

Math 540 Uncertainty Quantification for Physical and Biological Models
Spring 2021
3 Credit Hours

Instructor: Ralph C Smith

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Office Hours: By Zoom 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: This class is meeting face-to-face in 2215 Williams on Tuesdays and Thursdays from 11:45-1:00. Additionally, we will record all classes via Classroom Capture and post the videos on MediaSite. By your continued participation in this recorded course, you are providing your permission to be recorded. These videos will also be live-streamed so that they can be watched during class time. This will not provide the capability for immediate feedback from remote attendees during the lecture. All lectures, references and supplemental material will be posted on the class website as well as the class Moodle site. Links to all recorded MediaSite lectures will also be posted on Moodle. Students should feel free to contact me via email with any questions or concerns regarding the course, projects, or grading.

Course Delivery Changes Related to COVID-19: The situation regarding COVID-19 is changing frequently, and the delivery mode may need to be altered accordingly. This could include switching from face-to-face lectures to synchronous or asynchronous online lectures, which will be posted on the class Moodle site. Any necessary changes would be announced via email to the class and posted on the class Moodle site. Note that if I need to be out for an extended period of time, Dr. Alen Alexanderian will take over in my absence.

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 April 29, 2021

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/>.

COVID-19 Related Absences: If you need to miss class because you have been advised that you may have been exposed to COVID-19 or you have a personal or family situation related to COVID-19 that prevents you from attending our sessions, please contact me. Together we will develop a plan to help you keep up with your coursework during any such absences.

Grading/Scheduling Changing Options Related to COVID-19

If the delivery mode has a negative impact on your academic performance in this course, the university has provided tools to potentially reduce the impact:

- **Enhanced S/U Grading Option:** [Enhanced Satisfactory/ Unsatisfactory Grading Option](#)
- **Late Drop:** [Enhanced Late Drop Option](#)

In some cases, another option may be to request an incomplete in the course. Before using any of these tools, discuss the options with your instructor and your academic advisor. Be aware that if you use the enhanced S/U, you will still need to complete the course and receive at least a C- to pass the course.

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>).

Diversity, Equity, and Inclusion: Diversity, equity, and inclusion are important to the success of our students at NC State. Every student, every faculty member, and every staff member who comes to NC State enriches us through their varied perspectives, knowledge, and backgrounds. Our classroom is one in which every student is respected and feels heard. In an effort to affirm and respect the identities of transgender students in the classroom and beyond, please contact me if you wish to be referred to using a name and/or pronouns other than those listed in the student directory. I welcome any additional suggestions you have for including the value of diversity, equity, and inclusion in this course.

Due to the Coronavirus pandemic, public health measures have been implemented across campus. Students should stay current with these practices and expectations through the [Protect the Pack](https://www.ncsu.edu/coronavirus/) website (<https://www.ncsu.edu/coronavirus/>). The sections below provide expectations and conduct related to COVID-19 issues.

Health and Participation in Class

We are most concerned about your health and the health of your classmates and instructors/TAs.

- If you test positive for COVID-19, or are told by a healthcare provider that you are presumed positive for the virus, please work with your instructor on health accommodations and follow other university guidelines, including self reporting ([Coronavirus Self Reporting](#)): Self-reporting is not only to help provide support to you, but also to assist in contact tracing for containing the spread of the virus.
- If you feel unwell, even if you have not been knowingly exposed to COVID-19, please do not come to class.
- If you are in quarantine, have been notified that you may have been exposed to COVID-19, or have a personal or family situation related to COVID-19 that prevents you from attending this course in person (or synchronously), please connect with your instructor to discuss the situation and make alternative plans, as necessary.
- If you need to make a request for an academic consideration related to COVID-19, such as a discussion about possible options for remote learning, please talk with your instructor for the appropriate process to make a COVID-19 request (a university-level form can be found [here](#)).

Community Standards related to COVID-19

We are all responsible for protecting ourselves and our community. Please see the [community standards](#) (released on 7/28/2020) and Rule 04.21.01 regarding Personal Safety Requirements Related to COVID-19 [RUL 04.21.01 – Personal Safety Requirements Related to COVID-19 – Policies, Regulations & Rules](#).

Course Expectations Related to COVID-19:

- **Face Coverings:** All members of the NC State academic community are required to follow all university guidelines for personal safety with face coverings, physical distancing, and sanitation. Face coverings are required in class and in all NC State buildings. Face coverings should be worn to cover the nose and mouth and be close fitting to the face with minimal gaps on the sides. In addition, students are responsible for keeping their course/work area clean. Please follow the cleaning guidelines described by the university.
- **Course Attendance:** NC State attendance policies can be found at: [REG 02.20.03 – Attendance Regulations – Policies, Regulations & Rules](#) . Please refer to the course's attendance, absence, and deadline policies for additional details. If you are quarantined or otherwise need to miss class because you have been advised that you may have been exposed to COVID-19, you should not be penalized regarding attendance or class participation. However, you will be expected to develop a plan to keep up with your coursework during any such absences. If you become ill with COVID-19, you should follow the steps outlined in the health and participation section above. COVID 19-related absences will be considered excused; documentation need only involve communication with your instructor.

- **Classroom Seating:** To support efficient, effective contact tracing, please sit in the same seat when possible and take note of who is sitting around you; instructors may also assign seats for this purpose.
- **Technology Requirements:** This course may require particular technologies to complete coursework. Be sure to review the syllabus for these expectations, and see the [syllabus technology requirements](#) for your course. If you need access to additional technological support, please contact the Libraries' Technology Lending Service: ([Technology Lending](#)).

Health and Well-Being Resources

These are difficult times, and academic and personal stress are natural results. Everyone is encouraged to [take care of themselves](#) and their peers. If you need additional support, there are many resources on campus to help you:

- Counseling Center ([NCSU Counseling Center](#))
- Health Center ([Health Services | Student](#))
- If the personal behavior of a classmate concerns or worries you, either for the classmate's well-being or yours, we encourage you to report this behavior to the NC State CARES team: ([Share a Concern](#)).
- If you or someone you know are experiencing food, housing or financial insecurity, please see the Pack Essentials Program ([Pack Essentials](#)).

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/>

Important Resources for Students:

- **Keep Learning:** [Keep Learning](#)
- **Protect the Pack FAQs:** [Frequently Asked Questions | Protect the Pack](#)
- **NC State Protect the Pack Resources for Students:** [Resources for Students | Protect the Pack](#)
- **NC State Keep Learning, tips for students opting to take courses remotely:** [Keep Learning Tips for Remote Learning](#)
- **Introduction to Zoom for students:** <https://youtu.be/5LbPzzPbYEw>
- **Learning with Moodle, a student's guide to using Moodle:** <https://moodle-projects.wolfware.ncsu.edu/course/view.php?id=226>
- **NC State Libraries** [Technology Lending Program](#)