand. MARS is able to assist indentifying geological markers and distinctions between different sands by inserting geological marker layers into the model.

Figure 4.20 reveals the upgridded permeability distribution for Sand A, Sand B and Main Sand with and without geological marker set. The first row of this figure shows the original fine model, in which layer 31 is the marker layer and Sand B starts from layer 32 to 51. The second row presents the coarsened model in which local velocity was used as the static measure with two marker layers set to 31 and 52. By setting the marker layers, layer 31 and 51 will be isolated from merging with other layers. How the other layers will be combined and the “optimal” number will also be calculated based on the algorithm discussed earlier. The third row exhibits the 25-layer model without constraints. The 31st layer was a geologic marker which should be kept as it is without any merging with neighbor layers. Only after we set the constraint through MARS, this layer (Figure 4.20) can be preserved accurately as it should be. In the 25-layer model, this layer was combined with both Sand A and Sand B layers. Output files from MARS show a merging from layer 24 to 41 which covers Sand A, marker layer and Sand B. By way of explanation, the geological barrier was broken due to the needs of grouping. Sand B, locating through layer 32 to 51, and Main Sand starting from layer 52, have absolutely different shape and properties and should be seperated. However, a clear distinction between those two regions is exclusively visible when the geologic markers are set for model manually. After assigning two isolated layers to help group layers with honoring to geological reality and keeping the target number the same, Sand B, from layer 32 to 51, was combined into a single unit. This result can also explain why the channels in Sand B are smeared after upgridding in the 25-layer model with constraints. Loss of geologic

resolution is still serious in the updated model.

Figure 4.21 through Figure 4.23 shows the reservoir response of fine scale model, 35-layer model, 25-layer model with and without marker layers. It is obvious that, with properly settled geologic constraints, the new 25-layer model was considerably improved leading to a better reservoir response close to the true model responses. The deviations in oil production rate as well in water cut are significantly reduced after manually inserting geological markers into the model. We also compared the single well response regarding water cut and oil production rate. Compared to the 25-layer model without constraints, the new model matches more excellent to the original 81-layer model. It is proved that 25-layer model with constraint has much better performance and MARS is a useful tool assisting reservoir model coarsening. Also, it is confirmed that the geological markers and region type have a great impact on the flow response and the optimal coarsening layer should be chosen based on a combination of static calculation and geologic realistic.

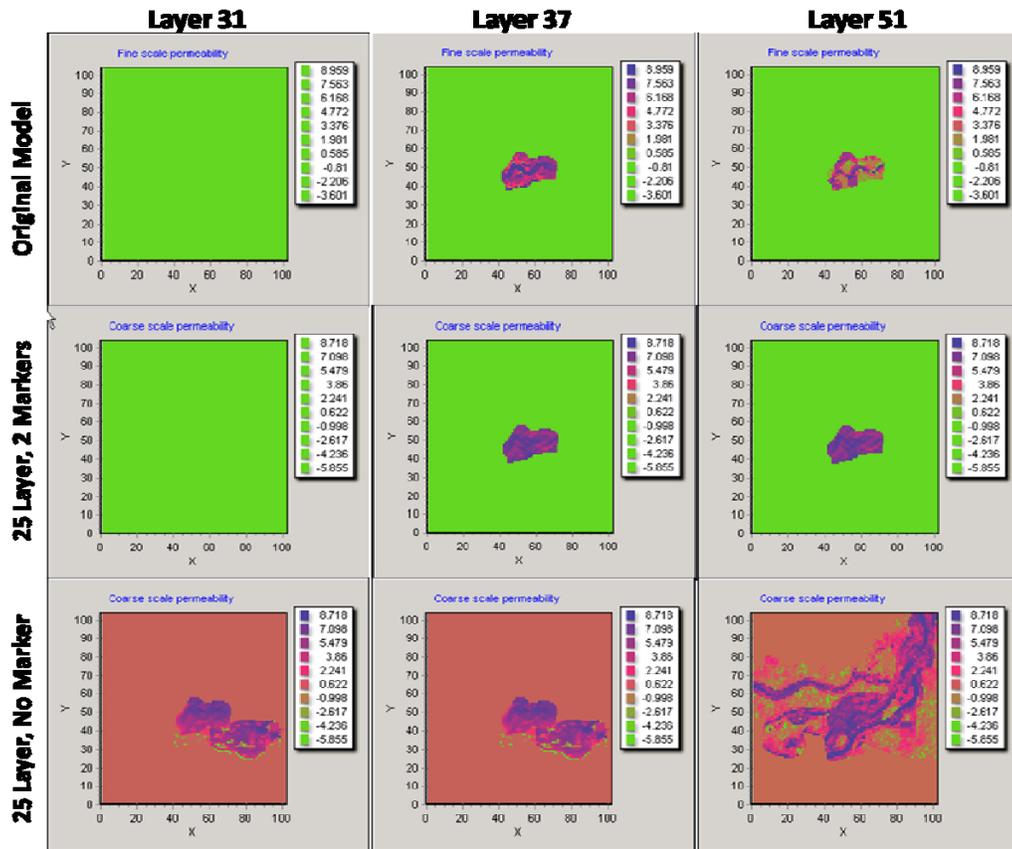


Figure 4.20 Comparison of merging with and without geological constraints

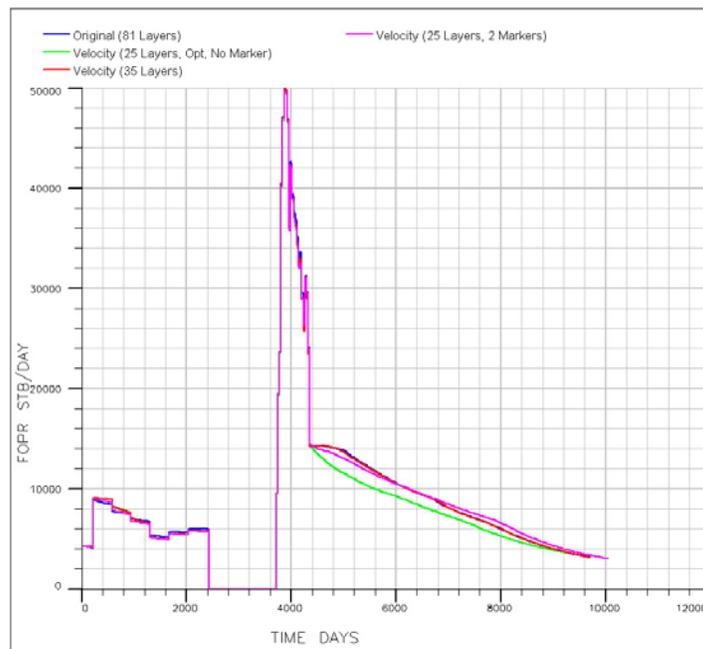


Figure 4.21 Field oil production rate for original (81 layers), optimal velocity model (25 layers) and general velocity model (35 layers) and velocity model (25 layers) with constraint

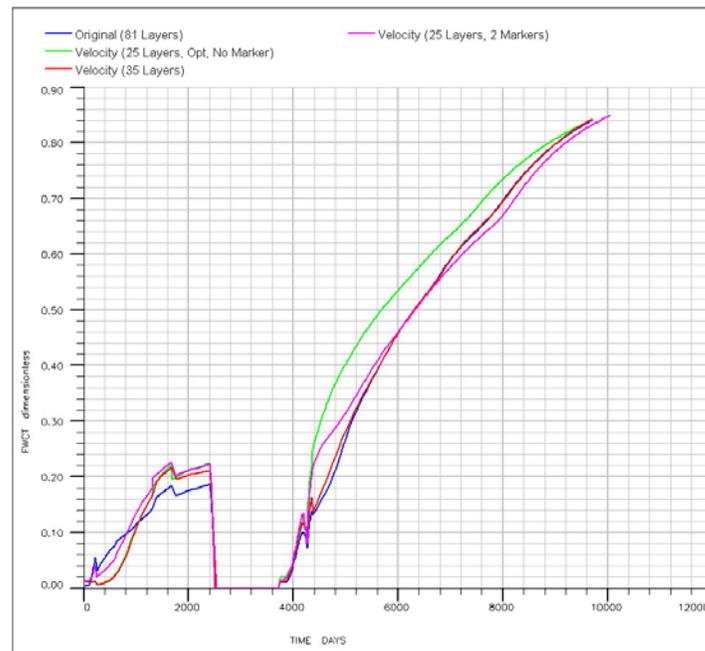


Figure 4.22 Field water cut for original (81 layers), optimal velocity model (25 layers) and general velocity model (35 layers) and velocity model (25 layers) with constraint

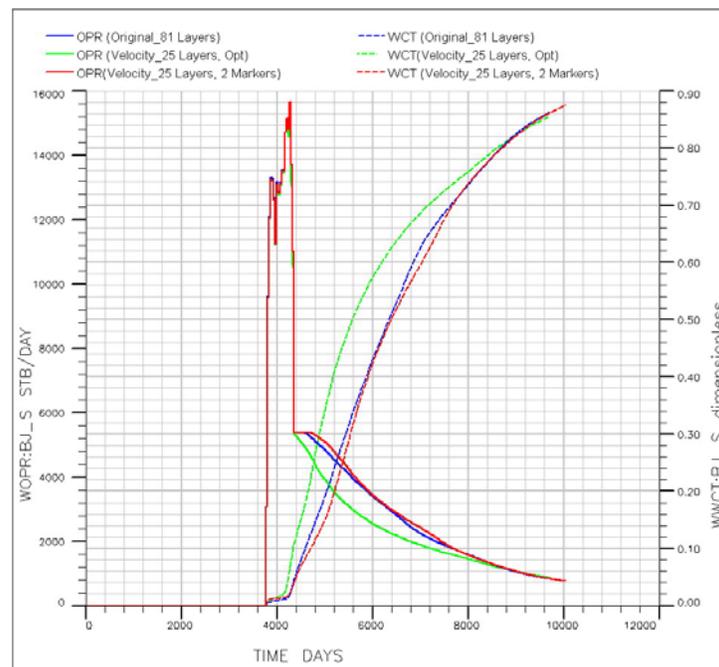


Figure 4.23 Single well (BJ_S) oil production rate and water cut for original (81 layers), optimal velocity model (25 layers) and general velocity model (35 layers) and velocity model (25 layers) with constraint

4.3 Field Case 2

4.3.1 Reservoir Description

In this case we are going to apply our upgridding algorithm on a faulted reservoir. The upgridding assistant tool, MRAS, will also be examined. The fields are located 100km SE of Bombay High field in India. It is one of the major hydrocarbon bearing structures associated with regional NNW-SSE Bassien-Ratnagiri trend in the western offshore basin of India. The field has been delineated through the drilling of 17 exploratory wells and developed into three phases. Phase I and Phase II was confined mainly to the Bassien Formation while the third phase is restricted to Mukta Formation. The major producing formation is the Bassein Formation also known as B-Zone whereas Mukta Formation is known as the A-Zone.

On the basis of the permeability, porosity and water saturation attributes, this reservoir model was developed a 24 layer structurally complex oil reservoir with more than 900,000 grids. This geological model has high quality sands with high permeability, excellent porosity and distinctive transitions between low and high quality sands. Figure 4.24 presented the 3D view perspective view of the 24 layer model permeability distribution.

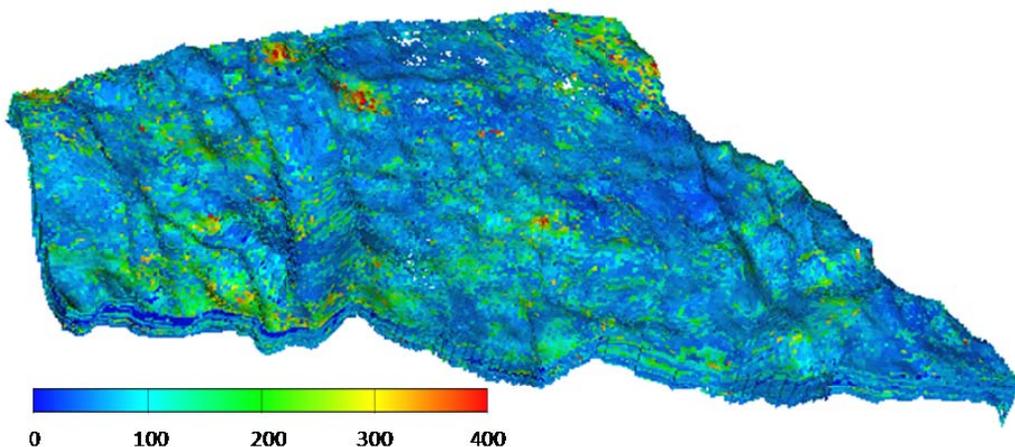


Figure 4.24 Original permeability distribution of field 2 in India

4.3.2 Upgridding Analysis

This field was analyzed with both local velocity and local slowness as the static measure and optimal number of layer was chosen based on calculation of RMSE as before. The 3D geological model can be seen in Figure 4.24. For this 24-layer model, using velocity and slowness both give the same optimal coarsening solution. After coarsening, 3 layers were remained in the reservoir model and the grid block number was reduced to 12.5% of the original. The greatly decreased grid block number means lots of computer time will be saved, computer efficiency is enhanced and major characteristics are kept. Figure 4.25 shows permeabilities for 3 typical layers for the initial fine-scale model and for the coarsened model. Column 1 in Figure 4.25 presents the merging of layer 1 to 9 into a single one which is the 1st layer in optimal (3- layer) model. The grouping of first 9 layers preserved the high permeability region, though in some areas coarse scale model shows a decrease in the permeability value leading to a smeared area. The 10th layer in original model is conserved to the second layer in the new model as shown in the second column. The third layer in the coarsened model was initially from layer 11 to 24. After coarsening, the zero permeability regions are filled with low values.

The optimal number of layer is obtained from calculation of RMSE. To quantify the loss of heterogeneity, we generated variation chart using MARS, as in Figure 4.26, and find a preservation of 90% of heterogeneity in this 3-layer model.

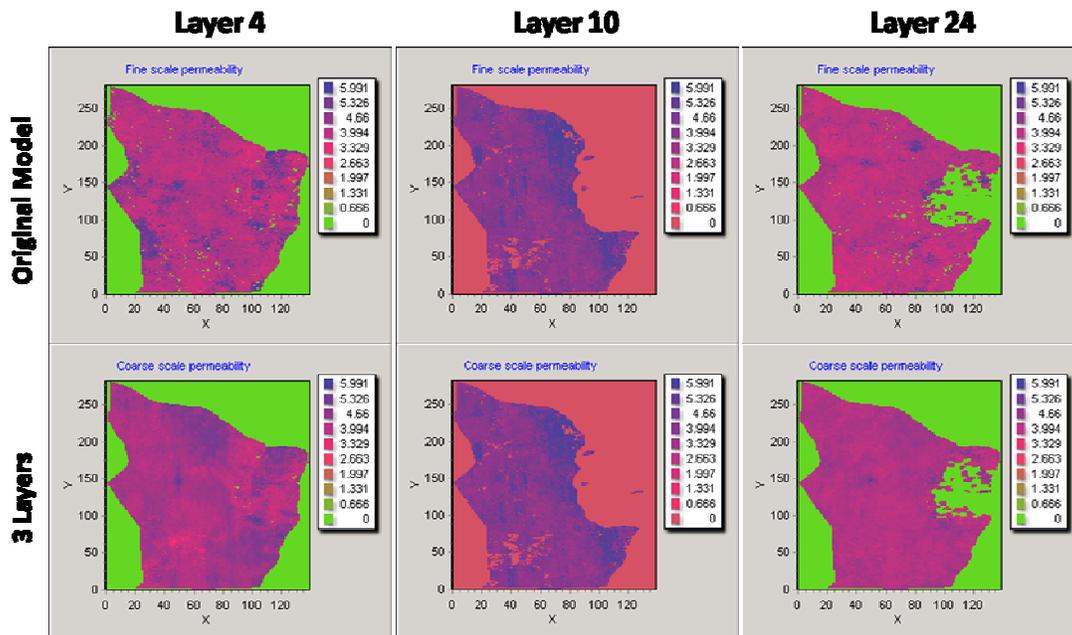


Figure 4.25 Permeability field of three typical layers: #4, #10 and #24

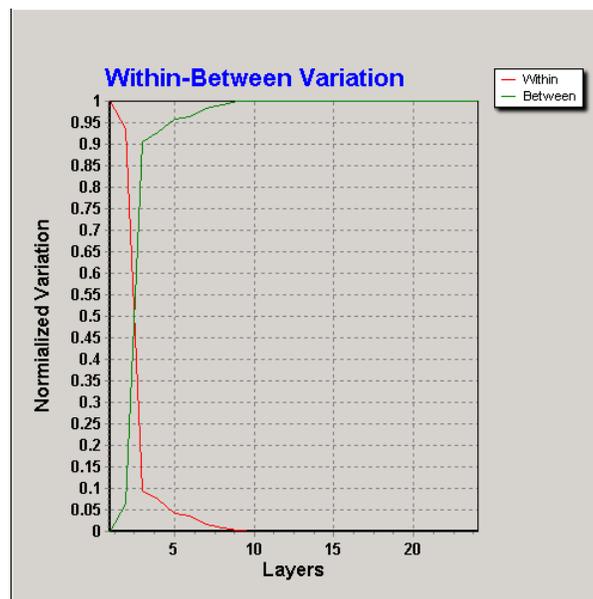


Figure 4.26 Between layer variation (B) and within cell variation (W) for 24-layer model

Figure 4.27 to Figure 4.31 reveals the oil production rate, gas production rate and water cut for the field wide and for one individual well. In each of the figure, there are three lines: blue, green and red representing response from original (24-layer) model, optimal upgridding using local velocity (3-layer) and optimal upgridding model using local

slowness (3-layers) respectively. Using local slowness as the static measure, we get a 3 as the optimal geological number which is exactly the same as using local velocity. Furthermore, the layer combination is also the same. So, we expected identical OPR, GPR and water cut for both field and individual wells.

With minimum deviation from the fine model response, coarsened model perfectly matched oil/gas production rate and water cut. For individual well response, Figure 4.30 to Figure 4.32 present well responses in terms of oil/gas production rate and the water cut. It is proved that the reservoir properties are mostly captured therefore resulting a minimum deviation in well response as seen in the individual well plots. As mentioned before, with only 3 layers remaining, the coarsened model is able to conserve 90% heterogeneity.

From Figure 4.26, we noticed that a 9-layer model can preserve as much as 99% heterogeneity with only 37.5% of original grid cell number. We set a target combination number of 9 through MARS and rebuild the reservoir model. Figure 4.33 reveals a comparison between original, 3-layer (optimal) and 9-layer model. The reservoir properties have been better preserved compared to the 3-layer model in which the high permeability area is removed. The consequent conclusion is that the reservoir response is therefore improved using a 9-layer model and it is demonstrated by Figures 4.34 and 4.35 which illustrate the water cut response of the fine scale model compared to the coarsened models on both field and an individual well basis. Figures 4.34 and 4.35, the water cut comparison, show that our 9-layer coarsened model (red curves) is an excellent match with the fine scale model (blue curves). Recall that the optimal number of layers is the one with the minimal mean square error. Another important rule for us determining the optimal number is that it should be selected based on a combination of reservoir model observation and the layer statistics rather than simply absolutely based on the statistical

criterion.

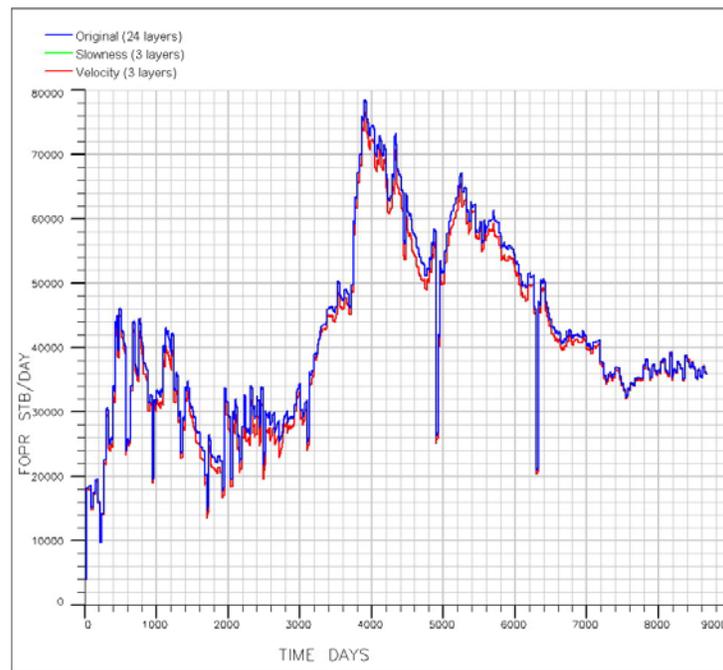


Figure 4.27 Field oil production rate for original (24 layers), optimal velocity mode (3 layers) and optimal slowness model (3 layers)

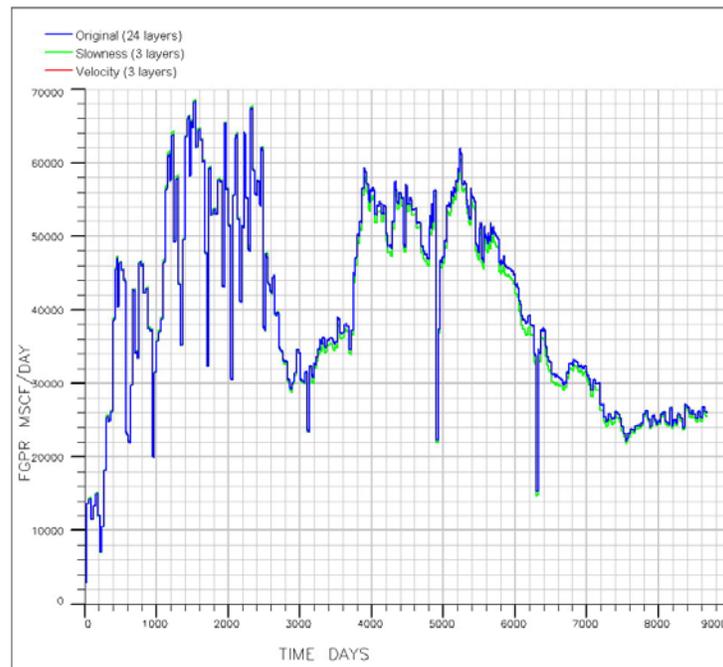


Figure 4.28 Field gas production rate for original (24 layers), optimal velocity mode (3 layers) and optimal slowness model (3 layers)

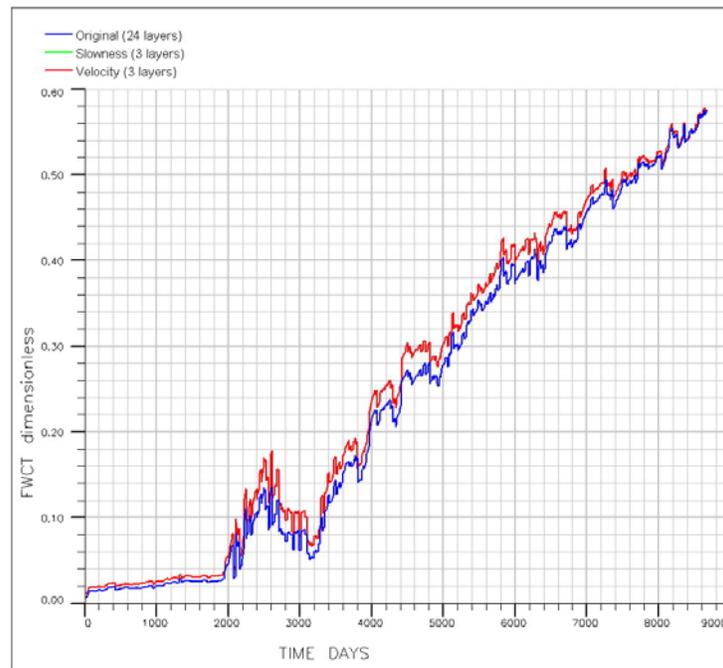


Figure 4.29 Field water cut for original (24 layers), optimal velocity mode (3 layers) and optimal slowness model (3 layers)

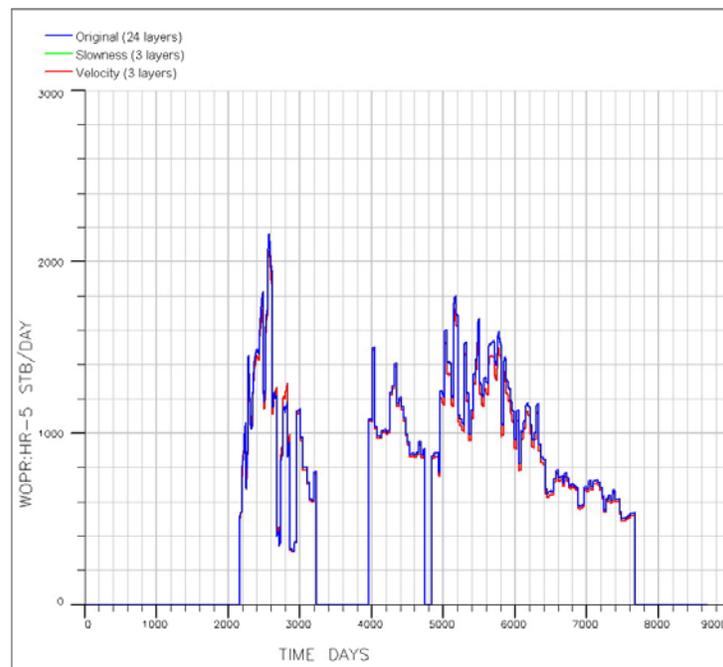


Figure 4.30 Single well oil production for original (24 layers), optimal velocity mode (3 layers) and optimal slowness model (3 layers)

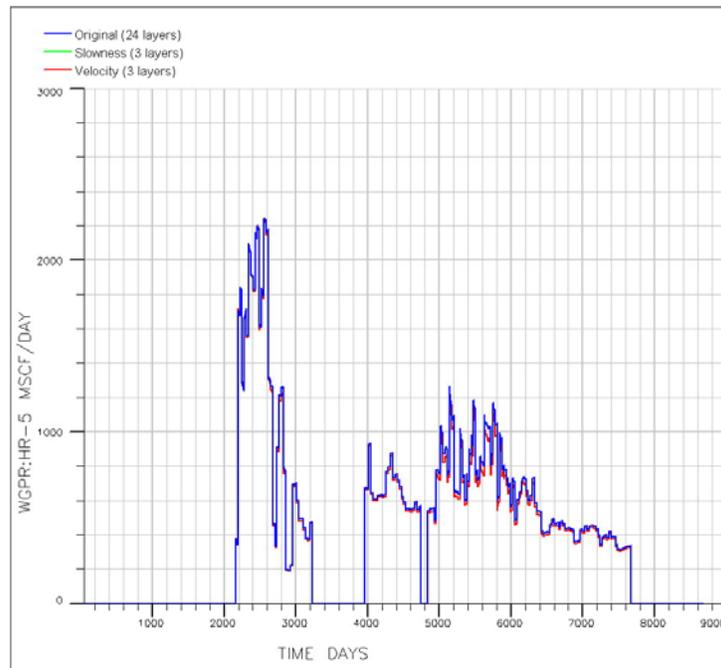


Figure 4.31 Single well gas production rate for original (24 layers), optimal velocity mode (3 layers) and optimal slowness model (3 layers)

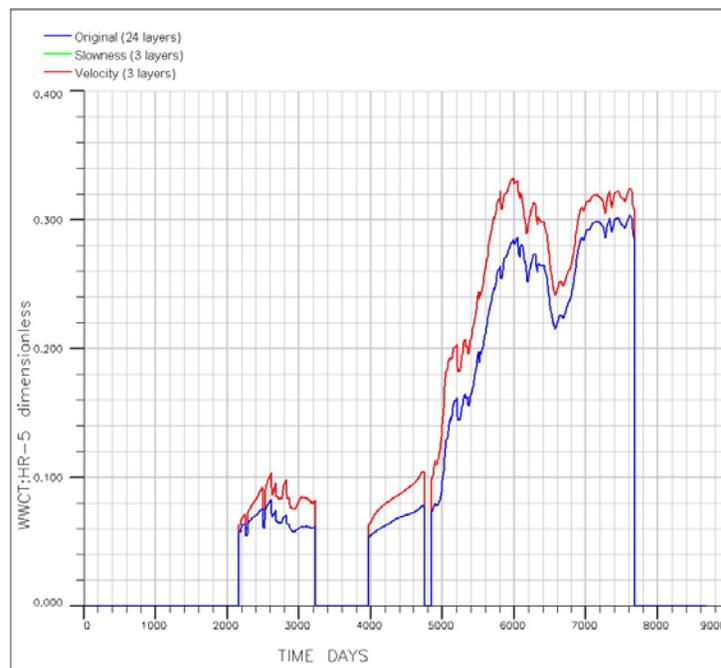


Figure 4.32 Single well gas production rate for original (24 layers), optimal velocity mode (3 layers) and optimal slowness model (3 layers)

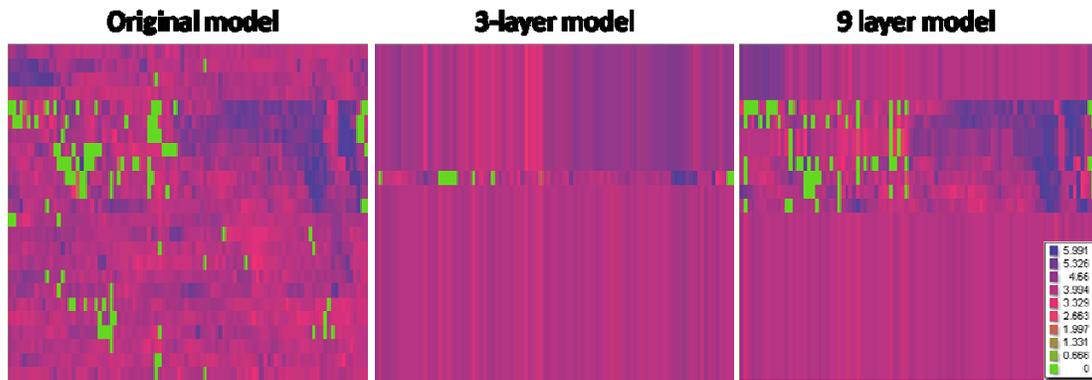


Figure 4.33 Initial permeability field and coarsened permeability field in 3 and 9 layer model

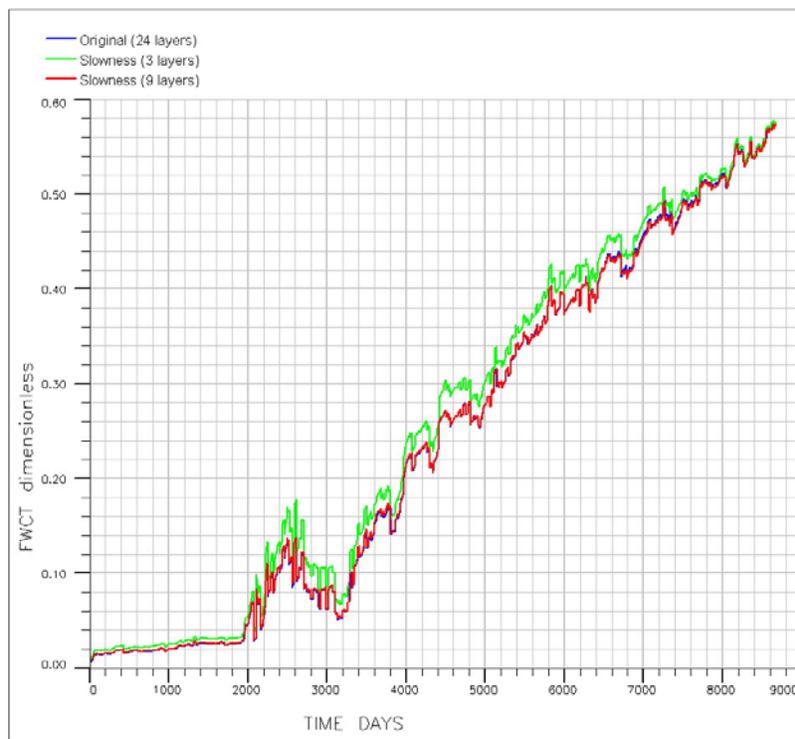


Figure 4.34 Field water cut for original (24 layers), optimal slowness mode (3 layers) and improved slowness model (9 layers)

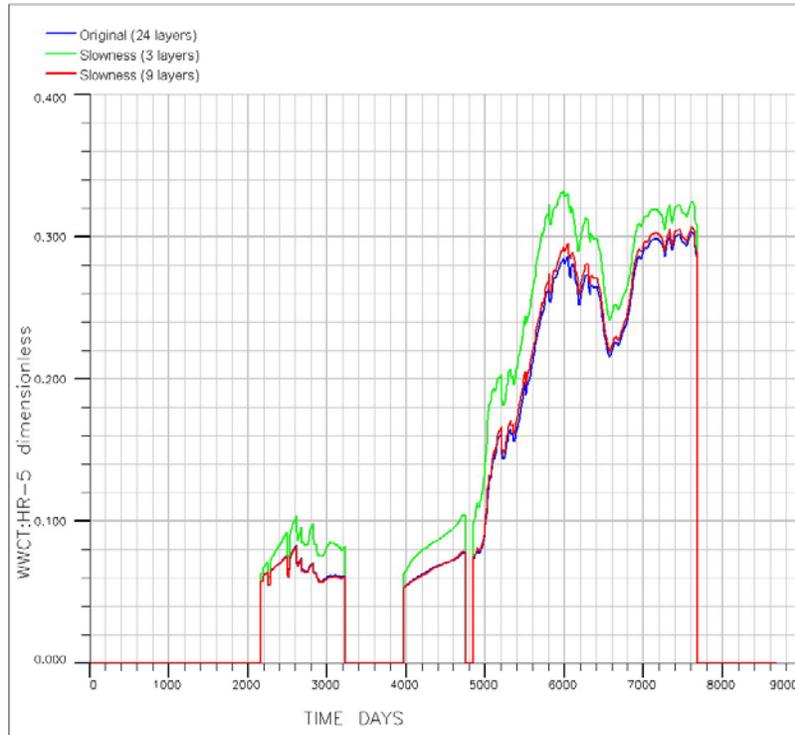


Figure 4.35 Well water cut for original (24 layers), optimal slowness mode (3 layers) and improved slowness model (9 layers)

CHAPTER V

CONCLUSION AND SUGGESTIONS

5.1 Conclusions

1. A static optimal upgridding method is introduced and modified. The updated FORTRAN program is more robust and able to handle geological constraints which are crucial for solving the problem of over combination of adjacently layers. The modified algorithm was applied to both synthetic and realistic field reservoirs. Reservoir responses of water cut and oil/gas production for both field and individual wells are used to demonstrate the effectiveness of the modified algorithm and geological constraints effects.
2. The problem of over merging between different sands is solved. By setting reservoir constraints, different sands can be identified and isolated from merging with each other. In this way, the coarsened model is getting closer to the true geological model. The importance of setting the correlated reservoir constraints is proved by comparison for models with and without geological markers.
3. A GUI (Graphical User Interface) is designed and implemented using C++ under the IDE of Borland C++ builder. This is a software package that helps users access the optimal coarsening procedures from start to finish. The GUI, MARS, is also a high performance data visualization and analysis platform that provides researchers with a highly interactive and extensible data exploration environment. It offers users the ability to visualize manipulate and interact with millions of data in a short period of time. The work ability and the effectiveness are validated by applying the synthetic and field cases.

5.2 Recommendations

The problem of upgridding fine scale models into the coarsened ones is still an attractive and challenging topic demanding much more effort in the reservoir simulation field. This modified static coarsening algorithm relies on static calculation and geological constraints therefore it is able to generate models more close to the true ones. So far, we solved the over merging problem by inserting geological markers into the model manually. This procedure is finished through MARS, which helps setting the geological constraints. This is coarsening algorithm has its nature disadvantage identifying different sand regimes automatically. The next step would be updating the algorithm to enable automatic recognizing of geological shape differences.

Regarding updating the geological properties after optimal coarsening, so far, we only update properties to fine grid and don't regenerate new models. It is necessary to rebuild a true geological coarsened model with updated properties.

MARS, the GUI and optimal coarsening assist tool, is designed and developed to help users on handling coarsening procedures and visualizing results. This is functionalized software with simply interactive features. However, this software has been working fine for Windows systems only, currently. Next step would be making this software package workable over platform. More than that, the output files cannot be used directly for commercial software, such as Eclipse. So, more work should be done to enable this functionality.

NOMENCLATURE

B	= between cell variance
BHP	= bottom hole pressure
f'	= Buckley-Leverett speed
H	= total heterogeneity
I	= number of realizations
J	= iterations
GOR	= production gas/oil ratio
k	= permeability vector
$n_{i,j,k}$	= bulk rock volume
NX	= number of cells in x axis
NY	= number of cells in y axis
NZ	= number of cells in z axis
p	= <i>defined reservoir property</i>
p^c	= <i>transitional column average of static property</i>
\bar{p}	= <i>fine scale column average of static property</i>
t	= time
W	= within cell variance
ϕ	= porosity

REFERENCES

- Bonsiepe. 1993. Gui. Interpretations of Human User Interface. *Visible Language*. **24**. (3):262- 285.
- Chyristie, M.A. 1996. “Upscaling for Reservoir Simulation”, *JPT*, November.
- Durlofsky, L.J., Jones, R.C., and Milliken, W.J. 1994 a. “A New Method for the Scale Up of Displacement Processes in Heterogeneous Reservoirs”, Proceedings of the 4th European Conference on the Mathematics of Oil Recovery, Roros, Norway, June.
- Durlofsky, L.J., Milliken, W.J., Dehghani, K., and Jones, R.C. 1994 b. “Application of a New Scale Up Methodology to the Simulation of Displacement Processes in Heterogeneous Reservoirs”, SPE 28704, Int. Petr. Conf. and Exhib. Of Mexico, Veracruz, 10-13 October.
- Durlofsky, L.J., Behrens, R.A., Jones, R.C., and Bernath A. 1996. Scale Up of Heterogeneous Three Dimensional Reservoir Descriptions. *SPE Journal* **1** (3): 313–326.
- Efendiev, Y. and Durlofsky, L. 2004, Accurate Subgrid Models for Two Phase Flow in Heterogeneous Reservoirs, *SPE Journal*, 9, 219-226,
- Englebart, Douglas. 1962. *Augmenting Human Intellect: A Conceptual Framework*, Menlo Park, CA. Stanford Research Institute.
- Fincham, A., Christensen, J., Barker, J., and P. Samier, P. 2004. Up-Gridding from Geological Model to Simulation Model: Review, Applications and Limitations. Paper SPE 90921 presented at Annual Technical Conference and Exhibition, Houston, 26–29 September.
- Harding, Bruce A. 1989. Windows & Icons & Mice, Oh My! The Changing Face of Computing. *Frontiers in Education Conference: 19th Annual*: 337-342
- Hosseini, Seyyed Abolfazl, and Kelkar, Mohan, 2008, Analytical Upgridding Method to Preserve Dynamic Flow Behavior, Paper SPE 116113 presented at Annual Technical Conference and Exhibition, Denver, 21-24 September

- King, M.J., Burn, K.S., Wang, P., Muralidharan, V., Alvarado, F., Ma, X. and Datta-Gupta, A. 2005. Optimal Coarsening of 3D Reservoir Models for Flow Simulation. Paper SPE 95759 presented at the SPE Annual Technical Conference and Exhibition, Dallas, Texas, 9-12 October.
- Li, D. and Beckner, B. 2000. Optimal Uplayering for Scaleup of Multimillion-Cell Geologic Models. Paper SPE 62927 presented at Annual Technical Conference and Exhibition, Dallas, 1-4 October.
- Ma, X. 2008. History Matching and Uncertainty Quantification Using Sampling Method. PhD dissertation, Texas A&M U. College Station, TX.
- Norman, Donald. 1988, *The Psychology of Everyday Things*. New York: Basic Books.
- Stern, D. and Dawson A. 1999. A Technique for Generating Reservoir Simulation Grids to Preserve Geologic Heterogeneity. Paper SPE 51942 presented at Reservoir Simulation Symposium, Houston, 14-17 February.
- Sablok, R. and Aziz, K. 2005. Upscaling and Discretization Errors in Reservoir Simulation. Paper SPE 93372 presented at the Reservoir Simulation Symposium, Houston, Texas, 31 January – 2 February. DOI: 10.2118/93372-MS.
- Testerman, J.D. 1962. A Statistical Reservoir-Zonation Technique. JPT **14** (8): 889-893. SPE- 286-PA. DOI: 10.2118/286-PA.
- Winograd, Terry. 1995. *From Programming Environments to Environments for Designing*. Communications of the ACM. **38**(6):65-74.
- Wu, X.H., Stone, M.T., Parashkevov, R.R., Stern, D., and Lyons, S.L. 2007. Reservoir Modeling with Global Scaleup. Paper SPE 105237 presented at the Middle East Oil and Gas Show, Kingdom of Bahrain, 11-14 March. DOI: 10.2118/105237-MS.
- Zhang, P., Pickup, G., and Christie, M. 2006. A New Method for Accurate and Practical Upscaling in Highly Heterogeneous Reservoir Models. Paper SPE 103760 presented at the International Oil and Gas Conference, Beijing, China, 5-7 December. DOI: 10.2118/103760

APPENDIX

USER MANUAL FOR USER INTERFACE OF MARS

Version 1.1

Presenter: SONG DU

Texas A&M University

This user manual provides information about how to run the Upgridding (MARS) system in the windows environment. For any detail about input data file structure and other information, please refer User Guide for the Upgridding (MARS).

1. Installation:

Double click on MARS.exe.

It will guide you through all the steps to set up the software in your computer. The default installation path is : “ C:\MARS”. Please note the installation path should avoid using space in the routine name. Please see **Figure 1**.

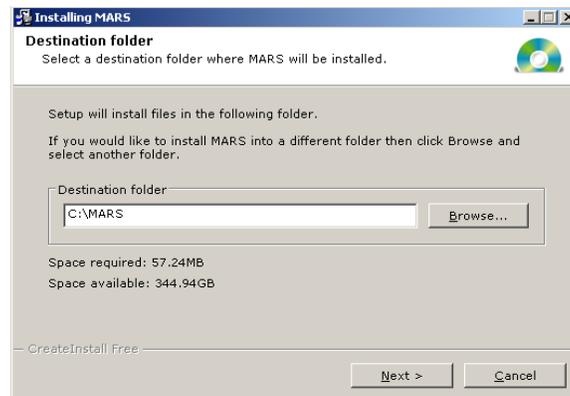


Figure 1 MARS setup

2. After installation is complete:

1. From **Start** -> **Programs**, click on MARS.
2. Once the program starts, the main screen appears as below (**Figure 2**)

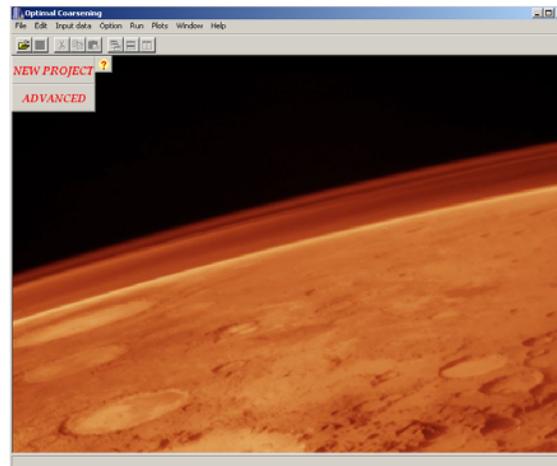


Figure 2 Starting Screen

3. For creation of new project, click on either **File -> New Project** or **NEW PROJECT** on the main window. This will lead user to the step by step guidance page (**Figure 3**).

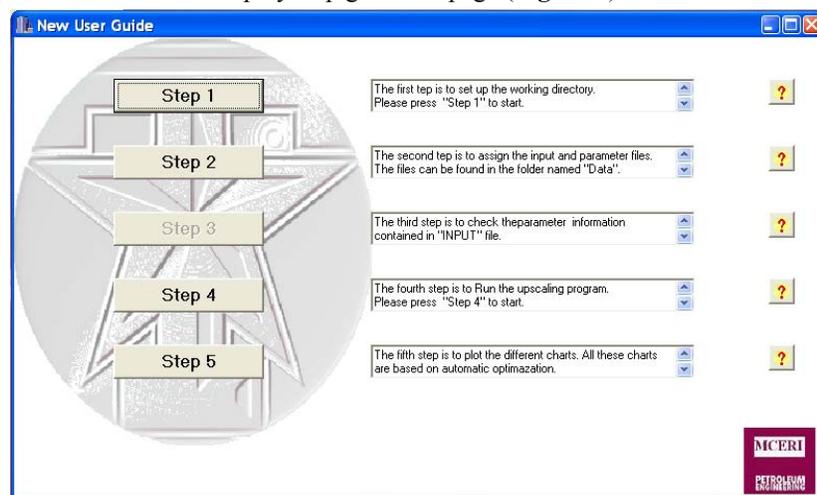


Figure 3 Step by Step Guide

The general help information is provided in the dialogue box right besides the step buttons. For more help information, please click on the question button.

3.1 The first step (**Figure 4**) is to setup the working directory. This working directory is automatically set up, however this step should **NOT** be skipped. The default directory contains the executable FORTRAN program and output files. Please click on the “Apply” button to confirm.



Figure 4 Working Directory Set Up

3.2 The second step (**Figure 5**) is to assign the input and parameter files which can be found in the folder named "Data".

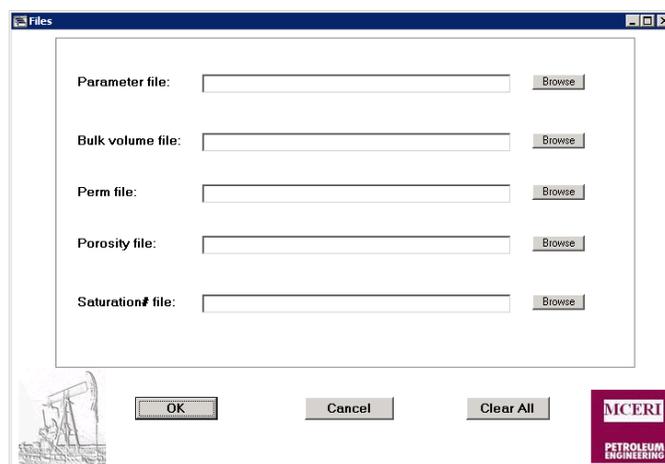


Figure 5 Data File Input

All the data file should be added. For different cases, please use the input files from different folders. Use Input. dat for "Parameter file", Bulkvol.dat for "Bulk volume file", Perm.dat for "Perm file", Poro.dat for "Porosity file" and Satnum.dat for "Saturation number table file". Please note that, missing input file will lead to failure in the programming. Once all input files are set, please click on “OK” button to confirm.

3.3 The third step (**Figure 6**) provides the information check for users. This step will not be available until all the data files are loaded.

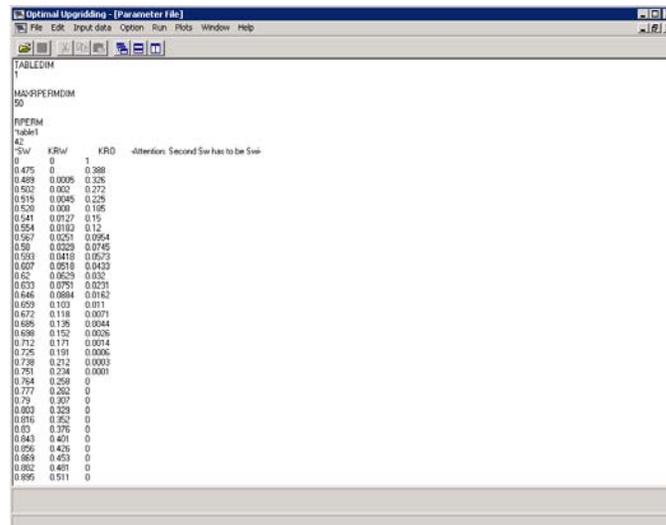


Figure 6 Data File Check

3.4 The fourth step was to run the program. Once modifications are complete (modified files need to be saved), project is ready to be executed. The window will look like the (Figure 6). Two choices were provided. User can pick up either the “Slowness” or “Velocity” mode, for detailed reference about the algorithm we provided, please refers the SPE paper 118950. A DOS window (Figure 8) will appear indicating progress of the simulation. The DOS window will be closed automatically after calculation.

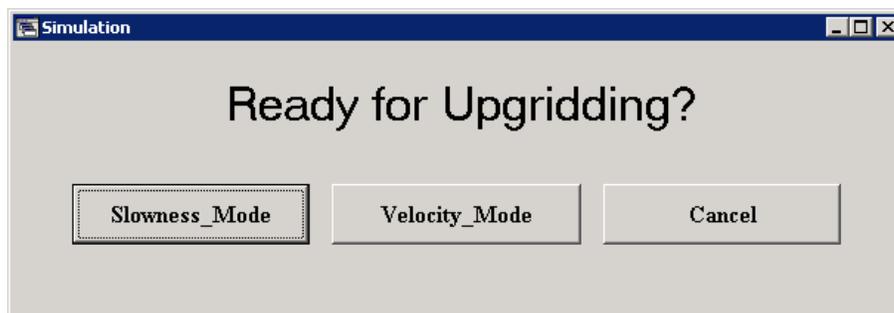


Figure 6 Running modes

```

C:\WINDOWS\system32\cmd.exe
Reading Porosity is Completed
Reading SatNum is Completed

*****
Reading the data is complete
*****

Generating the relative permeability table is complete

*****
Start UpGridding
*****

Step  s      e  LayerNum      Wt      Bw
      MinResidual  LC
1  0.  0.  10  0.00000000E+00  0.19400711E+07  0.00000000E+00
2  6.  7.  9  0.61508879E+05  0.18785639E+07  0.61508801E+05  0.5309
3  5.  7.  8  0.17906080E+06  0.17610101E+07  0.11755218E+06  0.4988
4  3.  4.  7  0.30547469E+06  0.16345956E+07  0.12641423E+06  0.4788
5  8.  9.  6  0.43323631E+06  0.15068374E+07  0.12776162E+06  0.4489
6  3.  7.  5  0.56090450E+06  0.13791640E+07  0.15198552E+06  0.3807
7  3.  9.  4  0.71233800E+06  0.12277270E+07  0.19181750E+06  0.2674

```

Figure 7 Simulation in Progress

3.5 The fifth step (**Figure 8**) was to generate the visible results and data report for the users.

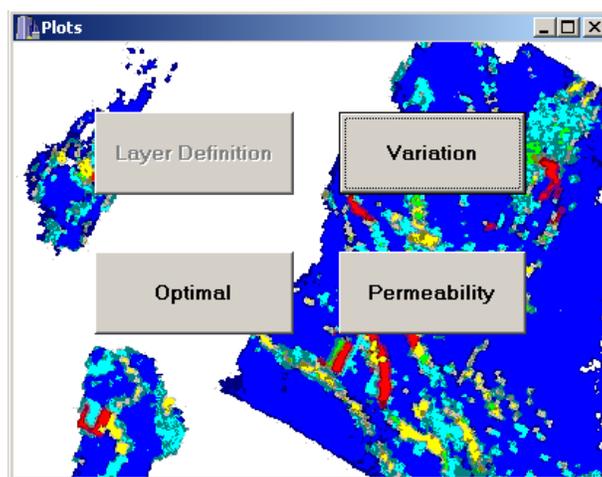
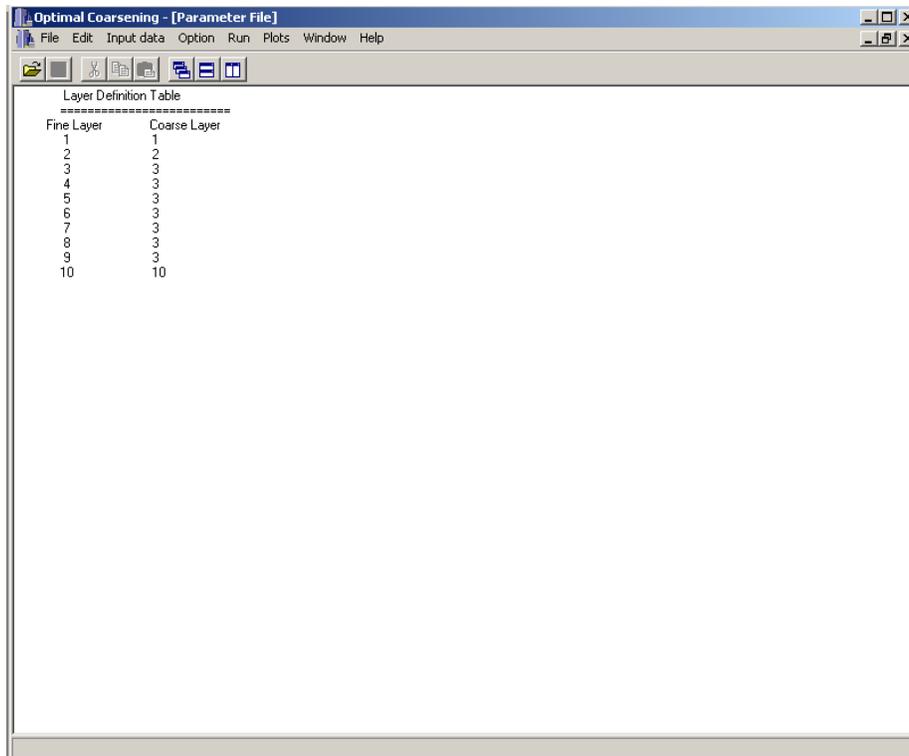


Figure 8 Results generation

Four different types of result will be available. Table, charts, and plots will be provided:

- Layer definition
- Variation
- Optimal
- Permeability

Layer definition: This function provides a table containing the layer information for both fine and coarsened layers. The typical layer definition table can be found in **Figure 9**.



Fine Layer	Coarse Layer
1	1
2	2
3	3
4	3
5	3
6	3
7	3
8	3
9	3
10	10

Figure 9 Layer Definition

Variation (Figure 10): This function provides a chart showing the SSW and SSB for each of the layer. This chart reveals the heterogeneity that preserved (SSB) and removed (SSW) from the system.

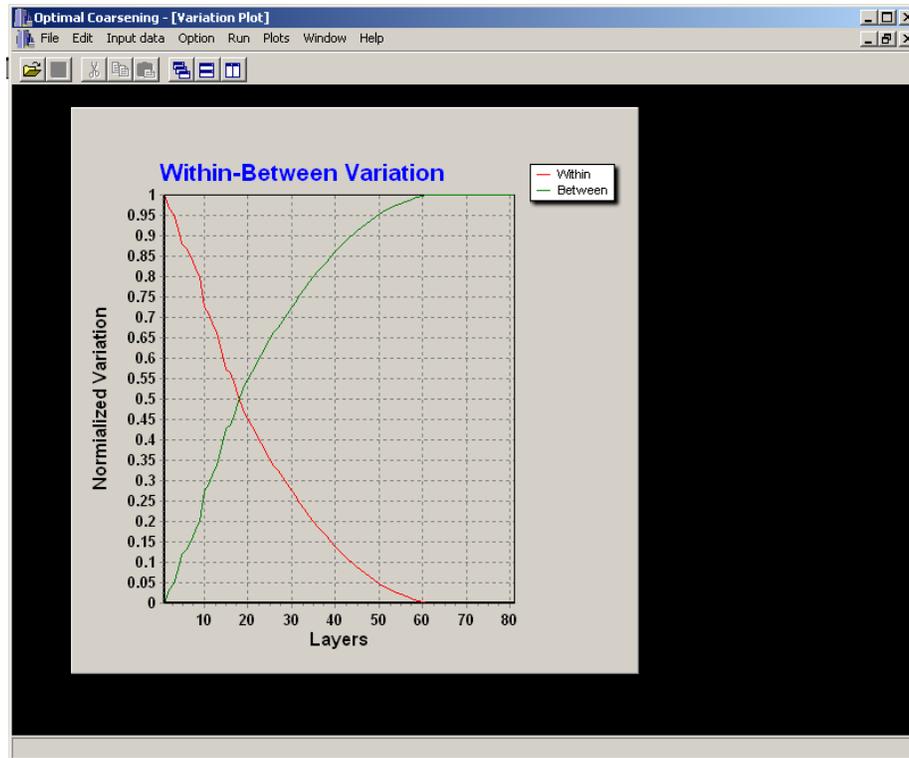


Figure 10 Variation Between/Within Layers

Optimal (Figure 11): This function provides a chart showing the normalized Root Mean Square Error. This chart reveals the “optimal” coarsening layer number that we provide. Again, this is the reference optimal layer number.

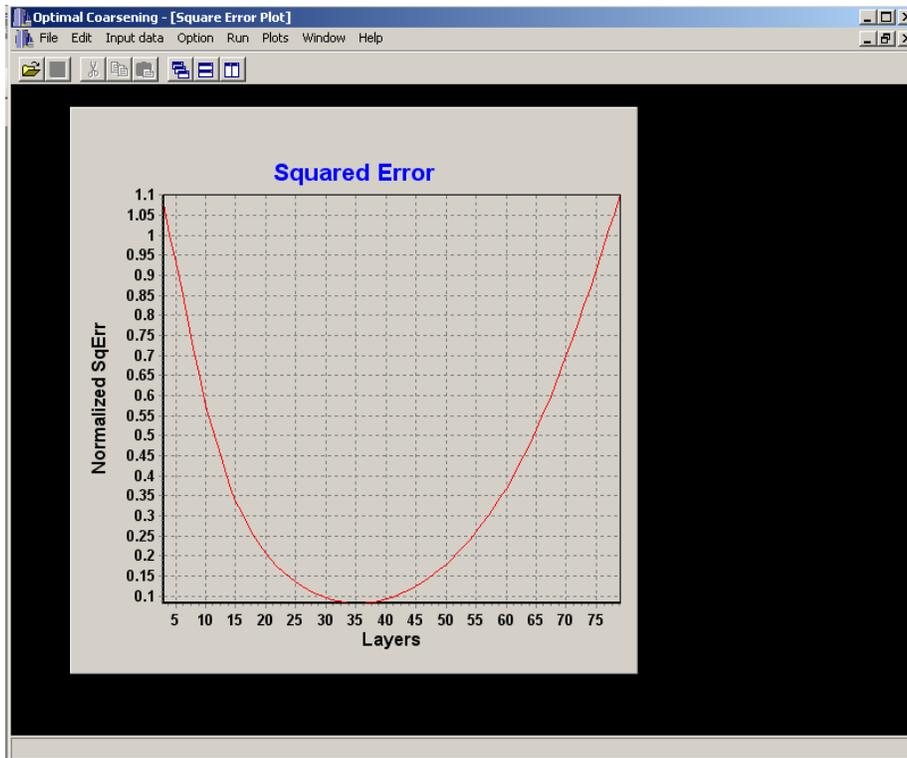


Figure 11 Optimal Layer

Permeability (Figure 12): This function generates the permeability fields. The upper figure is the original permeability field in fine scale and the lower one is the upgridded permeability field in coarse scale. To see different layers, please click on “Up” or “Down” button to change the layer numbers. The showing range can be adjusted by inputting the minimum and maximum value in the input box beside the figures.

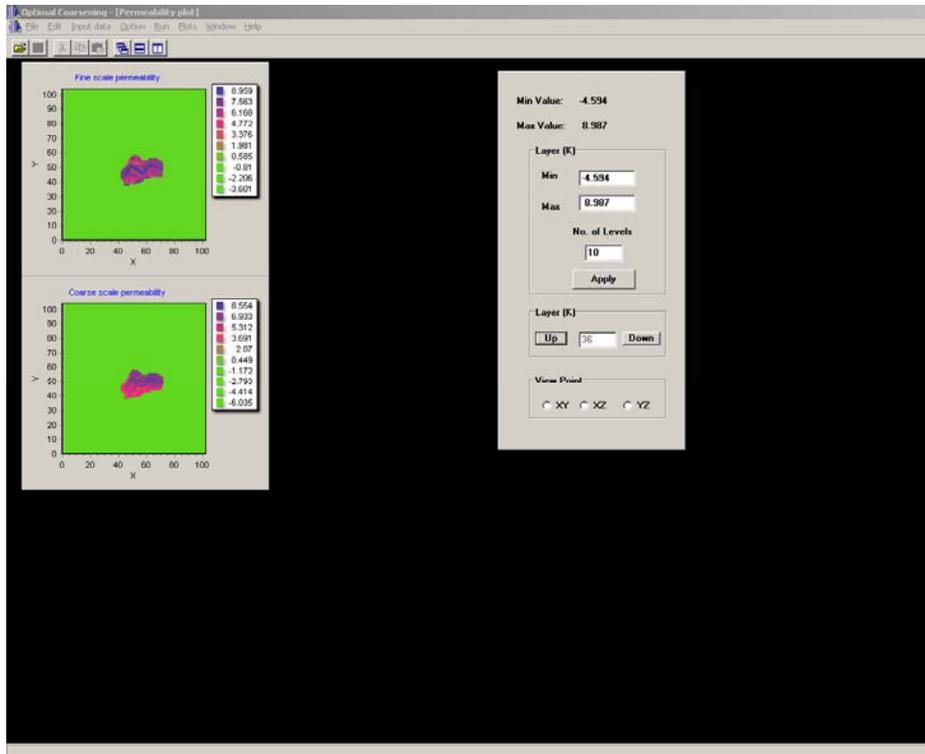


Figure 12 Permeability Field

4. Optional Setting

It is possible for the users to set up their own upgridding target. The final number of layers that preserved in this system is adjustable. Please click on ADVANCED->Coarsening Layer Definition for the layer setup. Please click the “Optimal Coarsening” if want to use the optimal algorithm that the system provided. Please note that, the target layer should not be greater than the maximum number of the layer. Otherwise, there will not be any combination at all.



Figure 13 Advanced Setting

To set up the marker layers, please click on the “Marker Layer Setting”. This will open another window shown in **Figure 14**.

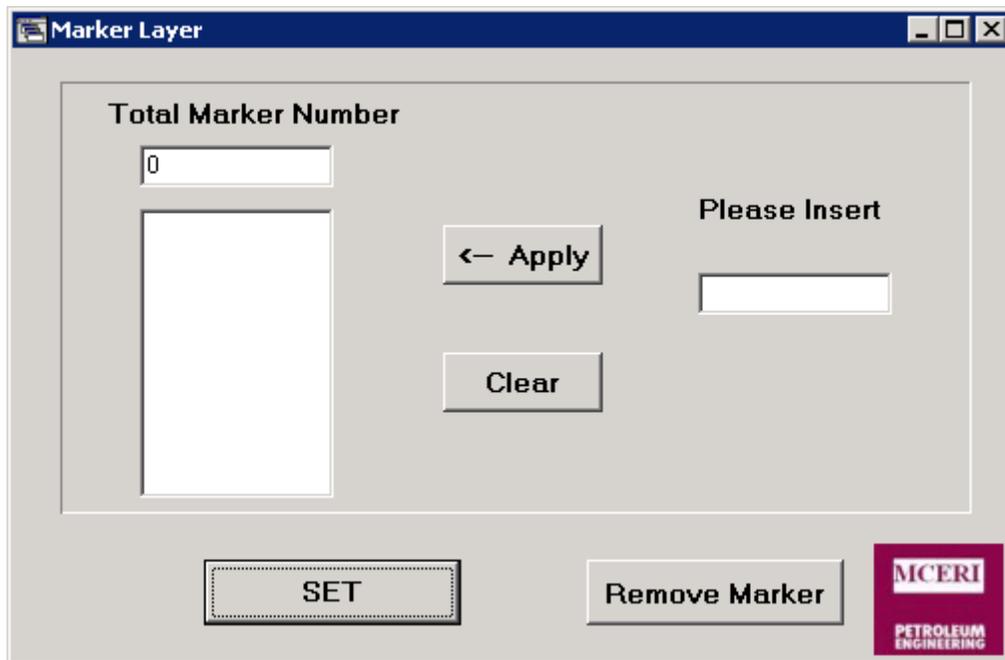


Figure 14 Marker Layer Setting

The marker layers will be preserved exactly as the original ones. The marker layers can prevent their neighbor layers from combining and thus preserving different shapes of the fields.

VITA

SONG DU

Department of Petroleum Engineering, Texas A&M University, College Station,
TX, 77840

song.du@pe.tamu.edu

(979) 209-4311

Education

Texas A&M University, College Station, TX

M.S. in Petroleum Engineering; Dec 2009

Advisor: Prof. **Akhil Datta-Gupta**

Texas A&M University, College Station, TX

M.Engr. in Mechanical Engineering; May 2008

Tsinghua University, Beijing, China

B.S. in Department of Thermal Engineering; Jul 2006

Minor in Computer Application Technology