EAS 4525/6525

Introduction to Weather Risk and Catastrophe Modeling

Spring Semester | 3 Credit Hours | Georgia Institute of Technology

Instructor	Dr. Ali Sarhadi	Email	sarhadi@gatech.edu
Office	ES&T 3244	Office Hours	Monday, 1:00–2:00 PM, ES&T L1114
Class Meeting	MW, 11:00 AM–12:15 PM, West Architecture, Room 260	TA Office Hours	TBD

General Course Information

Course Description

This course provides a rigorous, hands-on introduction to weather- and climate-driven risk and catastrophe modeling, with an emphasis on extreme events, compound hazards, uncertainty, and decision-relevant metrics. The course integrates statistical extreme value theory, non-stationary climate risk modeling, multivariate and compound extremes, uncertainty quantification, and damage/loss modeling, with applications to floods, hurricanes, heatwaves, and compound and cascading climate hazards.

Students will work directly with real-world hydroclimate and disaster datasets and develop end-to-end catastrophe risk models that connect hazard → exposure → vulnerability → loss. The course is designed for advanced undergraduates and graduate students interested in climate risk science, engineering design, insurance/reinsurance, resilience planning, and policy-relevant modeling.

Course Learning Outcomes

Upon successful completion of this course, students will be able to:

- Formulate weather and climate extremes as probabilistic risk problems, applying extreme value theory and non-stationary models to estimate rare-event probabilities and design levels under climate change.
- Quantify compound and multivariate climate hazards using joint statistics and copulas, and rigorously characterize and propagate uncertainty from data through models to decision-relevant metrics.
- Translate physical hazards into risk by integrating exposure data and vulnerability (damage) functions, enabling quantitative assessment of impacts, losses, and cascading consequences.
- Understand adaptation and mitigation solutions for reducing climate and weather risk, and evaluate their effectiveness using risk-based metrics and uncertainty-aware decision frameworks.
- Build reproducible, decision-relevant catastrophe risk models, and clearly communicate results through effective visualizations and professional oral and written presentations.

Prerequisites

No prior background in climate risk or catastrophe modeling is required. Students should have undergraduate-level training in probability and statistics, which will support understanding of uncertainty, extremes, and risk-based methods used in the course. The emphasis is on applied modeling rather than mathematical derivations, but a solid quantitative foundation is recommended.

Basic programming experience is expected. All coding, data analysis, and modeling will be conducted in R; students with prior experience in Python can transition to R with provided guidance and resources. Prior coursework in atmospheric science, hydrology, climate science, engineering, or a related quantitative field is recommended but not required. Students must have access to a personal computer or laptop capable of running the statistical and modeling tools used in live, in-class coding sessions.

Course Structure & Format

The course combines lectures focused on conceptual foundations and theoretical frameworks with hands-on labs centered on coding, data analysis, and modeling using R. Students complete 4–5 applied, computational assignments designed to reinforce core methods and real-world applications. The course culminates in a team-based final project (1–2 students per team) that integrates theory, data, and modeling, accompanied by a written report and oral presentation. The final two class sessions are dedicated exclusively to final project presentations.

Required Course Materials

The course will provide the following materials to support your learning:

- **Lecture slides:** Slides will be uploaded to Canvas after each lecture for reference and review.
- **Practical code examples:** For each topic, practical coding examples will be provided to help students implement the concepts learned in class. These will be available on Canvas and will serve as a guide for assignments and projects.

The following textbooks are recommended for students who wish to explore additional resources:

- Mudelsee, M. (2014). *Statistical Analysis of Climate Extremes*. Cambridge University Press.
- Dey, D. K., & Yan, J. (Eds.). (2016). *Extreme Value Modeling and Risk Analysis: Methods and Applications*. CRC Press / Taylor & Francis Group.
- Maity, R. (2018). *Statistical Methods in Hydrology and Hydroclimatology*. Springer.

Grading Policy

Student performance will be evaluated based on demonstrated understanding of weather and climate risk concepts, technical proficiency in probabilistic and computational modeling, and the ability to translate physical hazards into decision-relevant risk metrics under uncertainty. Final grades are awarded on a scale of A–F with no +/– grades permitted at Georgia Tech:

A>90; B>80; C>70; D>60

Component	Weight
Assignments (4–5 applied computational exercises)	**40%**
In-Class Activities (paper reviews, discussions)	**10%**
Research Proposal	**10%**
Oral Presentation (final project)	**20%**
Final Report	**20%**

Description of Graded Components

Assignments (40%)

Students will complete 4–5 applied assignments that combine conceptual questions with computational risk modeling exercises. Assignments will focus on implementing probabilistic methods—including extreme value analysis, non-stationary modeling, multivariate and compound risk analysis, and loss estimation—using real-world hydroclimate and disaster datasets. Emphasis will be placed on correct statistical reasoning, transparent handling of uncertainty, reproducible R workflows, and clear interpretation of results in a risk context.

In-Class Activities (10%)

In-class activities will emphasize critical engagement with the scientific and applied climate risk literature. Activities include structured, group-based paper reviews in which students evaluate modeling assumptions, sources of uncertainty, and decision relevance of published studies. Groups will share insights using a jigsaw discussion format. Credit is based on preparation, analytical contributions, and active participation in discussion.

Research Proposal, Final Report, and Presentation (50%)

The final project is either an individual or a team-based (1–2 students) end-to-end risk modeling study that integrates hazard characterization, exposure and vulnerability representation, uncertainty quantification, and impact or loss estimation. Projects may address weather- or climate-driven risks across earth, environmental, engineering, or socio-economic systems.

Proposal (10%)

Students will submit a concise research proposal defining a clear risk-focused research question. The proposal should articulate the weather or climate hazard of interest, its relevance to risk assessment or decision-making, and its contribution relative to existing work. It must describe the required data (or data acquisition plan) and present a justified methodological approach, including alternative strategies and anticipated challenges. Proposals must be original to this course (projects related to thesis work are encouraged) and limited to one single-spaced page (12-pt font). As part of the proposal component, teams may also be required to deliver a short in-class presentation mid-semester to present their proposed research question, data, and methodological approach, and to receive feedback from the instructor and peers.

Oral Presentation (20%)

Individuals or teams will present their project during the final class sessions. Presentations should clearly communicate the problem formulation, data and methods, uncertainty treatment, key results, and implications for risk assessment or adaptation decisions. Evaluation will emphasize clarity, technical accuracy, interpretation of results, and effective communication to a risk-informed audience.

Final Report (20%)

The final report expands on the presentation and documents the full modeling workflow, results, and evaluation. Reports should clearly describe methods, justify modeling choices, assess uncertainty and model performance, and discuss limitations and potential improvements. The report should not exceed 8 single-spaced pages.

Bonus Points: Students who complete the Course-Instructor Opinion Survey (CIOS) will earn 1–2 bonus points toward their final grade.

The grading scale will be based on overall class performance. The instructor reserves the right to adjust the scale if necessary to ensure a fair and balanced distribution of grades.

Course Outline

This is a tentative schedule, and topics may be adjusted as the course progresses.

Week	Topic	Details
1	**Foundations of Weather & Climate Risk**	• Course structure, expectations, and materials • Overview of major weather and climate extremes (floods, hurricanes, heatwaves, droughts, wildfires) • Physical drivers and characteristics of extremes • Societal, economic, and environmental impacts
2	**Introduction to Climate and Weather Risk**	• Role of probabilistic risk modeling in climate and weather risk assessment • Probabilistic representations of hazards • Distributional form, tail behavior, and extremes • Uncertainty structure and implications for risk estimates and design decisions
3	**Probability Foundations for Risk Analysis**	• Random variables, distributions, and moments • Discrete and continuous distributions • Interpreting probability for risk and decision-making
4–5	**Extreme Value Theory for Hazard Assessment**	• Distributional assumptions for hydroclimate variables • Parameter estimation and diagnostic tools • Block maxima (GEV) and peaks-over-threshold (GPD) frameworks • Return levels, exceedance probabilities, and uncertainty in extrapolation
6	**Non-Stationary Climate Hazard Modeling**	• Trend detection and change-point analysis • Time- and covariate-dependent distributions • Implications for infrastructure design and risk management • Limitations of stationary assumptions under climate change
7–8	**Compound and Multi-dimensional Extremes**	• Types of compound events (multivariate, preconditioned, cascading) • Dependence structures and joint exceedance • Copula theory for climate risk • Multivariate return periods and compound design events • Graph Theory and Vine Copula
9	**Uncertainty in Climate Risk Modeling**	• Uncertainty cascade: data → model → parameters → decisions • Frequentist (bootstrap), Bayesian, and ensemble-based approaches • Communicating uncertainty in risk estimates

10	**From Hazard to Loss: Risk Frameworks and Damage Functions**	• Risk definition and assessment • Damage and fragility functions • Expected annual damage (EAD) and tail risk
12	**Hurricanes, Wind and Flood Loss Modeling**	• Event-based vs probabilistic loss models • Hurricane wind and flood loss estimation • Linking stochastic hazards to loss distributions
13	**Physics-Based Hurricane Modeling**	• Generation of physics-based synthetic hurricanes in a warming climate • Physical simulation of storm surge • Physical simulation of coastal flooding
14	**Adaptation and Mitigation of Climate Risk**	• How adaptation alters hazard, exposure, and vulnerability • Comparing adaptation strategies using risk-based metrics • Decision-making under deep uncertainty • Trade-offs, robustness, and maladaptation
15	**Project Presentations**	• Presentation and discussion of student projects

Course Policies

Attendance and Participation

Regular attendance is expected. Students are responsible for all material covered in class, including announcements, schedule changes, and in-class activities. If you must miss a class, please notify the instructor in advance when possible. In-class activities cannot be made up except in cases of documented illness or emergency. Review Institute expectations related to attendance, including information about excused absences, at catalog.gatech.edu/rules/4/.

Academic Integrity

Georgia Tech aims to cultivate a community based on trust, academic integrity, and honor. Students are expected to act according to the highest ethical standards. Review Georgia Tech's Honor Code and the student Code of Conduct.

Any student suspected of cheating or plagiarism on a quiz, exam, or assignment will be reported to the Office of Student Integrity, who will investigate the incident and identify the appropriate penalty for violations.

Collaboration, Group Work, and Use of Generative AI

Assignments are to be completed individually unless explicitly stated otherwise. You are encouraged to discuss course concepts with classmates, but submitted work must be your own. For the team project, collaboration within the team is expected and encouraged.

The use of Generative AI tools (e.g., ChatGPT, GitHub Copilot) must be disclosed. If you use AI assistance in your work, include a brief statement at the end of your submission describing how it was used. Undisclosed use of AI to complete assignments constitutes an academic integrity violation.

Accommodations for Students with Disabilities

If you are a student with learning needs that require special accommodation, contact the Office of Disability Services (404-894-2563) as soon as possible to make an appointment to discuss your special needs and to obtain an accommodations letter. Please also e-mail the instructor as soon as possible in order to set up a time to discuss your learning needs.

Student-Faculty Expectations Agreement

At Georgia Tech, we believe that it is important to strive for an atmosphere of mutual respect, acknowledgement, and responsibility between faculty members and the student body. The Student-Faculty Expectations articulate basic expectations that you can have of the instructor and that the instructor has of you. All members of this class are expected to contribute to a respectful, welcoming, and inclusive environment.

Extensions, Late Assignments, and Missed Exams

Late assignments will be penalized unless an extension is arranged in advance with the instructor. Extensions may be granted for documented illness, emergency, or approved Institute activities. Requests for extensions should be made prior to the assignment deadline whenever possible. The final project deadlines (proposal, report, and presentation) cannot be extended without prior written approval.

Inclement Weather and Digital Learning Days

If a weather-related event affects campus operations, the instructor has the discretion to cancel class or pivot to digital instruction. Students will be notified via Canvas of any such changes. Please monitor Canvas and your Georgia Tech email for updates.

Campus Resources for Students

Graduate Student Academic and Professional Success Resources

A list of resources for graduate students is given on the Office of Graduate and Postdoctoral Education website, including academic resources, student resources, and professional development.

Undergraduate Student Academic Success Resources

A list of resources for undergraduate students' academic success and information about advising can be found at Success at Tech.

Student Well-Being

At Georgia Tech, we are concerned about your overall physical, social, and mental well-being. A comprehensive list of wellness-related resources has been compiled and maintained by the Office of the Vice President for Student Engagement and Well-being.

Online Course Evaluation

Students are encouraged to provide professional and constructive feedback on the quality of instruction in this course by completing the online course evaluations via the Georgia Tech Course Instructor Opinion Survey (CIOS). You will be notified when the evaluation period opens, and evaluations can be submitted through the email invitation you receive, directly in Canvas under the CIOS tab, or via the Georgia Tech CIOS website at academiceffectiveness.gatech.edu/surveys/cios. Students who complete the CIOS will earn 1–2 bonus points toward their final grade.