

AAEC/FREC/GEOG 5544 – REMOTE SENSING IN THE SOCIAL SCIENCES

Virginia Tech
Fall 2022

Instructor: Professor Elinor Benami (Office: [540-231-1147](tel:540-231-1147))

Teaching Assistant: Ozzy Campos

Course Meeting Time: Mon. & Wed. 2.30 - 3.45PM in Wallace 244

Labs: Wed. 4.00 - 5.15PM in Torgersen 1080

Student Advice Hours: Tues. 4.30-5.30pm, & Thurs. 9-10am, and by appt (Elinor); Ozzy by appt.

Credits: 4

1 Course Summary and Objectives

The increasing accessibility of frequently updated geospatial information from remote sensors is enabling novel ways to detect changes in environmental conditions, communities, and even cash flows. This geospatial data revolution has in turn been opening up new ways of enhancing environmental compliance, supporting sustainable development efforts, and even managing crisis relief logistics. Yet, the increasing accessibility also comes with the peril of potential misuse, however, and the possibility to bamboozle instead of enlighten. This graduate level course examines how remotely sensed data have and can be used in social science research, with a focus on the practical deployment of publicly available remote sensing data for applications in environment, agriculture, and economic development. By the successful completion of this course, you should be able to:

1. Distinguish the meaning and importance of core remote sensing principles relating to the electromagnetic spectrum, sensor resolution, data types, and processing techniques.
2. Apply basic spatial data wrangling (i.e., extracting, cleaning, visualization, and communication) skills to evaluate social science research questions.
3. Assess the fundamental challenges that spatial data can present for social science research as applied to important social issues such as deforestation, pollution, and economic development.
4. Evaluate the research designs and analytic methods used in recent publications across fields, including scholarship from engineering, as well as the natural and social sciences.
5. Integrate findings and approaches from seminal as well as current scholarship into a well-justified research proposal using remotely sensed data.

2 Readings and Course Materials

Course Readings: This course will draw upon portions of two primary textbooks:

- J.B. Campbell, R.H. Wynne, and V.A. Thomas (2023). *Introduction to Remote Sensing*. 6th ed. Guilford Press
- J.A. Richards (2022). *Remote sensing digital image analysis*. 6th ed. Springer

Both of these texts (abbreviated CWT and JR in the [Detailed Readings](#)) cover many foundational concepts of remote sensing and digital image analysis. As a graduate course, we will also draw upon a variety of recent academic articles that apply remote sensing in the pursuit of assessing the extent and impact of issues such as deforestation, pollution, agriculture, and economic development. A preview of these readings can be found in the [Detailed Readings](#) section.

Course Website: This term we will be using Piazza for class discussion, sharing announcements, and file organization. Piazza was designed by a team of engineers to simulate real class discussion and encourage class equity by ensuring all students to have access to the same information and collaboration opportunities. Importantly for our class, Piazza offers great threading and searching functions, and it also offers the ability to easily share code

snippets to help you debug issues you may be running into with your labs. We've also enabled an anonymous posting option on the discussion thread in case anyone prefers to ask questions or respond to queries without attribution.

You can access Piazza directly on its own site [here](#) or through the VT Canvas website, although you need to register for Piazza separately with your VT email. The Piazza system is designed to help you get help quickly and efficiently by leveraging the knowledge of your classmates, the TA, and myself. Rather than emailing questions directly to the teaching team, I strongly encourage you to post your questions on Piazza. If you have any problems or feedback for the developers, email team@piazza.com.

Gradescope

We will use [Gradescope](#) to submit assignments and provide feedback due to additional features it offers over Canvas, including easily-updatable rubrics and anonymous grading that allow for faster, more consistent, and fairer evaluations. You should receive an invitation to your vt email address in the first week, though if you would like to self-register for gradescope for our class, use the entry code "**ZZWEVP**".

Student Appointments (Open Question Hours) I'm happy to meet with my students and encourage you to come by *at least* once in the semester. You can meet with me in groups or individually to discuss a number of things, such as clarifying a reading or topic, asking for feedback on a project, discussing accommodations you might need if you're having challenges outside of this class, discussing future plans, seeking out research opportunities related to the class or work I do, etc. I have time dedicated for students in this class from 4.30-5.30pm on Tuesdays, which can be either via zoom or in person, COVID precautions permitting. You can also reserve twenty minutes at a time here on Thursdays from 9-10am here https://calendly.com/elinor_vt/student-times, and if none of these times work for you, feel free to contact me with 2-3 alternative times that do.

Prerequisites: We will be dissecting several empirical economics papers in this course. Although not required, a background with microeconomic theory and econometrics will help make this content more easily and quickly understood. Come speak with me at the beginning of the semester if you have concerns about this content so we can develop a strategy for you to keep up.

3 Software

Google Earth Engine As soon as possible, you should sign up for an account with google earth engine (<https://earthengine.google.com/signup/>). **You should use a non-VT email address to sign-up**, and it may take up to 1-2 days for approval. Google Earth Engine (GEE) is a cloud-based computing platform hosted by Google and is important resource that we will use in our course labs. GEE provides direct access to a multi-petabyte catalog of satellite imagery and geospatial datasets, including the entire EROS (USGS/NASA) Landsat catalog, MODIS, NAIP, and Sentinel-1 imagery, and precipitation, elevation, sea surface temperature, and CHIRPS climate data, among others. However, beyond simply being an image archive, GEE also provides APIs for JavaScript and Python to enable researchers to perform planetary-scale analysis of the Earth's surface. GEE is free for research, education, and nonprofit use.

4 Evaluation

Grades will be determined based on the following activities:

1. *Reading Responses (20%)*: An important part of this course – and scholarly work more broadly – involves becoming comfortable interacting and engaging with scientific research. Therefore, a portion of this grade will also come from weekly reading responses to papers related to the course content. For this, I expect you to demonstrate in written and oral form that you have grappled with concisely capturing the contribution of the paper and have started to generate critiques or extensions of them. More specifically, everyone will be expected to submit a write-up on at least one paper per week, and we will rotate through class participants to present (sign-ups will occur at the beginning of the semester).

I will post a template to help guide you through this process – I also encourage you to review guides to referee reports as a useful reference, especially Alain de Janvry's guide [here](#) and Jonathan B. Berk,

Campbell R. Harvey, and David Hirshleifer (2017). "How to Write an Effective Referee Report and Improve the Scientific Review Process". *Journal of Economic Perspectives* 31.1, pp. 452–480.

2. *Labs (40%)*: We will have five graded and three optional labs throughout the course of the semester that will cover the following:
 - (a) Remote Sensing Basics and Introduction to Google Earth Engine
 - (b) Digital Imagery and Image Processing
 - (c) Spectral Indices and Transformations
 - (d) Classification and Regression
 - (e) Time Series Analysis
 - (f) Using the Night Lights Dataset for Assessing Economic Development (optional)
 - (g) Intro to Active Sensing Data (Optional)
 - (h) Machine Learning and AI (Optional)

See the [Lab Outline](#) for more details on the goals of each lab.

3. *Paper Proposal (30%)*: Each student in the course will be expected to submit a paper proposal. Writing a paper proposal will help synthesize your thoughts on points we've been exploring, provide an opportunity to continue a conversation about the material, and lay a foundation for a paper you could write in the future. In these proposals, you are expected to (1) explain and motivate the question you're interested in (2) outline the structure of the argument or approach you propose to take that draws upon remotely sensed data – including the variables you'd plan to use and any assumptions required (3) demonstrate familiarity with some of the core problems or literature you expect to confront (4) sketch out the elements of the critical summary and results graphics you'd intend to show, as well as provide preliminary results from an attempt at the approach you lay out. The 30% will be cumulative, generated from the following milestones:

Milestone	Value	Due
Topic ideas/"pitch"	0%	Wed, Aug. 31
In-class proposal discussion	5%	Monday, Sept. 26
Preliminary results and rescopeing	5%	Wednesday, Oct. 26
Presentation	10%	Monday Dec 5 & Wed. Dec 7
Full proposal	10%	Tuesday, Dec. 13 at 6.45pm (in lieu of final exam)

For applied examples in this genre, think extended conference abstracts, write-ups for an advisor convincing them you're ready to pursue a paper topic, pitching a paper to your future self, etc.

4. *Engagement & Advancing the Conversation (5%)*: Throughout the course I expect you to engage in the course content and share your learning with your classmates. This engagement may manifest in several ways, including (1) posting relevant topics from ongoing news on our course discussion board (2) asking questions in class or on our course discussion board, and/or responding constructively to others' questions on Piazza (3) being responsive and active participants in class activities.
5. *Syllabus Reflection (5%)*: To help the teaching team get to know you better and gauge where the class is starting from, in the first week of class you will be asked to complete a survey in which you will share a bit more of your academic background as well as reflect on some of the highlights of this syllabus as it pertains to your research and semester plans. The beginning of the course survey is linked [here](#)
6. *Course Evaluations (Bonus 2%)*: Course evaluations are important for assessing student perceptions of the course and improving course quality, yet nonrandom response bias can dilute the value of them. We'll have a mid-term evaluation and a near-end-of term evaluation. While the content of these surveys will be anonymized, I can see the submission rate. To help overcome non-sampling errors, if the submission rate exceeds 80% of the enrolled course participants, everyone will receive a bonus 2% to their final grades.

Grading

I assume everyone is here because you anticipate it will be useful for your research, and in Ph.D. school, as long as you continue to meet the general requirements of your program, your research and publications typically matter far more than your grades anyway. That said, the university still requires grades, which will follow the below [standard grading schema used by Virginia Tech](#):

≥ 93 A	90–92 A–	87–89 B+	83–86 B	80–82 B–	77–79 C+
73–76 C	70–72 C–	67–69 D+	63–66 D	60–62 D–	< 60 F

Pass-Fail is also certainly for an option for this course, too. Fundamentally, I believe that with some effort and planning, everyone can master the essential components of this class. Reach out to the instructional team and your classmates to overcome stumbling blocks you perceive in your pursuit of content mastery. The earlier you connect, the more options are available to address your questions.

5 Course Policies

Class Attendance

Regular attendance is expected as well as beneficial to course discussion. Although we will not formally be taking attendance in every class, notable lack of participation can affect your ‘engagement’ grade. If you think you may be unwell, however, please do not come to class and reach out to the instructor as soon as is feasible.

Late Submissions

Prompt submission of assignments allows the instructional team to provide guidance and timely feedback. Due dates for each assignment are noted on the course calendar. Work turned in by the due date, as evidenced by the date stamp on submission, will be considered on time and will receive full credit. Assignments submitted after the due date will receive a 10% grade deduction per day past the due date. If an emergency arises that prevents you from completing your work on time, please contact the instructors as soon as possible so that arrangements can be made for you to keep up in the class. The late policy may be waived at the instructor’s discretion in case of an emergency.

Honor Code

While I strongly encourage you to work in groups and help tutor each other on concepts and examples, all work submitted in this course must be of your own production, and all sources must be properly acknowledged and documented. Failure to acknowledge your sources, whether deliberate or not, constitutes plagiarism. If you have questions about this policy, please reach out. I will appreciate your efforts to behave with integrity and will be happy to help.

The tenets of the Virginia Tech Graduate Honor Code apply in this course, and all assignments shall be subject to the stipulations of the Graduate Honor Code. For more information on the Graduate Honor Code, please refer to the GHS Constitution located at <https://graduateschool.vt.edu/academics/expectations/graduate-honor-system.html>

Accessibility

Virginia Tech welcomes students with disabilities into the University’s educational programs. The University promotes efforts to provide equal access and a culture of inclusion without altering the essential elements of coursework. If you anticipate or experience academic barriers that may be due to disability, including but not limited to ADHD, chronic or temporary medical conditions, deafness or hearing impairment, learning disabilities, mental health, or vision impairment, please contact the Services for Students with Disabilities (SSD) office (540-231-3788, ssd@vt.edu, or visit www.ssd.vt.edu). If you have an SSD accommodation letter, please meet with me privately during office hours as early in the semester as possible to deliver your letter and discuss your accommodations. You must give me reasonable notice to implement your accommodations, which is 5 business days generally and 10 business days for final exams or projects.

Emergency Well-Being Resources (Lauren's Promise)

I will listen and believe you if someone is threatening you. Any form of harassment or violence will not be excused or tolerated at VT. If you are in immediate danger, call 911. If you are experiencing harassment, relationship violence, or stalking, you can report it to me, and I will (and am obligated to) connect you to resources such as VT's Office of Equity and Accessibility, which has established procedures and resources for Sexual Misconduct Response and Prevention, detailed here: <https://oea.vt.edu/title-ix-vawa.html>. You may also contact a 24-7 emergency evaluation and crisis intervention team from the NRVCS (New River Valley Community Services) Emergency Services line at 540-961-8400.

Other University Resources

Virginia Tech has an array of resources available to students at low or no additional cost, including writing support, mental health services, or career counseling. I've included some of these resources below, and I ask that you please help share others in our class discussion page that you've found helpful and that your classmates might, too.

- Geospatial Data Services at VT <https://guides.lib.vt.edu/geospatialdata>
- Writing Center: <https://lib.vt.edu/study-learn/writing-center.html>
- Cook Counseling Center: <https://ucc.vt.edu/>
- Career and Professional Development Advising: <https://career.vt.edu/advising.html>

Acknowledgements

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6 Course Outline

Week of	#	Lecture Topic	Labs and Assignments
Aug-22	1	Intro to the Course. Basics of Earth Observation, the electromagnetic spectrum, & RS data	Lab 1: Remote Sensing Basics and Intro to GEE
Aug-29	2	Spatial Data Formats & Types; Geocomputation	Lab 2: Digital Imagery and Image Processing and <i>Paper Outline Due</i>
Sep-5	3	Spectral Indices & Transformations; Classification Methods; Accuracy Assessment; Smoothing & Edge Detection	Lab 3: Spectral Indices and Transformations
Sep-12	4	Change Detection and Applications: Forests and Land Cover Change	Lab 4: Classification & Regression
Sep-19	5	Nonclassical Measurement Error, Censoring, and Scale within the context of Land Use Classification and Change Detection	<i>Paper Outline Due</i>
Sep-26	6	Time Series Analysis and crop phenology, with applications to agriculture	Lab 5: Time Series
Oct-3	7	Weather Data, with an emphasis on uses and mis-uses of (interpolated) and gridded data on temperature, precipitation, and soil moisture for agricultural applications	
Oct-10	8	Economic Development: Night Lights, Daylights	Optional Lab: Night Lights
Oct-17	9	Aerosol optical depth and its uses for varying kinds of smog, haze, desert dust	<i>Paper Prelim Results Due</i>
Oct-24	10	Seeing Beyond the Visible: Thermal analysis, with applications to Fire	
Oct-31	11	Seeing Beyond the Visible: Gravimetric analyses for evaluating earth processes (e.g. water resource availability) and intro to the physics of active sensors (e.g., RADAR, LiDAR, and SAR)	Optional Lab: Sentinel-1 SAR
Nov-7	12	The use of remote sensors in (1) flood risk assessment (2) oil spill evaluation (3) building height/population estimation (4) soil moisture estimation	
Nov-14	13	Earth Observation in Disaster Risk Assessment & Disease Tracking: Opportunities and Limits.	Optional Lab: Machine Learning and AI
Nov-22		Thanksgiving Break	
Nov-28	14	Open Topics/Student Selected Topics	
Dec-5	15	Student Presentations on Paper Proposals	<i>Final Proposals Due Tues, Dec. 13 at 6.25PM</i>

7 Lab Outline

The first five labs were adapted from [Google Earth Engine tutorials for higher education](#) created by [David Saah](#), Director of the USF Geospatial Analysis Lab and [Nicholas E. Clinton](#), a member of the GEE developer team. They're writing a text on fundamentals and applications of cloud-based remote sensing that may be released this fall.

Title	Description
1: Remote Sensing Basics & Intro to GEE	<p>Describe a digital image, datum, projection, along with spatial, spectral, temporal, and radiometric resolution.</p> <p>GEE data structures: Strings, Numbers, Lists, Arrays, Objects, Functions Resources: Ujaval Gandhi's Module 1 on GEE Basics</p>
2: Digital Imagery & Image Processing	<p>Search, find, and visualize remotely sensed imagery in GEE. At completion, you should be able to understand the difference between radiance and reflectance, load imagery with the units of interest (e.g., radiance or reflectance), make true color and false color composites and visually identify land cover types based on spectral characteristics.</p> <p>GEE skills: Importing, Exporting, Assets, Sorting, Expressions</p>
3: Spectral Indices & Transformations	<p>Extract, visualize, combine, and transform spectral data in GEE so as to highlight and indicate the relative abundance of particular features of interest from an image. At completion, you should be able to understand the difference between wavelengths, load visualizations displaying relevant indices, compare the relevant applications for varying spectral transformations, and compute and examine image texture.</p> <p>GEE Skills: Clipping, Masking, Reducing Resources: David Moaza's Spectral Index Table</p>
4: Classification & Regression	<p>Introduction to classification, including exploring the processes of training data collection, classifier selection, classifier training, image classification and accuracy assessment. At completion, you should be able to apply these skills to assess change in a given area.</p> <p>GEE Skills: Band Math, Hyperparameter tuning, Change Detection</p>
5: Time Series	<p>Establish a foundation for analyzing time series of remotely sensed data, usually in the form of a temporally ordered stack of images. You will be introduced to concepts of smoothing, interpolation, linear modeling, and phenology. By completion, you should be able to perform analysis of multi-temporal data for evaluating trends and seasonality.</p> <p>GEE Skills: Map/Reduce II to Calculate Statistics, Time Series Charts</p>
6: World Bank Tutorial on the Night Lights Dataset (Optional)	<p>The World Bank's Open Night Lights tutorial provides guidance on using night light data while reviewing many of the basic elements of GEE from previous labs. Practice your previous skills for analyzing the earth's surface while applying it to the night lights dataset context. The tutorial also introduces data fusion with Sentinel-2 and the Global Human Settlement Layer.</p> <p>Resources: Qiushing Wu's open-source geospatial/cloud computing resources</p>
7: Introduction to Active Sensors (Optional)	<p>This lab will provide a brief introduction to active sensing by exploring some of the features of Sentinel-1's Synthetic Aperture Radar (SAR) instrument data. By the completion of this lab, you'll be familiar with how to access, visualize, and characterize SAR data.</p> <p>Resources: Sentinel-1 Analysis Ready Data Preparation in GEE</p>
8: Machine Learning with RS data (Optional)	<p>This lab will highlight cases and problem solving using machine learning, computer vision, and/or deep learning techniques.</p> <p>Resources: Land cover classification with ML - Apache Software Foundation</p>

8 Detailed Readings

**** Indicates Required.** All other references are provided as further background in the topic.

Week 1: Aug 22

Basics of Earth Observation, the Electromagnetic Spectrum, Orbits, and Resolution four ways (spatial, temporal, spectral, radiometric)

- CWT Ch 1-2 **
- JR Ch 1
- Mark Monmonier (2018). *How to lie with maps. Third Edition. Note: Humorous yet critical view of how the conscious and unconscious decisions of map-makers present but one of many stories about the place depicted.* University of Chicago Press. [Focus on the Intro and Chapter 12 "Image Maps: Picture That"] **
- Josh Gray (Apr. 2021). *What Economists Should Know About Remote Sensing.* Excellent video of about 1 hour 15 minutes for the NC State Center for Geospatial Analytics. URL: <https://youtu.be/DMbUtFSznvo> **
- Michael A Wulder et al. (2022). "Fifty years of Landsat science and impacts". *Remote Sensing of Environment* 280, p. 113195

Week 2: Aug 29

Spatial Data Literacy: Data Formats & Types; Geocomputation

- CWT Ch 5, 6 **
- JR Ch 2-4
- Noel Gorelick et al. (2017). "Google Earth Engine: Planetary-scale geospatial analysis for everyone". *Remote Sensing of Environment* 202, pp. 18–27 **

*******Note the following weeks are being updated – readings illustrative*******

Week 3: Sep 5

Labor Day Holiday Monday, Sept. 5

Spectral Indices and Transformations; Classification Methods; Accuracy Assessment; Smoothing and Edge Detection

- JR Chapter 5.1-5.5 **
- CWT Ch 13, 15
- Pontus Olofsson et al. (2014). "Good practices for estimating area and assessing accuracy of land change". *Remote Sensing of Environment* 148, pp. 42–57 **
- A Bannari et al. (1995). "A review of vegetation indices". *Remote Sensing Reviews* 13.1-2, pp. 95–120
- Gregory P Asner, David E Knapp, et al. (2005). "Selective logging in the Brazilian Amazon". *Science* 310.5747, pp. 480–482

Week 4: Sep 12

Land Cover Change Detection and Applications: Forests and Land Cover Change

- CWT Ch 21 *
- JR Ch 8, 9 (can skim), 11
- Zhe Zhu and Curtis E Woodcock (2014). "Continuous change detection and classification of land cover using all available Landsat data". *Remote Sensing of Environment* 144, pp. 152–171 **
- Matthew C Hansen et al. (2013). "High-resolution global maps of 21st-century forest cover change". *Science* 342.6160, pp. 850–853 **
- Seema Jayachandran et al. (2017). "Cash for carbon: A randomized trial of payments for ecosystem services to reduce deforestation". *Science* 357.6348, pp. 267–273
- Christian Baehr, Ariel BenYishay, and Bradley Parks (2021). "Linking Local Infrastructure Development and Deforestation: Evidence from Satellite and Administrative Data". *Journal of the Association of Environmental and Resource Economists* 8.2, pp. 375–409

Week 5: Sep 19

Nonclassical Measurement Error, Censoring, and Scale within the context of Land use Classification and Change Detection

- Jennifer Alix-Garcia and Daniel L Millimet (2021). *Remotely Incorrect? Accounting for Nonclassical Measurement in Satellite Data on Deforestation*. Working Paper. **
- Robert Heilmayr & Alberto Garcia (2021) "Conservation impact evaluation using remotely sensed data." Working Paper **
- Marcelo Gantier and Mina Karasalo (Nov. 2020). *Remote Sensing for Impact Evaluation: Reflections on a Workshop*. <https://cas.cgiar.org/spia/news/remote-sensing-impact-evaluation-reflections-workshop>. (Short Blog Post Summarizing Workshop, with link to recording of 3.5 hour workshop) **
- Robert Heilmayr et al. (2020). "Brazil's Amazon Soy Moratorium reduced deforestation". *Nature Food* 1.12, pp. 801–810
- Peter Richards et al. (2017). "Are Brazil's deforesters avoiding detection?" *Conservation letters* 10.4, pp. 470–476
- Meha Jain (2020). "The benefits and pitfalls of using satellite data for causal inference". *Review of Environmental Economics and Policy* 14.1, pp. 157–169
- Leopoldo Fergusson, Santiago Saavedra, and Juan F Vargas (2020). "The perils of misusing remote sensing data: The case of forest cover". *Documento CEDE* 15
- Andre Fernandes Tomon Avelino, Kathy Baylis, and Jordi Honey-Rosés (2016). "Goldilocks and the raster grid: selecting scale when evaluating conservation programs". *PloS one* 11.12, e0167945
- Eric F Lambin (1999). "Monitoring forest degradation in tropical regions by remote sensing: some methodological issues". *Global Ecology and Biogeography* 8.3-4, pp. 191–198

Week 6: Sep 26

Time Series Analysis and crop phenology, with applications to agriculture

- CWT Ch 17
- Marie Weiss, Frédéric Jacob, and G Duveiller (2020). "Remote sensing for agricultural applications: A meta-review". *Remote Sensing of Environment* 236, p. 111402 **
- David B Lobell, George Azzari, et al. (2020). "Eyes in the Sky, Boots on the Ground: Assessing Satellite-and Ground-Based Approaches to Crop Yield Measurement and Analysis". *American Journal of Agricultural Economics* 102.1, pp. 202–219 **
- David B Lobell, Stefania Di Tommaso, et al. (2020). "Sight for sorghums: Comparisons of satellite-and ground-based sorghum yield estimates in mali". *Remote Sensing* 12.1, p. 100
- Meha Jain et al. (2019). "The impact of agricultural interventions can be doubled by using satellite data". *Nature Sustainability* 2.10, pp. 931–934
- Eric Strobl and Robert O Strobl (2011). "The distributional impact of large dams: Evidence from cropland productivity in Africa". *Journal of Development Economics* 96.2, pp. 432–450 – *Note: incorporates satellite derived measures of ag. productivity into econometric framework to estimate impacts of dams on agriculture*
- Alyssa K Whitcraft, Eric F Vermote, et al. (2015). "Cloud cover throughout the agricultural growing season: Impacts on passive optical earth observations". *Remote Sensing of Environment* 156, pp. 438–447
- Alyssa K Whitcraft, Inbal Becker-Reshef, and Christopher O Justice (2015). "A framework for defining spatially explicit earth observation requirements for a global agricultural monitoring initiative (GEOGLAM)". *Remote Sensing* 7.2, pp. 1461–1481

Week 7: Oct 3

Fall Break Holiday: Friday, October 7

Weather Data, with an emphasis on uses and misuses of (interpolated) and gridded data on temperature, precipitation, and soil moisture for agricultural applications (e.g., Growing/Killing Degree Days)

- Maximilian Auffhammer et al. (2013). “Using weather data and climate model output in economic analyses of climate change”. *Review of Environmental Economics and Policy* 7.2, pp. 181–198 **
- Chris Funk et al. (2015). “The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes”. *Scientific Data* 2.1, pp. 1–21 **
- Amir AghaKouchak et al. (2015). “Remote sensing of drought: Progress, challenges and opportunities”. *Reviews of Geophysics* 53.2, pp. 452–480 **
- Zhiyun Li and Ariel Ortiz-Bobea (2022). *On the Timing of Relevant Weather Conditions in Agriculture*. Tech. rep. **
- Morgan C Levy et al. (2019). “Spatiotemporal error in rainfall data: consequences for epidemiologic analysis of waterborne diseases”. *American journal of epidemiology* 188.5, pp. 950–959
- Jillian M Deines et al. (2019). “Mapping three decades of annual irrigation across the US High Plains Aquifer using Landsat and Google Earth Engine”. *Remote Sensing of Environment* 233, p. 111400
- Wolfram Schlenker and Michael J Roberts (2009). “Nonlinear temperature effects indicate severe damages to US crop yields under climate change”. *Proceedings of the National Academy of sciences* 106.37, pp. 15594–15598 Note: Appendix covers best practices in use of weather data into econometrics, though many also covered and incorporated in the Auffhammer et al. (2013) paper
- Mauro Di Luzio et al. (2008). “Constructing retrospective gridded daily precipitation and temperature datasets for the conterminous United States”. *Journal of Applied Meteorology and Climatology* 47.2, pp. 475–497 – Methods discussed in previous paper. Data of daily minimum and maximum temperature as well as total precipitation on a 2.5x2.5 mile grid for the contiguous United States linked here: <https://prism.oregonstate.edu/recent/>, and Shlenker’s updated version of this dataset is linked here <http://www.columbia.edu/~ws2162/links.html> <http://www.columbia.edu/~ws2162/links.html>. Schlenker’s version corrects many of the issues with stations entering and exiting the PRISM sample.

Week 8: Oct 10

Economic Development: Night Lights, Daylights

- Xi Chen and William D Nordhaus (2011). “Using luminosity data as a proxy for economic statistics”. *Proceedings of the National Academy of Sciences* 108.21, pp. 8589–8594 **
- J Vernon Henderson, Adam Storeygard, and David N Weil (2012). “Measuring economic growth from outer space”. *American economic review* 102.2, pp. 994–1028 **
- John Gibson et al. (2021). “Which night lights data should we use in economics, and where?” *Journal of Development Economics* 149, p. 102602 **
- Neal Jean et al. (2016). “Combining satellite imagery and machine learning to predict poverty”. *Science* 353.6301, pp. 790–794 **
- Daniel Ayalew Ali, Klaus Deininger, and Michael Wild (2018). “Using satellite imagery to revolutionize creation of tax maps and local revenue collection”. *World Bank Policy Research Working Paper* 8437
- Mariaflavia Harari (2020). “Cities in Bad Shape: Urban Geometry in India”. *American Economic Review* 100.8, pp. 2377–2421
- Marshall Burke et al. (2021). “Using satellite imagery to understand and promote sustainable development”. *Science* 371.6535
- Benjamin Marx, Thomas M Stoker, and Tavneet Suri (2019). “There is no free house: Ethnic patronage in a Kenyan slum”. *American Economic Journal: Applied Economics* 11.4, pp. 36–70 Uses daytime satellite imagery to assess housing quality in Kibera
- Jessica E Steele et al. (2017). “Mapping poverty using mobile phone and satellite data”. *Journal of The Royal Society Interface* 14.127, p. 20160690
- Christopher Yeh et al. (2020). “Using publicly available satellite imagery and deep learning to understand economic well-being in Africa”. *Nature Communications* 11.1, pp. 1–11
- Ran Goldblatt, Kilian Heilmann, and Yonatan Vaizman (2020). “Can medium-resolution satellite imagery measure economic activity at small geographies? Evidence from Landsat in Vietnam”. *The World Bank Economic Review* 34.3, pp. 635–653

- Lukas Kondmann and Xiao Xiang Zhu (2021). “Under the Radar—Auditing Fairness in ML for Humanitarian Mapping”. *arXiv preprint arXiv:2108.02137 – A review of some of the daytime poverty prediction lit.*

Week 9: Oct 17

Aerosol optical depth and its uses for varying kinds of smog, haze, desert dust

- Bryan N Duncan et al. (2014). “Satellite data of atmospheric pollution for US air quality applications: Examples of applications, summary of data end-user resources, answers to FAQs, and common mistakes to avoid”. *Atmospheric environment* 94, pp. 647–662 **
- Meredith Fowlie, Edward Rubin, and Reed Walker (2019). “Bringing satellite-based air quality estimates down to earth”. *AEA Papers and Proceedings*. Vol. 109, pp. 283–88 **
- Daniel M Sullivan and Alan Krupnick (2019). “Using satellite data to fill the gaps in the US air pollution monitoring network”. *Resources for the Future Working Paper*. **
- Roland Stirnberg, Jan Cermak, and Hendrik Andersen (2018). “An analysis of factors influencing the relationship between satellite-derived aod and ground-level PM10”. *Environment international* 9, p. 1353
- Hai Zhang and Shobha Kondragunta (2021). “Daily and hourly surface PM2. 5 estimation from satellite AOD”. *Earth and Space Science* 8.3, e2020EA001599
- Qian Di et al. (2019). “An ensemble-based model of PM2. 5 concentration across the contiguous United States with high spatiotemporal resolution”. *Environment International* 130, p. 104909
- Colleen E Reid et al. (2021). “Daily PM 2.5 concentration estimates by county, ZIP code, and census tract in 11 western states 2008–2018”. *Scientific data* 8.1, pp. 1–15 – *Similar to Di et al. (2019) but purportedly outperforms their model in the Western US, where wildfire smoke is prevalent*
- Sam Heft-Neal et al. (2020). “Dust pollution from the Sahara and African infant mortality”. *Nature Sustainability* 3.10, pp. 863–871

Week 10: Oct 24

Seeing Beyond the Visible: Thermal and IR analysis, with applications to estimating impacts of fire and air pollution

- CWT Ch 10 **
- Tianjia Liu et al. (2020). “Diagnosing spatial biases and uncertainties in global fire emissions inventories: Indonesia as regional case study”. *Remote Sensing of Environment* 237, p. 111557 **
- Leigh B Lentile et al. (2006). “Remote sensing techniques to assess active fire characteristics and post-fire effects”. *International Journal of Wildland Fire* 15.3, pp. 319–345 **
- Gregory P Asner and Ane Alencar (2010). “Drought impacts on the Amazon forest: the remote sensing perspective”. *New Phytologist* 187.3, pp. 569–578 – compares findings from field and satellite studies
- Patrick Baylis and Judson Boomhower (2019). *Moral hazard, wildfires, and the economic incidence of natural disasters*. Tech. rep. Note: *doesn't use remote sensing, but does consider spatial elements associated with estimating wildfire losses*. National Bureau of Economic Research
- Wesley A Campanharo et al. (2019). “Translating fire impacts in southwestern amazonia into economic costs”. *Remote Sensing* 11.7, p. 764
- M Sowden and D Blake (2021). “Using infrared geostationary remote sensing to determine particulate matter ground-level composition and concentration”. *Air Quality, Atmosphere & Health*, pp. 1–10

Week 11: October 31

Seeing Beyond the Visible: an introduction to the uses of Gravimetric Modeling and Active sensing

- Byron D Tapley et al. (2004). “GRACE measurements of mass variability in the Earth system”. *Science* 305.5683, pp. 503–505 **
- Richard Bernknopf et al. (2018). “The value of remotely sensed information: The case of a GRACE-enhanced drought severity index”. *Weather, Climate, and Society* 10.1, pp. 187–203 **
- CWT Ch 8 **

- Ralph Dubayah et al. (2020). “The Global Ecosystem Dynamics Investigation: High-resolution laser ranging of the Earth’s forests and topography”. *Science of Remote Sensing* 1, p. 100002 **

Week 12: Nov 8

Active sensing data and its use in assessing (1) sea level rise (2) oil spills (3) detecting building height (4) assessing soil moisture/water depletion

- Trent W Ford and Steven M Quiring (2019). “Comparison of contemporary in situ, model, and satellite remote sensing soil moisture with a focus on drought monitoring”. *Water Resources Research* 55.2, pp. 1565–1582
- Donald W Vasco et al. (2019). “Satellite-based monitoring of groundwater depletion in California’s Central Valley”. *Scientific reports* 9.1, pp. 1–14 **
- Scott A Kulp and Benjamin H Strauss (2019). “New elevation data triple estimates of global vulnerability to sea-level rise and coastal flooding”. *Nature communications* 10.1, pp. 1–12 **
- Ben DeVries et al. (2020). “Rapid and robust monitoring of flood events using Sentinel-1 and Landsat data on the Google Earth Engine”. *Remote Sensing of Environment* 240, p. 111664
- Miroslav Kubat, Robert C Holte, and Stan Matwin (1998). “Machine learning for the detection of oil spills in satellite radar images”. *Machine learning* 30.2, pp. 195–215

Week 13: Nov 15

EO in Disaster Risk Assessment, Disease Tracking, Environmental Compliance: Opportunities & Limits.

- Elinor Benami et al. (2021). “Uniting remote sensing, crop modelling and economics for agricultural risk management”. *Nature Reviews Earth & Environment*, pp. 1–20 **
- Cassandra Handan-Nader and Daniel E Ho (2019). “Deep learning to map concentrated animal feeding operations”. *Nature Sustainability* 2.4, pp. 298–306 **
- Eric Zou (2021). “Unwatched pollution: The effect of intermittent monitoring on air quality”. *American Economic Review* 11.7, pp. 2101–26 **
- Hamsa Bastani and Joann F de Zegher (2019). *Are Bans Effective under Limited Monitoring? Evidence from High Seas Management*. Working Paper SSRN.
- Jingcheng Zhang et al. (2019). “Monitoring plant diseases and pests through remote sensing technology: A review”. *Computers and Electronics in Agriculture* 165, p. 104943
- Roberta Anniballe et al. (2018). “Earthquake damage mapping: An overall assessment of ground surveys and VHR image change detection after L’Aquila 2009 earthquake”. *Remote Sensing of Environment* 210, pp. 166–178
- Keith Cressman (2013). “Role of remote sensing in desert locust early warning”. *Journal of Applied Remote Sensing* 7.1, p. 075098
- Peiley G Lau (2021). “Essays in Monitoring and Enforcement of Environmental and Agricultural Policies”. PhD thesis. UC Berkeley – accessible at <https://escholarship.org/uc/item/5j60g25k>. Chapter 1: *Nat Gas Flaring and Misreporting*.

Thanksgiving Break: Nov 20-28

Week 14: Nov 29

Student Proposed Topics/Open Topic Week

Week 15: Dec 6

Student Presentations

Final Paper Proposals Due: Tuesday, December 13 at 6.45pm

[End of VT Final Exam slot for our course time]