Course Number: **PTE572L**
Course Name: **Applied Geostatistics for Subsurface Modeling**

Number of Units: **Total 4 Units (3-hrs lecture + 1-hr Lab)**

Instructor: Behnam Jafarpour, Petroleum Engineering Program, Mork Family Department of Chemical Engineering and Material Science, HED 313, 925 Bloom Walk, TEL: (213) 740-2228

Teaching Assistant
The instructor will prepare and present lab material to students. Depending on the enrollment, a graduate teaching assistant (TA) will help the instructor with hands-on practices and troubleshooting during the computer lab sessions. The name and contact information of the TA will be provided at the beginning of the semester.

Course Description
Introduction to conventional and modern geostatistical estimation and simulation techniques, combining theory with hands-on computer application of geostatistical methods in modeling the spatial phenomena

Catalogue Description:
PTE572L is a graduate course that covers the basic concepts in stochastic modeling of the spatial phenomena in the subsurface environments and offer hands-on experience with state-of-the-art geostatistical software packages though weekly computer lab sessions. The course introduces the students to classical and modern spatial estimation and stochastic simulation techniques including variogram-based, objected-based and training image-based stochastic simulation methods. Topics include stochastic processes, multivariate distributions, variogram estimation and modeling, spatial interpolation (e.g., variations of kriging and cokriging), stochastic simulation (e.g., sequential Gaussian simulation), object-based (Boolean) simulation and multiple-point geostatistics. The course includes weekly computer lab sessions that will familiarize students with state-of-the-art data analysis and geostatistical modeling and simulation techniques and software. Hands-on practice computer labs session and related assignments will help to consolidate the learning of the fundamentals introduced in lectures. Geostatistical software packages will also be introduced during the lab sessions and are needed to complete the assignments. Case studies from energy industry and environmental sciences will be discussed.

Learning Objective: Students will develop skills needed for spatial data analysis, including models of spatial variability, random functions, various spatial interpolation (Kriging) methods, stochastic simulation, and uncertainty quantification. These skills will be developed through lecture material, reading assignments, homework problems, and hands-on computer lab exercises.

Recommended Preparation
Basic knowledge and familiarity with general Calculus, Linear Algebra, and Probability is the recommended preparation of this course. Reading material will be provided at the beginning of the term to help students prepare for the main topics of the course.

Course Staff and Office Hours

The course staff information (including office hours and contact information) is summarized below.

	Name	Office / Hours	Email	Phone
Instructor	Behnam Jafarpour	HED-313 / TBD	jafarpou@usc.edu	213-740-2228
TA	TBD	TBD	TBD@usc.edu	NA

Lectures
There will be 160 minutes of class lectures and 50 minutes required weekly computer lab per week. Weekly computational lab sessions are included in the syllabus to introduce students to Matlab and SGeMS software for geostatistical modeling and analysis. Depending on room availability, the lectures can be presented either as one session during the week with the computer lab having a separate session, or the entire class can be offered in two sessions, one 120 minutes full lecture session and one mixed session of 40 minutes lecture and 50 minutes computer lab. Lectures will take place in Room **TBD** and are scheduled for **M-W 9:00-10:50am**.

Lab Sessions

Required weekly computer lab sections (50 minute per week) are included to review the lecture material and provide students with an opportunity for hands-on practice with the learned material to computer simulation software. The computer lab sessions are tentatively (to be confirmed) scheduled for **TBD**.

Grading Scale and Policy

Homework & Lab Assignments = 40%; Class Project = 20%; Exam = 40%

Homework and Lab Assignments (40%)

There will be a total of eight (8) problem sets and weekly lab assignments accounting for 40% of the final course grade. Problem sets will be posted to DEN on the specified dates in the tentative course schedule sheet (posted to DEN) and are due at the beginning of the lecture on the due date. Lab assignment will be given during the lab session and are due before the start of the next lab session (unless otherwise indicated). Late homework/assignment submissions will only be accepted when prior arrangement is made with the instructor.

Project (20%)

The term project is an opportunity to supplement and consolidate the fundamentals covered in the lectures and problem sets with in-depth study of one topic. The instructor will guide the student throughout the project so that this exercise becomes an effective learning experience. The term project is required of all enrolled students and carries 20% of the final course grade. Students may choose any topic related to the subjects and methods discussed in the class or other relevant topics to the subject of the course. Students should decide about their project topic in consultation with the instructor no later than Week 6 of the class. A project progress review will be scheduled on Week 10 to ensure that students are making good progress toward completion of their project. The project report will be due on the scheduled date/time for the class final examination.

Projects may take several forms, for example implementing and comparing the methods covered in the lectures, learning and discussing extensions or more advanced versions of some of the methods discussed in the class, or analysis and discussion of more advanced and relevant topics that are not covered in the lectures, as well as analysis of field data using the methods discussed in the course. The instructor will be available during scheduled office hours to guide students in selecting and completing their projects. Students can form teams to define and complete a project or choose to do so individually. The scope of the project and the tasks involved will be reviewed and approved by the instructor by week 6 of the class.

Sample projects "Integration of Soft Data into Multiple-Point Statistical Simulation":

The goal of the project is to present and discuss the integration of probabilistic sources of information into multiple point geostatistical simulation methods. Students can find resources available online, including journal and conference papers and benchmark datasets and examples, to include in the project. Depending on the scope of the project, this can be a team work (2-3 students). The team will work together on collecting paper and examples to study and analyze the results and finding of prior work in the literature and possibly field applications. The project can include a discussion of advantages and limitations of the existing workflow and some of the ongoing research to address the existing gaps.

Exam (40%)

The course will have an exam after Week 10. The exam will be **closed-book**/**closed-notes**. A formula sheet will be provided by the instructor.

Text Book

Reading material for each topic will be posted to DEN. While there is no required textbook for this course, the following textbooks are useful references for the topics covered in this course.

1. Isaaks E.H., Srivastava R.M. (1989): *An Introduction to Applied Geostatistics*, ISBN: 0195050134.
2. Goovaerts P. (1997): *Geostatistics for Natural Resources Evaluation*. Oxford University Press.
3. Chiles J.P., Delfiner P.. (1999): *Geostatistics: Modeling Spatial Uncertainty*, John Wiley and Sons Inc., NY.
4. Remy N., Boucher A., Wu J. (2009): *Applied Geostatistics with SGeMS – A User's Guide*, ISBN: 9780521514149
5. Deutsch C.V., Journel A.G. (1998): *GSLIB: Geostatistical Software Library and User's Guide*. Oxford University Press.

Tentative Course Topics and Schedule

Week	Date	Lecture	Reading	Out	In
Part 0. Introduction, Objectives, and Overview (Weeks 1)					
1	TBD	**Topic 1: Introduction, Objectives, and Overview** T1-1: Course Information, Objectives, and Expectations T1-2: Course Overview and Application T1-3: Probability and Univariate Statistics: A Refresher	T1R1		
		Computer Lab: Introduction to Matlab (1)			
Part I. Univariate and Bivariate Statistics (Weeks 2-3)					
2	TBD	**Topic 2: Expectation and Statistical Moments** T2-1: Expectation and Moments: Definition and Computation Variance: Definition and Properties Common Distribution Types T2-2: Properties of Normal Distribution CDF Transformation and Normal-Score Transform Sampling and Monte-Carlo Simulation	T2R1	HW1	
		Computer Lab: Introduction to SGEMS/PETREL			
3	TBD	**Topic 3: Bivariate Statistics** (1 Week) T3-1: Bivariate Distributions and Joint PDFs Marginal and Conditional Distributions Covariance and Correlation T3-2: Stationary Random Processes Strict and Second-Order Stationary Processes	T3R1	HW2	HW1
		Computer Lab: Univariate Statistical Data Analysis with Matlab			
Part II. Two-Point Spatial Statistics (Weeks 4-5)					
4	TBD	**Topic 4: Second-Order Spatial Statistics** (1 Week) T4-1: Two-Point versus Multiple-Point Spatial Relations Spatial (Auto)-Covariance and Cross Covariance Functions (Semi)-Variogram: Definition and Properties	T4R1	HW3	HW2
		Computer Lab: Bivariate Statistical Data Analysis with Matlab			
5	TBD	**Topic 5: Variogram-Based Spatial Modeling** (1 Week) T5-1: Variogram Inference and Modeling Variogram Estimation from Data Empirical Variogram Models and Their Properties Variogram Modeling with Data	T5R1	HW4	HW3
		Computer Lab: Spatial Statistical Analysis, Covariance and Correlation			
Part III. Classic Geostatistics: Spatial Interpolation - Kriging and CoKriging (Weeks 7-10)					
6	TBD	**Topic 6: Linear Spatial Estimation and Kriging** (1 Week) T6-1: Linear Estimators and Their Properties Estimation Bias and Variance Spatial Interpolation: Inverse Distance versus Kriging	T6R1	HW5	HW4
		PROJECT TOPIC SELECTION DEADLINE			
		Computer Lab: Variogram Estimation with Matlab			
7	TBD	**Topic 7: Kriging Methods** T7-1: Simple and Ordinary Kriging T7-2: Kriging with Trend and Block Kriging	T7R1		HW5
		Computer Lab: Variogram Modeling with SGEMS/PETREL			
		Topic 8: Indicator Kriging			

8	TBD	T8-1: Modeling Discrete Random Fields T8-2: Indictor Kriging for Geologic Facies Modeling	T8R1		
		Computer Lab: Simple and Ordinary Kriging with SGEMS/PETREL			
	TBD	**SPRING RECESS**			
9	TBD	**Topic 9: CoKriging** T9-1: Co-Kriging Formulation Co-Kriging with Type-I and Type-II Markov Models T9-2: Collocated Co-Kriging		HW6	
		Computer Lab: Indicator Kriging and Co-Kriging with SGEMS/PETREL			
Part IV. Uncertainty Quantification with Conditional Simulation (Weeks 11 & 12)					
10	TBD	**Topic 10: Two-Point Simulation Methods** (2 Weeks) T10-1: Estimation vs. Stochastic Simulation T10-2: Sequential Gaussian Simulation (SGS) T10-3: Sequential Indicator Kriging (SIK) T10-4: Co-Simulation Using Co-Kriging T10-5: Comparing SGS with Kriging	T10R1		
		PROJECT PROGRESS REVIEW WEEK			
		Computer Lab: Conditional Simulation for Uncertainty Quantification with SGEMS/PETREL			
	TBD	**COURSE EXAM**			
11	TBD	**Topic 11: Object-Based (Boolean) Simulation Methods** T11-1: Limitations of Two-Point Geostatistics T11-2: Modeling Discrete Geologic Objects T11-3: Marked Point Process Modeling	T11R1	HW7	HW6
		Computer Lab: Sequential Gaussian Simulation and Co-Simulation with SGEMS/PETREL			
Part V. Modern Geostatistics (Weeks 13-15): Modeling Complex Geologic Environments					
12	TBD	**Topic 12: Multiple-Point Statistics (MPS)** T12-1: Motivations for Multiple-Point Geostatistical Simulation T12-2: Training-Images for Encoding Multiple Point Statistics T12-3: MPS Simulation (SNESIM Algorithm) T12-4: Properties of the SNESIM Algorithm	T12R1	HW8	HW7
		Computer Lab: Object-Based (Boolean) Simulation with PETREL			
13	TBD	**Topic 13: Overview of Alternative Pattern-Based Simulation Methods** T13-1: Simulation with Patterns (SIMPAT) T13-2: Simulation with Filtering (FILTERSIM) T13-3: Truncated Pluri-Gaussian Simulation T13-4: Level-Set Simulation Method	T13R1		HW8
		Computer Lab: Multiple-Point Geostatistical Simulation (MPS) with SGEMS/PETREL			
14	TBD	**Topic 14: Integration of Nonlinear Dynamic Data (A Preview):** T14-1: Flow Prediction with Geostatistical Models T14-2: Uncertainty Reduction with Dynamic Data T14-2: Bayesian Inversion	T14R1		
		Computer Lab: Sensitivity Analysis in MPS Modeling			
Week 15 in Class		**CLASS PROJECT PRESENTATIONS**			
		PROJECT REPORTS DUE ON SCHEDULED FINAL EXAM DATE BY UNIVERSITY			

Abbreviations: TBD: To Be Determined ; TxLy: Topic x Lecture y ; TxRy: Topic x Reading y ; HW: Homework