SIOC 290: Climate Mathematics
10:00-11:50am MTWR, 10:00-10:50am F, August 17 (M)-September 18 (F), 2015
Classroom Spiess 330

Instructor: Samuel Shen Office: NH428 Tel: 858-246-0205
Email: s4shen@ucsd.edu
Course website:
http://scrippsscholars.ucsd.edu/s4shen/pages/sioc-290-climate-mathematics

Office Hours: 12:00-1:00pm MTWRF or by appointment

Text: *Climate Mathematics*, Lecture Notes by Samuel Shen, plus online materials

Prerequisites: Basic science background and pre-calculus.

Topics covered in this course: The students will learn the minimum necessary skills in probability, statistics, mathematics, and plotting to present and describe climate data from both observations and models, particularly about climate extremes and uncertainties. This course will start from basic concept of calculus without limit, and go to Taylor series and line integral, from basic concept of probability and statistics to advanced theory of sampling error estimation, and from basic R programming to more advanced plotting and visualization skills.

PhD students who need additional mathematics and statistics skills or who would like to learn modern tools and unconventional approaches to climate data analysis and models can also take this course.

Computing: R will be taught, but a student can use Matlab or others.

Grading Policy: The final grades for this class will be determined as follows:

Homework assignments (3 times)	54%
Midterm exam(75 minutes)	20%
Final project	26%
Total--------------------------------------	100%

Class Attendance: The students are required to attend all the classes. The class attendance will be taken randomly in lectures. Those who attend every lecture will receive a 2% bonus.

Note-taking: Each student should build a portfolio (folder) for this class. Class notes are an important part of the folder. Each student should take class notes. A detailed and neat SIOC 290 folder will earn 1% bonus. The instructor will check the folder at the end of the course.

Table 1. Course chapters, lecture hours, schedules for three assignments, one midterm, and a final project.

SIOC 290	**Climate Mathematics: August 17 (M)-Sept 18 (F), 2015**		
Chapter	**Materials**	**Hours**	**Accumulated Hours**
1	Calculus review	2	2
2	R programming	2	4
3	Concepts of probability and statistics	2	6
4	Linear algebra and linear regression	3	9
Assgn #1	**Assignment #1 (6 problems, 18 points, due in one week)**		
5	Ordinary differential equations for climate models	2	11
6	Climate science topics of calculus	5	16
Assgn #1	**Assignment #2 (6 problems, 18 points, due in one week)**		
7	Spectral methods for time series	4	20
8	Advanced energy balance climate models	2	22
9	Empirical orthogonal functions for climate data analysis	4	26
Midterm	**Midterm in-class written exam (75 minutes, 11:00am-12:15pm, Friday; 20 points)**		
10	Canonical correlation analysis for climate data	2	28
11	Conservation laws and climate model equations	3	27
12	Mathematics for atmospheric thermodynamics	3	34
13	Introductory complex analysis	2	36
Assgn #3	**Assignment #3 (6 problems, 18 points, due in one week)**		
14	Topics of statistical analysis of climate data	2	38
15	Extreme value distribution	3	41
16	Monte Carlo simulations	2	43
17	Concept of the probabilistic weather forecast	2	45
			Total 45 hours
Final Project	**Final project report is on a topic in Chapters 14-17 (20 double pages, including cover, references, figures, and tables) (26 points, due by September 23, 2015 Wednesday, 11:59pm). It can be a review paper or research based on real observed or model data.**		

Learning outcome: SIOC 290 is designed for the students in the Masters of Advanced Studies program in Climate Sciences and Policy. These students will need to understand, explain and present the results from climate models and observations. The students will use SIOC 290 to prepare themselves to take SIO 210 (Physical Oceanography) and SIO 217A (Atmospheric Thermodynamics). The students will learn probability, statistics, mathematics, and plotting skills to present and describe climate data from both observations and models, particularly about climate extremes and uncertainties.

The students may have different mathematics background, ranging from three semesters of calculus, linear algebra, differential equations, complex variables and basic statistics, to only Calculus I and basic statistics. Even the students who have taken many mathematics courses before may find that the mathematics and statistics in climate science are used in a different format. Thus, SIOC 290 will adopt an innovative instruction of mathematics and statistics to present the minimum amount of mathematics needed to make effective climate data interpretation and presentation. This climate math class will start from the basic concept of calculus (without limits), and go to Taylor series and line integral, from the basic concept of probability and statistics to advanced theory of sampling error estimation, and from R programming to more advanced plotting and visualization skills.

PhD students who need additional mathematics and statistics skills or who would like to learn modern tools and unconventional approaches to climate data analysis and models can also take this course.

A Course at the Scripps Institution of Oceanography

University of California San Diego

SIOC 290: Climate Mathematics

Table of Contents

Chapters, hours of instruction, and sections of materials

6. Climate science topics of calculus (5)

   6.1. Linear approximation and Newton's method
      6.1.1. Linear approximation: theory
      6.1.2. Newton's method for solving nonlinear algebraic equations
      6.1.3. Stefan-Boltzmann black body radiation and its linear approximation
   6.2. Taylor approximation
      6.2.1. Taylor approximation for exponential functions
      6.2.2. Second order approximation example
   6.3. Partial derivatives
      6.3.1. Geo-potential height surface and contours
      6.3.2. Wind direction and speed
   6.4. Multiple integrals
      6.4.1. Double integral and Green's theorem
      6.4.2. Triple integral and Gauss divergence theorem
      6.4.3. Convergence and divergence
      6.4.4. Conservation of mass and momentum over a grid box
   6.5. Line integral
      6.5.1. Work in a potential field
      6.5.2. Work on a closed contour

7. Spectral methods for time series (4)
   7.1. Fourier series
   7.2. Spectra of long and short wave radiation
   7.3. Wavelet time-frequency analysis
   7.4. HHT time-frequency analysis

8. Advanced energy balance climate models (2)
   8.1. Non-steady 1-Dim EBM: a partial differential equation formulation
   8.2. Concept of stability
   8.3. Small ice cap instability

9. Empirical orthogonal functions for climate data analysis (4)
   9.1. Introduce EOF from space-time decomposition perspective: EOF, PC, and variance/eigenvalues
   9.2. Data representation
   9.3. Stationarity and EOF validity
   9.4. EOF and PC pattern interpretation examples: temperature, precipitation
   9.5. Spectral optimal averaging (SOA)
   9.6. Spectral optimal gridding (SOG)
   9.7. Objective analysis and its relationship with SOG

10. Canonical correlation analysis for climate data (2)
   10.1. CCA as a multivariate factor analysis
   10.2. CCA formulation in EOF spectral space
   10.3. NOAA Climate Prediction Center's CCA climate prediction

11. Conservation laws and climate model equations (3)
    11.1. Conservation laws and climate dynamic equations on a rotational Earth
    11.2. Potential functions and stream functions
    11.3. Linear traveling wave solutions
    11.4. Eigenvalues and eigenfunctions
    11.5. Dispersion relation
    11.6. Examples of nonlinear waves

12. Mathematics for atmospheric thermodynamics (3)
    12.1. Equations of ideal gas
    12.2. Kinetic theory of gas: moments, permutation, probability
    12.3. Exact differentials
    12.4. Stefan-Boltzmann law for radiation and its derivation from Planck's law
    12.5. Budyko and other EBMs

13. Introductory complex analysis (2)
    13.1. Potential flow
    13.2. Vorticity equation

14. Topics of statistical analysis of climate data (2)
    14.1. Sampling error for SOA
    14.2. Sampling error for SOG
    14.3. Randomization method to unify grid box models and point observations

15. Extreme value distribution (3)
    15.1. Commonly used extreme value distributions (EVD)
    15.2. Generalized EV (GEV) and R
    15.3. Quantile regression

16. Monte Carlo simulations (2)
    16.1. Introduction to Monte Carlo method
    16.2. Risk analysis

17. Concept of the probabilistic weather forecast (2)
    17.1. Define events over areas
    17.2. Definition and production of probabilistic forecasts

Appendices

A1. Matlab basics and examples for climate sciences

A2. Singular value decomposition (SVD) method

A3. Spherical harmonics

A4. Turbulence and closure: Mean and fluctuations, wind stress, turbulent closure, meridional overturn, and energy cascade