

Math 540 Uncertainty Quantification for Physical and Biological Models
Fall 2019
3 Credit Hours

Instructor: Ralph C Smith
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Office Hours: By appointment

Prerequisite: MA 341 and basic knowledge of probability, linear algebra and scientific computation

GEP Category: This course does not fulfill a General Education Program requirement.

Materials/book: *Uncertainty Quantification: Theory, Implementation, and Applications*, Ralph C Smith, SIAM, Philadelphia, PA 2014.

Course Description: Introduction to uncertainty quantification for physical and biological models. Topics include fundamental concepts from probability and statistics, parameter selection techniques, frequentist and Bayesian model calibration, propagation of uncertainties, surrogate model construction, quantification of model discrepancy, and local and global sensitivity analysis. Applications include weather and climate, nuclear power plant design, materials characterization and control, and biological and biomedical phenomena.

Learning Objectives/Outcomes: By the end of the course, students should be able to:

- Determine the sources and impacts of input and response uncertainties in models arising in their discipline as well as prototypical weather, climate, hydrology, nuclear and biology models.
- Explain the basic probability, stochastic process and statistics concepts required for uncertainty quantification.
- Formulate models in a manner that isolates the influential parameters and facilitates statistical analysis. This includes the use of local and global sensitivity analysis techniques.
- Construct surrogate models for complex processes that retain the fundamental underlying behavior while providing the computational efficiency required for model calibration and uncertainty propagation.
- Compute confidence intervals using frequentist analysis and employ Markov chain Monte Carlo methods to construct posterior distributions and credible intervals for parameters. Be able to verify the accuracy of distributions constructed using Bayesian analysis.
- Compute confidence, credible and prediction intervals for model responses and quantities of interest using sampling techniques and numerical stochastic spectral methods.

Course Structure and Rules of Engagement: This is a distance education course so all lectures are available online. Students should feel free to contact me via email with any questions or concerns regarding the course, projects, or grading.

Email: All emails will be sent to your specified email address.

Computing: We will use MATLAB and provide software. Students may substitute Python or R if they are more comfortable with these packages.

Course Topics Schedule:

- Motivating applications and prototypical models (1 day)
- Fundamental aspects of probability, random processes and statistics (1.5 weeks)
- Representation of random inputs (1 week)
- Parameter selection techniques and local/global sensitivity analysis (2 weeks)
- Frequentist and Bayesian model calibration (3 weeks)
- Uncertainty propagation in models (2 weeks)
- Surrogate model construction (1.5 week)
- Stochastic spectral methods and sparse grid techniques (2 weeks)
- Model discrepancy and active subspace-based inference (1.5 week)

Note that the above course schedule is subject to change.

Grading: Grades are based 100% on the 6 assigned projects.

Final Project: Due on December 5, 2019

Standard Grading Scale: $99 \leq A+ \leq 100$, $92 \leq A < 98$, $90 \leq A- < 92$, $88 \leq B+ < 90$, $82 \leq B < 87$, $80 \leq B- < 82$, $78 \leq C+ < 80$, $72 \leq C < 77$, $70 \leq C- < 72$, $68 \leq D+ < 70$, $62 \leq D < 67$, $60 \leq D- < 62$, $0 \leq F < 60$

Requirements for Credit-Only (S/U) Grading: To receive a grade of S, students are required to complete all projects and earn a grade of C- or better. Conversion from letter grading to credit only (S/U) grading is subject to university deadlines. Refer to the Registration and Records calendar for deadlines related to grading. For more details refer to <https://policies.ncsu.edu/regulation/reg-02-20-15/>.

It is important that you consult with your advisor to see if the course will count towards your graduation requirements before taking this course as credit-only.

Incomplete Grades: Incomplete grades will be handled on an individual basis. Note, however, that if an extended deadline is not authorized by an instructor or department, an unfinished incomplete grade will automatically change to an F after either (a) the end of the next regular semester in which the student is enrolled (not including summer sessions), or (b) the end of 12 months if the student is not enrolled, whichever is shorter. Incompletes that change to F will count as attempted courses on transcripts. The burden of fulfilling an incomplete grade is the responsibility of the student. The university policy on incomplete grades is located at <https://policies.ncsu.edu/regulation/reg-02-50-03/>.

Late Projects: You are expected to complete all projects by the assigned deadlines. You should contact me by email if you anticipate delays regarding a project.

For complete attendance and excused absence policies, please see <https://policies.ncsu.edu/regulation/reg-02-20-03-attendance-regulations/>.

Academic Integrity/Honesty: It is my understanding and expectation that your submission of any project means that you have neither given nor received any unauthorized aid. Students are required to comply with the university policy on academic integrity/honesty found in the Code of Student Conduct (<https://policies.ncsu.edu/policy/pol-11-35-01/>).

Electronically-Hosted Course Components: All reading materials are maintained on the course website. Note that I received licenses to include pictures and biographies of the mathematicians and mathematics educators that appear in the notes under the provision that the materials would be located on a secure site. Although you may copy the notes for your own use, you should not share the pages with the pictures and biographies with anyone else.

Accommodations for Disabilities: Reasonable accommodations will be made for students with verifiable disabilities. In order to take advantage of available accommodations, students must register with the Disability Resource Office at Holmes Hall, Suite 304, Campus Box 7509, 919-515-7653. For more information on NC State's policy on working with students with disabilities, please see the [Academic Accommodations for Students with Disabilities Regulation \(REG02.20.01\)](#).

Non-Discrimination Policy: NC State prohibits discrimination, harassment, and retaliation that are based upon a person's race, color, religion, sex (including pregnancy), national origin, age (40 or older), disability, gender identity, genetic information, sexual orientation, or veteran status (individually and collectively). If you feel that you have been the subject of prohibited discrimination, harassment, or retaliation, you should contact the Office for Institutional Equity and Diversity (OIED) at 919-515-3148.

NC State's policies and regulations covering discrimination, harassment, and retaliation may be accessed at <http://policies.ncsu.edu/policy/pol-04-25-05> or <http://oied.ncsu.edu/divweb>.

Basic Needs Security: Please notify me, if you are comfortable doing so, if you face challenges securing your food or housing or if you have other severe adverse experiences, and you believe your challenges may affect your performance in the course. Alternatively, you can contact the Division of Academic and Student Affairs to learn more about the Pack Essentials program (<https://dasa.ncsu.edu/pack-essentials>).

Supporting Fellow Students in Distress: As members of the NC State Wolfpack community, we each share a personal responsibility to express concern for one another and to ensure that this classroom (as well as the campus as a whole) remains a healthy and safe environment for learning. Occasionally, you may come across a classmate whose personal behavior concerns or worries you, either for your classmate's well-being, for your well-being or for the well-being of others. When this is the case, I would encourage you to report the behavior on the link located on NC State's Students of Concern website (<http://go.ncsu.edu/NCSUcares>).

List of Policies: Students are responsible for reviewing the NC State University PRRs (policies, rules and regulations) that pertain to their course rights and responsibilities:

- Equal Opportunity and Non-Discrimination Policy Statement <https://policies.ncsu.edu/policy/pol-04-25-05/> with additional references at <https://oied.ncsu.edu/equity/policies/>
- Code of Student Conduct <https://policies.ncsu.edu/policy/pol-11-35-01/>
- Grades and Grade Point Average <https://policies.ncsu.edu/regulation/reg-02-50-03/>
- Credit-Only Courses <https://policies.ncsu.edu/regulation/reg-02-20-15/>
- Audits <https://policies.ncsu.edu/regulation/reg-02-20-04/>