Introduction to Geostatistics

GEOL 5446
3 Credits
Spring, 2018

Dept. of Geology & Geophysics
University of Wyoming
Instructor: Ye Zhang

Grading: A-F
Location: ESB1006
Time: TTh (9:35 am~10:50 am),
Office hour: Th (4:00~6:00 pm), GE 220 or online
Email: yzhang9@uwyo.edu

Course Objectives:
Geoscientists routinely face interpolation and estimation problems when analyzing data from the field. Geostatistics has emerged as a valuable tool to aid such analyses. It originated from the mining industries where it found acceptance through successful applications to problems where decisions concerning large-investment operations are based on interpretations of limited and sparse data. In characterizing and simulating subsurface reservoirs, geostatistics offers a means to quantify prediction uncertainty. In this class, both the principles of geostatistics and its applications will be presented. The main topics include variogram analysis, kriging, and stochastic simulations (unconditional and conditional). The potential audience for this course includes geologists, geophysicists, geological engineers, civil, agricultural and petroleum engineers, soil scientists, and other physical scientists.

The class is organized into seven Chapters:
1. Overview
2. Probability Theory Review
3. Spatial Analysis
4. Experimental Variogram
5. Variogram Modeling
6. Geostatistical Estimation (Kriging, CoKriging, Collocated Cokriging)
7. Geostatistical Simulation (Unconditional, Conditional);
8. Advanced Estimation (Cross Validation, Block Kriging, Indicator Kriging, Simple Kriging);
9. Advanced Simulation (SGS, SIS, SGS Collocated Cokriging, MPS, Reservoir Uncertainty Analysis)

**If we're short on time, some advanced topics may be dropped. Unless otherwise stated, most advanced topics will not be tested.*

Learning Outcomes:
The students will learn the basic approach in conducting a variogram analysis, including the calculation of experimental variograms, directional analysis (Rose Diagram and variogram surface) and variogram modeling. They will also learn the mathematical and statistical principles behind Kriging, Co-kriging and stochastic simulations as well as how to apply these geostatistical methods in spatial interpolation based on a set of 2D sampled data. Though some exercises and homework are done by hand or small computer codes (mostly Matlab), throughout the class, Surfer, a commercial geostatistical package will be used to help students gain familiarity with the tools as well as learn to integrate the various components of a geostatistical analysis.

Prerequisite:
- Calculus I & II;
- Linear Algebra (optional)
- Probability & Statistics (optional);
- Matlab Programming language (required)*;

*A quick start to help you learn Matlab (will take ~ 2-3 hours): http://faculty.gg.uwyo.edu/yzhang/files/Matlab_Basics.pdf

Textbook, Tools, Questions & Answers:
The instructor has written a set of lecture notes for this course. Though an official textbook does not exist, the lecture notes (Chp 1) has listed several books that are helpful for additional reading.

Tools for simple exercises include ruler, calculator and Excel spreadsheet. For programs of modest complexity, Matlab programming will be used. For more complex projects, we'll use software packages such as Surfer or Gslib.

Questions for the instructor: (1) during lecture; (2) office hour (online or in person); (3) email instructor to set up an appointment for other times.

Course Web Page:
A course site will be used (via *Wyocourse*) where assignments and course notes will be regularly posted. The course notes are specifically written for this class. It is a good source for information since it contains a lot of explanations and in-depth discussions to complement the lectures. Often, a lot of materials are presented in a lecture, so reading the course notes afterwards is a good way to reinforce your new knowledge. However, the course notes do not contain derivations, nor solutions to homework/exercise/exam problems. So, lecture attendance is key for this class.

Course requirements:
Students are expected to attend the lectures, work out the exercises, chapter projects and presentations independently, as well as complete assigned literature readings. A midterm and final exam will be given to evaluate the students' performance.

Attendance Policy:
Each student is expected to attend the lectures to fulfill the academic requirements. For participation in a University-sponsored activity or for unusual circumstances (personal hardship), an authorized absence may be issued to the student by the Director of Student Life or the Director's authorized representative. If a student has been hospitalized, or if the student has been directed by the Student Health Service or the student's private physician to stay at the student's place of residence because of illness, the Health Service medical staff or the student's private physician must issue a statement to the student giving the dates of the student's confinement. If a student produces the proof of absence, a makeup session can be arranged with the instructor. http://uwadmnweb.uwyo.edu/legal/Uniregs/ur713.htm

Grading Policy:
The final grade will be given based on the performance in homework, in-class exercises and chapter projects, presentations and exams. The approximate percentage is shown:

Homework	35.0%
Projects	25% -- 30%
Class Presentation (tentative)	5.0 -- 0%
Final Project	20.0%
Final Exam	20.0%

Note that each homework/exam has a standalone grade of 100 points. When determining the final grade, these will be normalized reflecting the percentage distribution above. The final letter grade is given based on the numerical grade:

A	B	C	D	F
90-100	80-89	70-79	60-69	< 60

As a graduate level course, the final grade is not determined based on a curve. The student's final grade reflects his/her overall absolute performance throughout the semester.

Concerning homework/lab/exams:
Four points must be emphasized: (1) For problems involving equations or derivations, if appropriate, provide a complete analysis rather than a single number/result. (2) Be professional in your presentations. If applicable, write down the unit for your results and round off the numbers to 2 decimal points. (3) You can discuss the problems with fellow students or the instructor, but complete your assignments by yourself. (4) Hand in the homework on time.

Policy on Late papers, make-up exams, grade of incomplete:
Policy for this class:

- Unless otherwise stated, homework is expected to be handed in to the instructor in the beginning of the class one week after the homework is assigned; If not handed in on time, each day it is delayed, 10 points will be taken out of the grade (100) of that particular homework until no points remain.

- Unless otherwise stated, projects should be handed in by the specified due date. If not handed in on time, each day it is delayed, 10 points will be taken out of the grade.

- If you cannot attend the class (you must produce valid proof of absence), you must independently finish the exercises/projects and present the evidence of your work to the instructor within a week.

- Exams are expected to be handed in at the end of the quiz/exam.

If a student can provide valid proofs of absence, the above rules do not apply. Within a reasonable time (1 week), the student is expected to hand in the late homework to the instructor, or, arrange with the instructor on a make-up exam (the usual time will be on weekends when the computer room is available). It is the student's responsibility to contact the instructor to make arrangement in a timely manner and in advance if at all possible, failing to do so will result in the forfeiture of the relevant points.

Grade of incomplete:
During the semester, if a student has suffered severe problems (e.g., serious physical or mental incapacitation) and cannot complete the course as a result, he/she may be issued an "I" (incomplete) grade. The UW regulation on how to make up for this grade is: http://uwadmnweb.uwyo.edu/legal/Uniregs/ur720.htm

Academic dishonesty:
UW has a time-tested procedure to judge such cases, and serious penalties may be assessed. Please refer to UW Regulation 6-802 for details: http://www.uwyo.edu/generalcounselsupport/clean%20uw%20regulations/UW%20Reg%206-802.pdf Please, do not cheat and do not help others cheat. If a student is caught cheating, he or she may be assigned a "F" for the course. Plagiarism is considered a form of cheating. Both students will lose the full points on the particular homework or lab assignments. However, when writing papers, a student may cite other's work, but proper attribution must be given.

Classroom decorum:
Turn off the cell phone. No smoking. Wear appropriate clothes. Do not bring food or drinks. Be respectful.

Statement on Diversity:
The University of Wyoming values an educational environment that is diverse, equitable, and inclusive. The diversity that students and faculty bring to class, including age, country of origin,

culture, disability, economic class, ethnicity, gender identity, immigration status, linguistic, political affiliation, race, religion, sexual orientation, veteran status, worldview, and other social and cultural diversity is valued, respected, and considered a resource for learning.

Disability Support:
The University of Wyoming is committed to providing equitable access to learning opportunities for all students. If you have a disability, including but not limited to physical, learning, sensory or psychological disabilities, and would like to request accommodations in this course due to your disability, , please register with and provide documentation of your disability as soon as possible to Disability Support Services (DSS), Room 128 Knight Hall. You may also contact DSS at (307) 766-3073 or udss@uwyo.edu. It is in the student's best interest to request accommodations within the first week of classes, understanding that accommodations are not retroactive. Visit the DSS website for more information at: www.uwyo.edu/udss.

Duty to Report:
UW faculty are committed to supporting students and upholding the University's non-discrimination policy. Under Title IX, discrimination based upon sex and gender is prohibited. If you experience an incident of sex- or gender-based discrimination, we encourage you to report it. While you may talk to a faculty member, understand that as a "Responsible Employee" of the University, the faculty member MUST report information you share about the incident to the university's Title IX Coordinator (you may choose whether you or anyone involved is identified by name). If you would like to speak with someone who may be able to afford you privacy or confidentiality, there are people who can meet with you. Faculty can help direct you or you may find info about UW policy and resources at http://www.uwyo.edu/reportit You do not have to go through the experience alone. Assistance and resources are available, and you are not required to make a formal complaint or participate in an investigation to access them.

Student Resources:
- DISABILITY SUPPORT SERVICES: udss@uwyo.edu, 766-3073, 128 Knight Hall, www.uwyo.edu/udss
- COUNSELING CENTER: uccstaff@uwyo.edu, 766-2187, 766-8989 (After hours), 341 Knight Hall, www.uwyo.edu/ucc
- ACADEMIC AFFAIRS: 766-4286, 312 Old Main, www.uwyo.edu/acadaffairs
- DEAN OF STUDENTS OFFICE: dos@uwyo.edu, 766-3296, 128 Knight Hall, www.uwyo.edu/dos
- UW POLICE DEPARTMENT: uwpd@uwyo.edu, 766-5179, 1426 E Flint St, www.uwyo.edu/uwpd
- STUDENT CODE OF CONDUCT WEBSITE: www.uwyo.edu/dos/conduct

Disclaimer:
The syllabus is subject to changes as deemed necessary by the instructor. If a significant change were to be made, all students will be informed of it and given appropriate reasons for such a change.

Tentative Schedule

Each homework generally consists of two related portions: (1) problem solving; (2) literature reading. The problem sets are typically described in the class Powerpoint files; the selected papers are posted on WyoWeb;.

Week 1 Jan 29 Jan 31	**Course Overview** *What is geostatistics? What kind of problems can geostatistics solve? Geostatistics versus simple interpolation. What is the overall approach in geostatistics? Are there problems and pitfalls to look out for? What is the characteristics of this class? What are expected from the students?* *Homework 1: Read 1.1~1.6 of Geostatistical Reservoir Simulation Textbook* **Mathematics & Statistics Review** *Summation; Vector; Matrix; Linear Algebra;*
Week 2 Feb 5 Feb 7	*Univariate Analysis; Bivariate Analysis; Multivariate Analysis; Gaussian Distribution (univariate);* *Homework 2: (1) see Powerpoint for problem descriptions; (2) Read 2.1~2.3 of Geostatistical Reservoir Simulation Textbook* ***Project One**: Univariate correlation among 2 data sets.*
Week 3 Feb 12 Feb 14	**Spatial Continuity Analysis** *Non-geostatistical Analysis (Posting, Contour, Symbol, Indicator, Moving Window); Spatial Continuity Analysis: Experimental Variogram;* *h-Scatterplot; Variogram versus Univariate Statistics; Higher Dimensions & Statistical Anisotropy;*
Week 4 Feb 19 Feb 21	**Spatial Continuity Analysis**: *Pure Nugget Variogram; Standard Deviation of Variogram Estimate;* *Homework 3: (1) see Powerpoint for problem descriptions; (2) Read Olea (1994).* *Irregular Data: Variogram Search Envelope; Exploring anisotropy;*
Week 5 Feb 26 Feb 28	**Spatial Continuity Analysis** (Continued): *Rose Diagram, Correlation Ellipse, Statistical Axis, Statistical Anisotropy, Variogram Surface* *Homework 4: Read Gringarten & Deutsch (1999)* *Issues; Outline of an Experimental Variogram Analysis;*
Week 6 March 5 March 7	**Spatial Continuity Analysis** (Continued): *Recommendations from both the Environmental and Petroleum fields.* *Homework 5: see Powerpoint for problem descriptions;* ***Project Two**: Experimental Variogram Analysis of 2 data sets using Surfer*
Week 7 March 12 March 14	**Variogram Modeling**: *Basic Permissible Models; Model Fitting "Rule of Thumb"; recommended workflow from petroleum reservoir modeling; invited lecture (Dr. Mohammad Koneshloo) on 'real world variogram modeling issues;* *Homework 6: (1) see Powerpoint for problem descriptions; (2) Read Chu et al. (1994).* ***Project Three**: Variogram Modeling of the 2 data sets analyzed in Project Two using Surfer.*

Week 8 March 19 March 21	**Spring Break: No classes**
Week 9 March 26 March 28	**Estimation**: *Non-geostatistical Estimation; Geostatistical Estimation; Random Function Models; Ordinary Kriging (OK);*
Week 10 April 2 April 4	*Ordinary Kriging (continued); Kriging with a moving neighborhood;* *Homework 7 (1) see Powerpoint for problem descriptions;*
Week 11 April 9 April 11	*Co-Kriging; & Collocated CoKriging* ***Project Four**: Using OK to conduct spatial interpolation analysis based on the 2 data sets previously analyzed for the variograms;*
Week 12 April 16 April 18	*Finish up Cokriging topics; Cross Validation; Indicator Kriging; Simple Kriging;* *Homework 8 (1) collocated Co-Kriging (see class powerpoint); (2) Read 4.6 of Geostatistical Reservoir Simulation Textbook (creating cross variograms for the Co-Kriging analysis).*
Week 13 April 23 April 25	*Block Kriging; Unconditional Simulation (Cholesky Decomposition); Conditional Simulation;* ***Project Five (Optional)**:* *Using Conditional Simulation to generate images (a stochastic ensemble) based on the 2 data sets previously analyzed for the OK estimation. What are the difference between Kriging and Simulation?*
Week 14 April 30 May 2	*Sequential Gaussian Simulation (SGS); Sequential Indicator Simulation (SIS);* ***Term Project (4 alternatives):*** *(1) Instructor will assign a term project to the class;* *(2) For a set of 2D data (given by the instructor or the students' own choosing), conduct a full suite of geostatistical analysis including an exploratory univariate analysis, experimental variogram analysis, anisotropy analysis, variogram modeling, and OK interpolation (both Kriging estimate and variance of the Kriging error). Results must be presented with all relevant plots and a report discussing the findings found at each step.* *(3) Write a 1D Matlab code for Ordinary Kriging, unconditional, and conditional simulations.* *(4) A small research problem may be substituted (student must communicate the content and nature of this project to the instructor for prior approval);*
Week 15 May 7 May 9	*Collocated Co-Simulation; Multiple point geostatistics; Static/Dynamic data integration; Reservoir Uncertainty Analysis;*
Week 16	***Final Exam, Location/Time TBA*** • *Please turn in the Term Project on the date of the Final Exam.* • *In the Final Exam, a bonus problem (10 points) will be given, involving full derivations of either an estimation or simulation problem.*