Developments Toward Multiscale Modeling

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Scale is an important issue in reservoir modeling. Often an array of data are available for reservoir modeling. Eventually using all available data will reduce the level of uncertainty in reservoir models; however, data scale must be taken into account when integrating them into numerical reservoir model. Integrating data from these wide ranges of scales into the reservoir model is a complex task because data measured at different scales reflect different degrees of heterogeneity and can have different degrees of accuracy. Also data from different scales tend to be of different variables, Therefore understanding how variables are correlated at different locations is important task in developing the theory of multi-scale modeling. This paper presents in very general way the attempts to develop a methodology for multi-scale reservoir heterogeneity and uncertainty modeling. The goal is a reservoir model that reproduces the multi-scale data in a way that encounters no artifacts, no biases and handles numerical features of geological data such as nonlinearity and the proportional effect.

Introduction

Predicting future reservoir performance is an important goal of reservoir flow models. Performance forecasting permits optimization of the economic recovery of the oil and gas resources. Reservoir simulation is an established approach to forecast the performance of a reservoir for a particular development strategy. Data is expensive and sparse. Geostatistical models are used with the available data to build numerical models for reservoir simulation. Petroleum reservoirs are heterogeneous. Reservoir properties such as facies, porosity, permeability, faults, fractures and fluid saturations vary in space. The heterogeneity comes from variability in the depositional environment and subsequent events such as compaction, solution and cementation. An important goal of geostatistics is to build numerical models of heterogeneity that can be used in flow simulation. Detailed geological and petrophysical models are extremely important in reservoir simulation. Simplified geological and petrophysical models will produce poor reservoir flow model which cannot be used as a performance forecasting tool. For the past forty years geostatistical methods proved its effectiveness in estimating the reserves in the mining industry. Recently its application has been extended to the petroleum industry. Geostatistical methods can be used to construct detailed geological and petrophysical models that can be used in fluid flow simulator. There are always continuous attempts to enhancing those models.

A central premise of geostatistics is to represent realistic spatial variability. Flow simulation is more reliable using geostatistical models that take into account heterogeneity. Historical geological models built using different techniques such as inverse distance led to less accurate flow forecasting.

Scale is an important issue in reservoir modeling. The aim is to describe a reservoir volume of 10^5-10^7 cubic meters of rock with few data. The data are gathered from different sources often at a much smaller scale. Accounting for the data scale is essential for accurate forecasting. For example, porosity values may be determined from cores or well logs that have significantly different scale than the grid blocks in flow simulation. The difference in scale should be accounted for when assigning properties to flow simulation grid blocks of an even larger scale. **Table1** shows some of the available measurements at different scales. Geostatistical models can be produced at different scales. The resulting models should be consistent when upscaled or downscaled: however, they will not be if the models are constructed by conventional techniques. **Figure1** illustrates the upscaling and downscaling concept. The scale is in cubic metres. There have been attempts to construct scale consistent models. Several methods for multi-scale modeling are available including conventional techniques such as cokriging, sequential gaussian simulation with block kriging and bayesian updating of point kriging.

Direct simulation is one approach. The direct simulation proposal is difficult to implement because of practical problems such as the proportional effect. In a real reservoir high valued areas of a petrophysical properties often show more variability than low valued areas. This natural phenomenon is called the proportional effect. In a statistic term it is called heteroscedasticity; . The proportional effect is a natural phenomenon; it is a fundamental fact that needs to be dealt with. The proportional effect can be seen on the variogram and in the prediction of local uncertainties. Relative variograms can be used to address the issue of the proportional effect on the variograms; however, there is no clear methodology on how to tackle the proportional effect issue in the prediction of local uncertainties. Transferring the data to Gaussian units mitigates the proportional effect issue, however, multi-scale data cannot be transferred directly to Gaussian units as data from different scale do not average linearly which can lead to biases and inconsistencies in the results. A common practice is to perform multi-scale modeling with direct simulation techniques, that is, using the data in their original units. This practice can handle the difference in scale, but the proportional effect issue still exists as direct simulation techniques assume that the variance is independent of the mean, while in reality the variance is indeed a function of the mean. A consequence of this assumption is that uncertainty in low valued areas is overestimated and uncertainty in high valued areas is underestimated.

Vision on how multi-scale modeling could proceed

Assume that we have data from three different scales, seismic, well log and core samples, the probability density function (PDF) can be can be established. **Figure 2** shows a hypothetical PDF sketch for three different types of data. The red PDF represent data collected from large scale (seismic), The yellow PDF represents data collected from a smaller scale (well log) and the blue PDF represent data collected from small scale (core smaples).

The aim is to develop a methodology that can provide mapping of point variable Z to the Gaussian variable Y and vice-versa for different scales. **Figure 3** shows a hypothetical sketch of the target chart. **Figure 4** shows a flow chart of how developing a methodology for multi-scale reservoir heterogeneity and uncertainty modeling can be achieved. First, available data from different sources at different scales must be transformed to Gaussian space without introducing a bias. To do so a scale dependent transformation methodology has to be developed, then the transformed data must be processed simultaneously for estimation at unsampled location. A methodology has to be developed to perform this task**.** Co kriging and/or block kriging under multi-Gaussian model can be used to develop a methodology to simultaneously process all the transformed data. The output of this process is the prediction of a conditional mean and conditional variance at unsampled location. At this stage a conditional distribution at unsampled location can be generated in Gaussian units, it then can be back transformed to obtain a scale dependent conditional distribution in original units which has no artifacts, no biases and handles numerical features of geological data such as nonlinearity and the proportional effect.

Comments on Implementation

The multivariate Gaussian distribution is considered for this proposed approach. A characteristic feature of this distribution is that means and covariances fully parameterize any dimension distribution. These covariances, however, represent different scales. A number of examples have been constructed to verify that multiscale covariances predicted from theory are matched by numerical calculations. Full implementation is underway at the present time.

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Table 1. Measurements at different scales.

Type	Level	Measurement Scale	Measurements
Micro	Pore	~Millimetre	Pore geometry Grain size Mineralogy
Macro	Core	~ Centimetre	K,kr,Ø,Pc Wetability Saturation
Mega	Grid block	~Metre	Logs Single well tracer
Giga	Interwell	~Kilometre	Well test Surface seismic Interwell tracer test

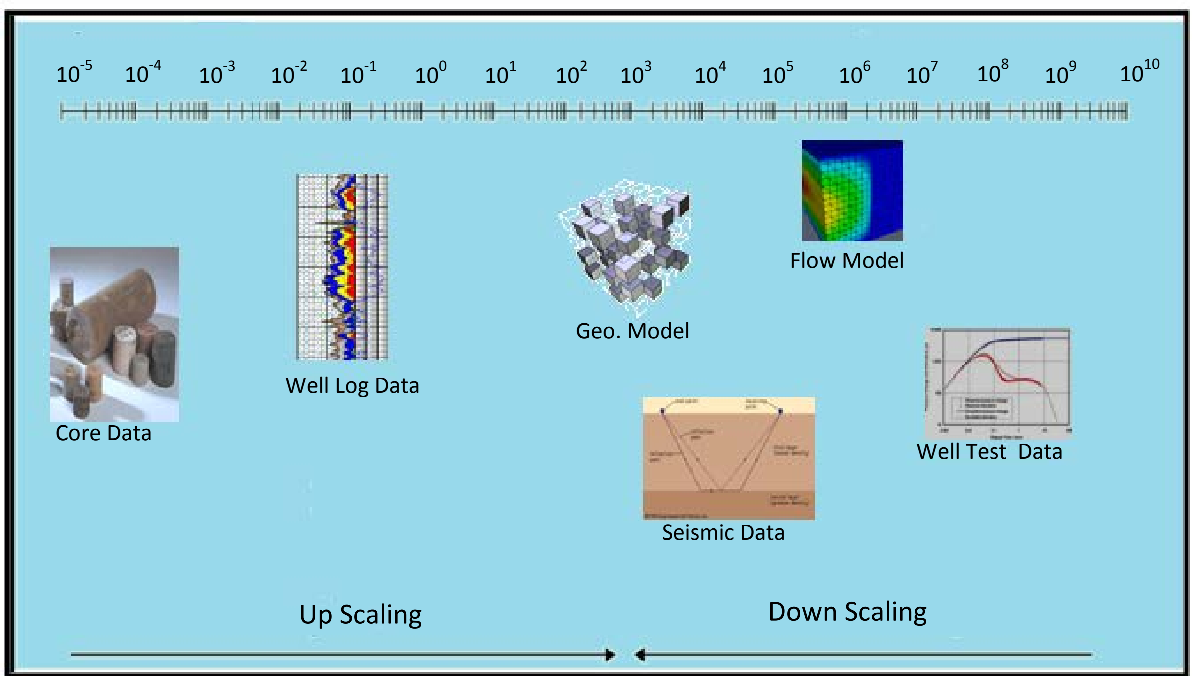
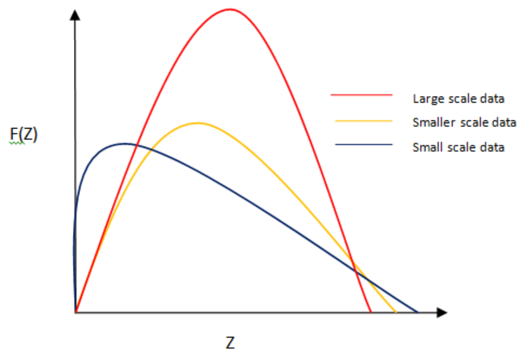


Figure 1. Upscaling , downscaling concept.



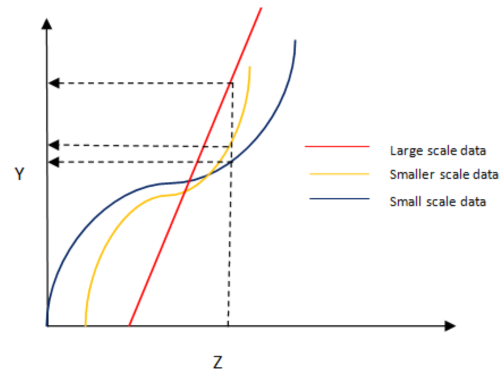


Figure 2 (left). Hypothetical distributions for data from different scales. **Figure 3** (right). Mapping of point variable Z to the Gaussian variable Y

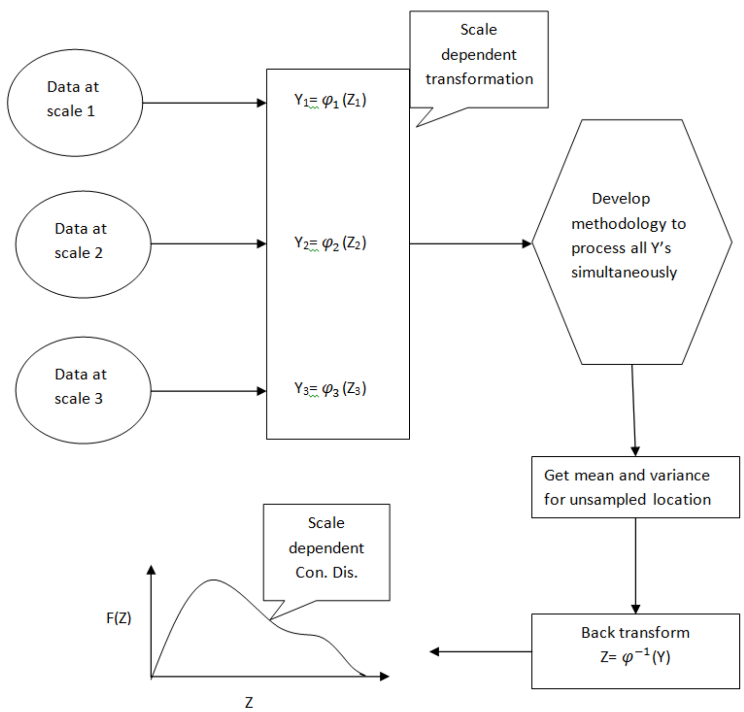


Figure 4. flow chart of developing a methodology for multi-scale reservoir heterogeneity and uncertainty modeling.