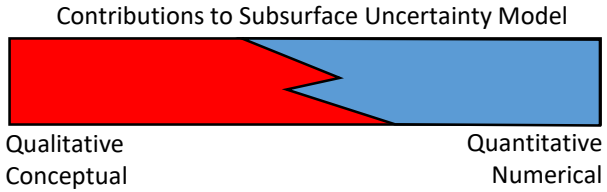
Quantification in Subsurface Modeling for Geoscientists and Geo-engineers.

Michael Pyrcz, University of Texas at Austin, @GeostatsGuy

A discussion on qualitative and quantitative approaches to subsurface modeling.

1. Qualitative and Quantitative Approaches?

Models of the subsurface are required to support environmental remediation, exploration for minerals and hydrocarbon, geotechnical engineering etc. These models are generally a combination of conceptual / qualitative and numerical / quantitative information.



Qualitative Subsurface Approaches: include the development of interpretation-based conceptual models of the subsurface. Skilled geoscientists are trained to develop these conceptual models by combining their experience and understanding of geoscience processes. This approach is essential to building the fundamental framework and scenarios applied in subsurface uncertainty modeling. For example, consider the breadth of knowledge available on subsurface sequence stratigraphy (Catuneanu, 2006), sedimentary systems (Reading, 1996) and facies models (Walker and James, 1992) etc.

Quantitative Subsurface Approaches: include the use metrics calculated from available data and interpretations based on data. These methods require assumptions such as stationarity and abstraction such as simplification of heterogeneities to parameterized geometries or limited statistics. In return quantification improves transparency, repeatability, model building efficiency, model comparison and portability, model prediction accuracy and checking, and the impact of geological information on decision making.

2. How Do We Quantify the Subsurface?

Types of Quantification:

Univariate Distributions: the most basic quantification include the proportions of rock types or facies, the probability density function of continuous features such as grade or contaminant concentration.

Semivariograms: a two point spatial heterogeneity measure that captures linear spatial change vs. offset distance.

Transition Probabilities: the probability of leaving a current category such as rock type over offset distance by Markov statistics or indicator semivariogram.

Bivariate Distributions: including correlation coefficients to exhaustively modeled relationships between features.

Multivariate Distributions: when data is sufficient or a parametric form is assumed, it is possible to characterize beyond two variable.

Multiscale: the change in heterogeneity over scale may be captured with dispersion variance, lacunarity and Ripley's K function (Hajek et al., 2010) etc.

Multiple Point: spatial statistics beyond the semivariogram borrowed from 3D conceptually-focused models of the subsurface.

Stacking Patterns: a variety of metrics including compensational index (Wang et al., 2009) characterize random, compensational and anti-compensational stacking.

Assumptions Required:

Each of these forms of quantification require a decision of stationarity. The metric considered is invariant over the locations it is calculated and is appropriate and invariant over the locations it is applied in the model. This decision cannot be tested, but may be determined to be inappropriate given the available data.

Each metric is based on abstraction / simplification of complicated subsurface patterns, including linear spatial features, centroids of geobodies, Gaussian multivariate relationships, linear scale up etc.

3. Comments on Quantification.

Benefits of Quantification:

Objectivity: quantification provides transparency and repeatability. These are essential to improving objectivity in subsurface modeling.

Portability: quantitative measures may be applied to other analogous subsurface volumes of interest, allowing for exporting information from more mature, better understood settings.

Comparison: quantitative measures from various volumes of interest and within volumes of interest may be compared to detect important differences or changes.

Prediction: quantitative measures may be applied as features to assist with prediction of subsurface response including contaminant transport, mineral grade or recovery factor.

Line of Sight: quantification may be directly applied in the subsurface model, improving impact of geologic information.

Future of Quantification:

New measures are being developed and new modeling technology will meet the need to integrate this information. AI is demonstrating that more and more can be quantified. Quantification will expand in subsurface modeling with the benefits indicated above. Qualitative methods remain essential and are aided by expanded quantification.

References:
Catuneanu ,O. Principles of Sequence Stratigraphy. Elsevier, Boston, 3rd edition, 2006.
Hajek EA, Heller PL, Sheets BA. 2010. Significance of channel-belt clustering in alluvial basins. Geology 38:535–38
Reading, H. G. Sedimentary Environments: processes, facies and stratigraphy. Blackwell Science, Oxford, 3rd edition, 1996.
Walker, R. G. and James, N. P. Facies Models: Response to Sea Level Changes. Geologic Association of Canada, pages 454, 1992.
Wang, Y., Straub, K. M., and Hajek, E. A. Scale dependent compensational stacking: an estimate of autogenic timescales in channelized sedimentary deposits. Geology, 39(9):811–814, 2011.
For more information see: Pyrcz, M.J., and Deutsch, C.V., 2014, Geostatistical Reservoir Modeling, 2nd edition, Oxford University Press.