# RADAR SOUNDING: PRINCIPLES AND PLANETARY APPLICATIONS (REMOTE SENSING & DATA ANALYSIS)

EAS 4430/8803

Instructors: Indujaa Ganesh, Winnie Chu Course website: http://canvas.gatech.edu

## COURSE DESCRIPTION AND GOALS

This course provides a comprehensive introduction to radar sounding techniques used to probe subsurface structures on Earth, ice sheets, and planetary bodies. Students will learn how electromagnetic waves interact with different materials, how to design and interpret radar sounding experiments, and how to process and analyze radar data. The course bridges engineering fundamentals with Earth and planetary science applications, preparing students to work with data from sounding radar instruments onboard planetary missions (e.g. SHARAD, MARSIS, REASON, etc.), Earth-orbiting and planetary altimeters (e.g. ICESat-2, Magellan), and airborne ice-penetrating radar systems.

The goals of this class are to: (1) develop a solid understanding of electromagnetic wave propagation and radar system principles, (2) gain hands-on experience with radar data processing and interpretation techniques, (3) understand how radar sounding reveals subsurface structure in ice sheets, planetary surfaces, and terrestrial environments, and (4) critically evaluate radar sounding studies in the scientific literature and design radar investigations for specific scientific questions.

## PREREQUISITES

Prerequisites include MATH 1551 and MATH 1552 (or equivalent classes on Calculus), and PHYS2211.

## COURSE MATERIALS AND RECOMMENDED TEXT

Lecture notes and assignments will be made available on the course website. There is no required textbook, however parts of the course will closely follow topics in Ulaby, F. T. & Long, D. G. (2013). *Microwave Radar and Radiometric Remote Sensing*. Artech House. ISBN-13: 978-0472119356. Please see course outline for relevant chapters.

## COURSE REQUIREMENTS

This course involves lectures, homework assignments, and a final project. The percentage contribution of each component to the final grade is below.

| Assignments | Number | EAS4430 | EAS8803 |
|---|---|---|---|
| Homework assignments | 5–6 | 50% | 40% |
| Class participation & discussion | | 10% | 10% |
| Final project presentation | | 15% | 15% |
| Final project report | | 25% | 35% |

## DESCRIPTION OF GRADED COMPONENTS

*Homeworks*. Five to six homework assignments will be distributed throughout the semester. These assignments will primarily be an extension of in-class Python- or MATLAB-based programming exercises (see course outline) that focus on manipulating and/or modeling radar sounding data of Earth and other planets. These programming assignments will be supplemented by questions requiring students to interpret their results in the context of concepts discussed in class. Students are encouraged to work together, but must submit individual solutions and acknowledge collaborators. Homework assignments will be due one week from the date of assignment.

*Class participation.* Active engagement in class discussions, particularly during case study sessions and guest lectures, is expected. Students will occasionally present recent research papers or lead discussions on radar sounding applications.

*Final project.* Students will complete an independent project involving either: (1) analysis of real radar sounding data from a planetary mission or terrestrial campaign, (2) theoretical modeling of radar wave propagation in a specific geological/planetary context, or (3) design of a radar sounding investigation for a scientific objective. Please discuss with the instructor(s) beforehand if you have any concerns regarding topic selection for your project. Graduate students (EAS8803) are expected to produce more comprehensive analyses and engage with current literature more deeply. The project consists of a written report (10-15 pages for undergraduates, 15-20 pages for graduate students) and a 15-minute presentation during the final week of class. The final report should properly cite supporting material and not plagiarize any previous publications.

## GRADING SCHEME

The final grade will be assigned as a letter grade according to the following scale: **A** >90%; 80 > **B** ≥90%; 70 > **C** ≥80%; 60 > **D** ≥70%; **F** ≤60%.

## ABSENCE AND LATE ASSIGNMENTS

Students are required to attend and actively participate in class. However, if students foresee the need to miss class, due to other obligations or illness, please contact me to discuss alternate arrangements. If a student needs an extension due to exceptional circumstances, I request them to contact me as early as possible. Absence and/or late submission of assignments due to unexpected dependent care obligations will be treated equivalently to those caused by illness or obligations of the student themselves.

## 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. It is expected that all students are aware of their individual responsibilities under the Georgia Tech Academic Honor Code, which will be strictly adhered to in this class. For information on Georgia Tech's Academic Honor Code, please visit https://www.catalog.gatech.edu/policies/honor-code/ or https://www.catalog.gatech.edu/rules/18. Any student suspected of cheating or plagiarizing on a quiz, exam, or assignment will automatically receive a zero on the assignment and will be reported to the Office of Student Integrity, which will investigate the incident and identify the appropriate penalty for violations.

## ACCOMMODATIONS FOR STUDENTS WITH DISABILITIES

If you are a student with learning needs that require special accommodation, contact the Office of Disability Services at (404)894-2563 or http://disabilityservices.gatech.edu /, as soon as possible, to make an appointment to discuss your special needs and to obtain an accommodations letter. Then please contact me as soon as possible to discuss your learning needs.

## STUDENT-FACULTY EXPECTATIONS

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 articulates some basic expectations that you can have of me and that I have of you. Additional information for research-related work is given in The Expectations of Advisors and Advisees. In the end, simple respect for knowledge, hard work, and cordial interactions will help build the environment we seek. Therefore, I encourage you to remain committed to the ideals of Georgia Tech while in this class.

## USE OF ARTIFICIAL INTELLIGENCE

The use of generative artificial intelligence (AI) and large language model (LLM) tools is not permitted. Materials generated by these programs may be inaccurate, incomplete, biased, problematic, and hinder independent thinking and creativity (see results from a recent study).

## RESOURCES

### ACADEMIC SUPPORT

- Center for Academic Success
  - 1-to-1 tutoring
  - Peer-Led Undergraduate Study (PLUS)
  - Academic coaching
- Residence Life's Learning Assistance Program
  - Drop-in tutoring for many 1000 level courses
- OMED: Educational Services
  - Group study sessions and tutoring programs
- Communication Center
  - Individualized help with writing and multimedia projects
- Academic advisors for your major

### PERSONAL SUPPORT

- The Office of the Dean of Students; 404-894- 6367; Smithgall Student Services Building 2nd floor
  - You also may request assistance here
- Counseling Center; 404-894-2575; Smithgall Student Services Building 2nd floor
  - Services include short-term individual counseling, group counseling, couples counseling, testing and assessment, referral services, and crisis intervention. Their website also includes links to state and national resources.
  - Students in crisis may walk in during business hours (8am-5pm, Monday through Friday) or contact the counselor on call after hours at 404-894-2204.
- Students' Temporary Assistance and Resources (STAR)
  - Can assist with interview clothing, food, and housing needs.
- Stamps Health Services; 404-894-1420

  - Primary care, pharmacy, women's health, psychiatry, immunization and allergy, health promo- tion, and nutrition
- OMED: Educational Services
- Women's Resource Center; 404-385-023
- LGBTQIA Resource Center; 404-385-2679
- Veteran's Resource Center; 404-385-2067

## TENTATIVE COURSE OUTLINE

| WEEK | MON | WED |
|---|---|---|
| | **1. INTRODUCTION TO RADAR SOUNDING** *Ulaby & Long Ch. 1, 4 & 5* | |
| 1 | Course overview; History of radar sounding from Apollo to present; Applications | EM waves fundamentals; Derive wave equation from Maxwell's equations |
| 2 | Wave polarization representation; Plane wave propagation | ***Ex 1.*** *Digital representation of waves as timeseries, sampling, complex sinusoids* |
| 3 | Dielectric properties (permittivity, permeability, conductivity); Reflection and transmission at interfaces; Attenuation in bulk media | Radar systems: Basics and parts; Radar equation, Link budget analysis; ***In-class Demonstration*** *w/ Groundhog radar parts* |
| | **2. DESIGNING A RADAR SOUNDING EXPERIMENT** *Ulaby & Long Ch. 3, 13 & 14* | |
| 4 | Sounding radar design: PRF, Bandwidth, Center frequency, and considerations in choosing parameters / design | Waveforms (impulses and chirps, CW, stepped); Time domain and frequency domain systems |
| 5 | ***Ex 2.*** *GPRMax modeling (or) Student presentations on the design of a terrestrial or planetary radar instrument* | Antennas and Antenna patterns, Surface clutter; Clutter mitigation strategies used by SHARAD, REASON, and airborne systems |
| | **3. HOW TO PROCESS RADAR DATA** *(all topics in this module will involve manipulating digital signals in-class using Python)* | |
| 6 | Discrete Fourier Transforms; Frequency domain manipulation of time series | Causal vs. acausal filters; Matched filters for pulse compression; Windowing |
| 7 | Estimation of coherent noise; Random noise | ***Ex 3.*** *Implementation of full processing chain for ice and/or planetary sounder* |
| 8 | Impulse radar processing specifics - real sampling, poorly defined bandwidth problem | ***On-campus Demonstration*** *w/ PulseEkko or Zond Aero LF systems* |
| | **4. ANALYSIS AND INTERPRETATION: BULK PROPERTIES** *Ulaby & Long Ch. 14 & 11* | |
| 9 | Material property estimation: (1) Independent thickness; (2) Hyperbolas; (3) CMP surveys | ***Ex 4.*** *Dielectric permittivity estimation using CMP data acquired on ice* |
| 10 | Introduction to synthetic aperture imaging | Application of imaging algorithms to sounding radar data (omega-k, RTM, etc.) |
| 11 | Dielectric loss and attenuation estimation techniques | ***Ex 5.*** *Attenuation estimation from ice and/or planetary radar data* |
| | **5. ANALYSIS AND INTERPRETATION: INTERFACE PROPERTIES** *Ulaby & Long Ch. 5, 10, & 17* | |
| 12 | Rough surface scattering; Parameterizing roughness; Volumetric scattering contribution to extinction | Polarimetric scattering; Stokes and Mueller matrix representations for monostatic and bistatic configurations; Mini-RF instrument case study |
| 13 | ***Ex 6.*** *Simulate radar reflection at interfaces using scattering models* | Radar altimetry: Pulse and beam limited; Waveform analysis; CryoSat, ICESat-2, Europa Clipper altimetry case study. |

| 6. ADVANCED TOPICS & PROJECT PRESENTATIONS | | |
|---|---|---|
| 14 | Interferometric sounding; Tomographic imaging; Machine learning for interpretation | Thanksgiving Break |
| 15 | Final Presentations | Final Presentations |
| 16 | Wrap-up / Submit Final Reports | Reading Period |

*Note: This schedule is tentative and may be adjusted based on class progress and student interests. Guest lectures from radar scientists and mission teams will be incorporated where possible.*