

Time & Location: Tuesday/Thursday, 12:30 – 1:50 PM

Professor: Cory Cleveland **Email:** Cory.Cleveland@umontana.edu

Course Web Site: [UM Box](#)

Office hours: 9 – 9:50 AM, Tuesdays and Thursday (by appointment via Zoom)

Course Zoom Link:

<https://umontana.zoom.us/j/92725338754?pwd=eTEreFQvM25oTkJUcTlFVWsySHdTdz09>

Note: I will also be using UM Moodle.

Course Description:

When Bob Dylan asks: “How many years can a mountain exist, before it is washed to the sea?” he echoes a question that has intrigued philosophers and geologists for centuries. The atmosphere reacts with the land surface, rivers carry eroded materials to the ocean, and deposited ocean sediments ultimately become new mountains – completing just one of many biogeochemical cycles that have been operating since the beginning of time. In this course, we will explore the Earth’s major biogeochemical cycles, how they are linked, how they have been altered by human activities, and how they influence the global climate system. With that as a backdrop, we will investigate and evaluate a number of climate change solutions through a biogeochemical lens.

Learning Outcomes:

Students will analyze and compare each of the earth's major global biogeochemical cycles, evaluate the ways and extent to which each of the of them influences and interacts with the global climate system. We will critically examine a number of potential climate change mitigation strategies – solutions to the climate crisis – and assess their costs, benefits, and potential consequences. Students will demonstrate their understanding through a number of written assignments and exams, and by producing an oral presentation and leading in-class discussions and debates. At the end of the course, students will understand the potential benefits and pitfalls of currently proposed strategies for mitigating global climate change, and will be able to assess their efficacy, practicality, and potential unintended consequences of those strategies.

Course Format:

In most courses, you attend lectures, perhaps memorize lots of facts, occasionally ask a question or two, and study for a series of exams. This course will be a bit different. I will use the first part of the semester I will offer an overview of the climate system and the major biogeochemical cycles, focusing on how they interact. This will set the stage for the remaining 1/3 of the class where each of you will take a much more active role: leading and participating in discussions, making presentations, and helping each other work through, evaluate and learn about a complex but critically important topic. The goal of these classes is to promote thoughtful reasoning, critical evaluation of "fact" from “hype,” and to help you develop skills that will serve you well in the “real world” - no matter what profession you choose. To that end, in this class you will be expected to *think*, and to do so in a critical way.

Each student will be expected to do some independent research, to do some writing, lead an independent project and presentation, and be active participants in the class. Ultimately, the goal is to have fun digging into a set topics that are relevant to all of us, and to work as a group to achieve a better understanding that will allow you, as educated citizens, to make more informed decisions about the

science of climate change, and some of the potential solutions.

How Will it Work?

As a class, we will explore how the major biogeochemical cycles operate, how they influence climate, and how they underlie some of the potential solutions to this important problem. During the spring of 2021, the course will be delivered virtually. There will be synchronous course meetings, and I will expect everyone to join the synchronous sections as often as possible. The course will play out in three general ways:

First, there will be a series of lecture/discussion days led by me in which the major biogeochemical cycles and their major climate interactions are presented and discussed. These lectures will be augmented by reading from the text and from a number of important recent scientific papers, videos, recorded lectures by other experts, or other sources.

Second, you will spend a few weeks researching an array of climate change solutions, with each of you ultimately presenting an overview of the science behind the solution you choose. This research will culminate in a series of group presentations at the end of the semester and a final paper.

Third, you will use the information you gather to prepare written Congressional Testimony statements about a climate change mitigation strategy. These will be modeled after the real thing, and everyone will be asked to prepare a written testimonial.

Please Note: This class will rely heavily on classroom discussion and interaction, thus we all must work to foster an environment in which all students feel comfortable sharing their opinions. You can challenge opinions and disagree, but please be respectful.

Class Responsibilities and Preparation:

This class is about active learning and critical thinking. That means everyone must do some research, present and discuss material, debate topics and articulate opinions verbally and in writing. Regular attendance and participation are critical for this to work, and thus these will be part of your formal grade (10%). They are easy points! Just show up and participate. In addition, while you will only have one day in which you are a lead presenter of some kind, everyone is expected to do research before each class, even on topics you are not leading, and come ready to participate each day.

Presentations:

Near the end of the course, there will be a series student group-led presentations and discussions. For each discussion day, leaders will decide on some combination of relevant material to direct their discussion and distribute it a week in advance (these should be approved by me ahead of time as well). On days you lead a presentation you will be expected to make a presentation on your topic and/or lead the class in discussion. Your group presentation should take up 45-60 minutes of class time – i.e., you should leave plenty of time for discussion.

Writing Assignments:

You will do a fair amount of writing in this class, but all of it will consist of fairly short assignments, hopefully in formats you find enjoyable. On days that a topic is presented (and when you are not in the lead group), you will be expected to write a short op-ed piece on this topic; see below for more information). These must include a minimum of three citations (websites, newspaper articles, journal papers, NPR stories, etc.), and must be between 500 and 750 words (that's about 1 single-spaced page). The word count does not include your list of citations you use, which can be printed after the op-ed itself. These must be printed out and handed in during class that day – email or handwritten versions

will not be accepted. I may encourage some of you to submit your pieces to the Missoulian. It's important to share good ideas with others outside of this classroom!

Prerequisites:

There are no formal prerequisites for this course, but some background in chemistry, biology and geology will certainly help. I would also argue that to be successful, you should have a basic understanding of the science of climate and climate change. This course is highly interdisciplinary and uses as a language and framework derived from multiple disciplines. *You do not need an advanced background in science to succeed in this class, but if you are uncomfortable with the basics of any of them you should probably talk to me, and be willing to work hard in the early part of the semester to keep up.*

Textbooks and Reading:

Required Texts: [Treatise on Geochemistry](#), Volume 8: Biogeochemistry (2005) William Schlesinger (Editor), Elsevier. ISBN: 978-0080446424. If you connect using a UM computer, you should be able to download all the relevant chapters as PDFs.

Bloom, A. J. (2010). Global Climate Change: Convergence of Disciplines. Sinauer Associates, Sunderland, MA. ISBN-13: 978-0878930272. This book should be widely available on-line, and I will place a copy on reserve in Mansfield Library.

We will also rely heavily on several chapters from the [IPCC \(AR5\) Report](#), published in 2013. Most of the IPCC reading is from Chapters 6 and 7 in Climate Change 2013: The Physical Science Basis: Contributions of Working Group 1 to the Fifth Assessment Report of the IPCC. However, we will also read the Summary for Policymakers sections from all three Working Groups. All can be downloaded following the link above. **Note:** The IPCC has now completed the sixth assessment (AR6), but the report is not available at this time.

Recommended Text: Blockstein D.E. and Wiegman L. (2010). The Climate Solutions Consensus: What We Know and What to do About it. Island Press, Washington. ISBN. **ISBN-13:** 978-1597266741

This textbook material will be supplemented by readings from other sources (*e.g.*, primary literature), especially in the second half of the semester when students are making presentations. These additional readings will be available as .pdf files on the course web site. You should print them out, read them, bring them with you to class every day, and be prepared to discuss them. Periodically, I may prepare quizzes that cover the reading. All readings are available on the course Moodle site.

Grading*:

Grades will be assigned based on the following percentages:

Midterm exams (2): 50%
Climate Change Solutions Final Project Outline: 10%
Climate Change Solutions Presentation (1 per person): 15%
Climate Change Solutions Essay (1 per person): 20%
Class Attendance & Participation: 5%

**This course is offered for traditional letter grade only.*

Students with Disabilities:

The University of Montana assures equal access to instruction through collaboration between students with disabilities, instructors, and Disability Services for Students (DSS). If you think you may have a disability adversely affecting your academic performance, and you have not already registered with DSS, please contact DSS in Lommason 154 or 406.243.2243. I will work with you and DSS to provide an appropriate modification.

Course Withdrawal Deadlines:

To 15 th instructional day	Students can drop classes on CyberBear with refund & no "W" on Transcript, last day to change to Audit	February 3, @5 PM
16 th to 45 th instructional day	A class drop requires a form with instructor and advisor signature, a \$10 fee from registrar's office, student will receive a 'W' on transcript, no refund.	February 4 – March 24 @5 PM
Beginning 46 th instructional day	<i><u>Students are only allowed to drop a class under very limited and unusual circumstances.</u></i> Not doing well in the class, deciding you are concerned about how the class grade might affect your GPA, deciding you did not want to take the class after all, switching majors, and similar reasons are not among those limited and unusual circumstances. If you want to drop the class for these sorts of reasons, make sure you do so by the end of the 45 th instructional day of the semester. Requests to drop must be signed by the instructor, advisor, and Associate Dean (in that order) so if you pursue this request, leave sufficient time to schedule meetings with each of these individuals (generally this will take at least 3-5 working days). A \$10 fee applies if approved. Instructors must indicate whether the individual is Passing or Failing the class at the time of request.	March 25 – May 1 @5 PM

Basic Needs Security Statement

Any student who has difficulty affording groceries or accessing sufficient food to eat every day, or who lacks a safe and stable place to live, and believes this may affect their performance in the course, is urged to contact the [Office of Student Success] for support. Furthermore, please notify the professor if you are comfortable in doing so. This will enable her to provide any resources that she may possess.

Finally, the usual rules concerning academic honesty apply in this course:

All students must practice academic honesty. Academic misconduct is subject to an academic penalty by the course instructor and/or a disciplinary sanction by the University. All students must be familiar with the [Student Conduct Code](#). Academic misconduct includes plagiarism. Don't plagiarize someone else's work, period.

Class Schedule (subject to some change)

Mtg #	Date	Topic	Required Reading	Recommended Reading/Preparation
Part I Climate & the Global C Cycle				
1	1/12	Course Overview & Intro to the Science of Climate Change: Richard Alley	Alley (2003)	W. Schlesinger: New Perspectives on Biogeochemical Cycles
2	1/14	Intro to Climate Change	Ruddiman Ch. 2	Bloom Ch. 1
3	1/19	Intro to Climate Change and Links to Biogeochemistry	Arneeth et al. (2010)	IPCC WG1 – Summary; IPCC Intro (6.1)
4	1/21	Decoding the Weather Machine		
5	1/26	The Pre-industrial C Cycle; Symposium topics DUE	Schlesinger Ch. 8.09 (pp. 425-454); Ciais 6.2	Falkowski et al. (2000)
6	1/28	The Modern C Cycle	Friedlingstein et al. 2019; Ciais 6.3	Bloom Ch. 4
7	2/2	C Cycling in the Oceans	Schlesinger Ch. 8.05; Ciais 6.3	Falkowski et al. (1998)
8	2/4	The C Cycle on Land (part 1)	Schlesinger Ch. 8.06; Ciais 6.3	Solomon et al. (2009)
9	2/9	The C Cycle on Land (part 2)	Schlesinger Ch. 8.07 (pp.249-256; 266-268-306; Ch. 8.08 (pp. 332-348)	Heimann & Reichstein (2008)
10	2/11	Midterm Exam 1; Essay outlines due.		
Part 2				
11	2/16	CO ₂ and the Biosphere	Bloom Ch. 5	Walker et al. (2020)
12	2/18	Climate Change & The Biosphere: Fire	Bloom Ch. 6	Holden et al. (2018)
13	2/23	The Hydrologic Cycle	Schlesinger Ch. 10; IPCC 7.1-7.2	Zhou et al. (2016)
14	2/25	The N Cycle	Schlesinger Ch 8.12; Schlesinger Ch. 8.08 (pp. 350-361); Ciais 6.4	Erismann et al. (2011) Suddick et al. (2013)
15	3/2	The P Cycle and S Cycles	Schlesinger Ch. 8.13 (585-593)	Wieder et al. (2015) Charlson et al. (1987)

16	3/4	Student Break – No Class		
16	3/9	Intro to Part III/Review	Projects, presentations, etc.	
17	3/11	Midterm Exam 2		
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Part 3				
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18	3/16	Student Break – No class		
18	3/18	Mitigate, Adapt, or Suffer	Anderson et al. (2019)	
19	3/23	Climate Change: The Six Americas	The Six Americas in 2020	
20	3/25	Climate Change Solutions: Overview	IPCC: WG3 Summary; Pacala & Socolow (2004)	Blockstein & Wiegman (2010)
21	3/30	Climate Change Solutions: Geoengineering	Neimeier & Tilmes (2017); Caldeira et al. 2013	David Keith: A Critical Look at Geoengineering
22	4/1	Climate Change Solutions: Natural Climate Solutions	Griscom et al. 2017	
23	4/6	Climate Change Solutions	Student Presentations	
24	4/8	Climate Change Solutions	Student Presentations	
25	4/13	Climate Change Solutions	Student Presentations	
26	4/15	Climate Change Solutions	Student Presentations	
27	4/20	Climate Change Solutions	Student Presentations	
28	4/22	Climate Change Solutions; Final papers due	Student Presentations	

Supplemental Reading: Available as PDFs for download on the course UM Box site.

Alley, R. B. (2003) Paleoclimatic insights into future climate change. Proceedings of the Royal Society of London A 361: 1831-1849.

Arneth, A. et al. (2010) Terrestrial biogeochemical feedbacks in the climate system. Nature Geoscience 3: 525-532.

Anderson, C. et al. (2019) Natural climate solutions are not enough. Science 363: 933 – 934.

Blockstein, D. E. and L. Wiegman (2010) No silver bullet, many silver wedges. Pp. 104 – 199 in, The

- Climate Solutions Concensus, Island Press, Washington.
- Blockstein, D. E. and L. Wiegman (2010) Strategies for stabilization, mitigation and adaptation. Pp. 245 – 261 in, The Climate Solutions Concensus, Island Press, Washington.
- Caldeira, K., Bala, G., & Cao, L. (2013). *The Science of Geoengineering*. Annual Review of Ecology, Evolution, and Systematics. 41: 231–258.
- Ciais, P., C. Sabine, G. Bala, L. Bopp, V. Brovkin, J. Canadell, A. Chhabra, R. DeFries, J. Galloway, M. Heimann, C. Jones, C. Le Quéré, R.B. Myneni, S. Piao and P. Thornton, 2013: Carbon and Other Biogeochemical Cycles. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Charlson, R. J., J. E. Lovelock, M. O. Andreae and S. G. Warren. (1987) Oceanic phytoplankton, atmospheric sulphur, cloud albedo and climate. *Nature* 326: 655-661.
- Erismann, J. W., J. Galloway, S. Seitzinger, A. Bleeker and K. Butterbach-Bahl. (2011) Reactive nitrogen in the environment and its effect on climate change. *Current Opinion in Environmental Sustainability* 3: 281-290.
- Falkowski, P. G.. et al. (1998) Biogeochemical controls and feedbacks on ocean primary production. *Science* 281: 200-206.
- Falkowski, P. et al. (2000) The global carbon cycle: A test of our knowledge of earth as a system. *Science* 290:291-296.
- Friedlingstein, P., Jones, M. W., Sullivan, M. O., Andrew, R. M., Hauck, J., Peters, G. P., Peters, W., Pongratz, J., Sitch, S., & Quéré, C. Le. (2019). *Global Carbon Budget 2019*. 1783–1838.
- Griscom, B. W., Adams, J., Ellis, P. W., Houghton, R. A., Lomax, G., Miteva, D. A., Schlesinger, W. H., Shoch, D., Siikamäki, J. V, Smith, P., Woodbury, P., & Zganjar, C. (2017). *Natural climate solutions*. 114(44), 11645–11650. <https://doi.org/10.1073/pnas.1710465114>.
- Heimann, M., and M. Reichstein. (2008) Terrestrial ecosystem carbon dynamics and feedbacks. *Nature* 451: 289-292.
- Holden, Z. A., Swanson, A., Luce, C. H., Jolly, W. M., Maneta, M., Oyler, J. W., Warren, D. A., Parsons, R., & Affleck, D. (2018). *Decreasing fire season precipitation increased recent western US forest wildfire activity*. 12. <https://doi.org/10.1073/pnas.1802316115>.
- IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- IPCC, 2014: Summary for Policymakers. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T.

Zwicker and J.C. Minx (eds.)). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

- Neimeier, U. and S. Tilmes. (2017) Sulfur injections for a cooler planet: Can injections of sulfur into the stratosphere help to counteract climate change? *Science* 357: 246-248.
- Pacala, S. and S. Socolow (2004) Stabilization wedges: Solving the climate problem for the next 50 years with current technologies. *Science* 305: 968-972.
- Pecl, G.T. et al. (2017) Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being. *Science* 355: DOI: 10.1126/science.aai9214.
- Robock, A. (2002) The climatic aftermath. *Science* 295:1242-1244.
- Ruddiman, W. F. (2001) *Earth's Climate: Past and Future*. Freeman and Co., New York.
- Solomon, S., G. Plattner, R. Knutt, and P. Friedlingstein. (2009) Irreversible climate change due to carbon dioxide emissions. *PNAS* 106:1704-1709.
- Suddick, E. et al. (2013) The role of nitrogen in climate change and the impacts of nitrogen-climate interactions in the United States: forward to thematic issue. *Biogeochemistry* 114: 1-10.
- Walker, A. P., Walker, A. P., Kauwe, M. G. De, Bastos, A., Belmecheri, S., Georgiou, K., Keeling, R. F., McMahon, S. M., Medlyn, B. E., Moore, D. J. P., Norby, R. J., Anderson-teixeira, K. J., Cailleret, M., Campbell, E., Canadell, J. G., Ciais, P., Craig, M. E., Ellsworth, D. S., Farquhar, G. D., ... Steve, L. (2020). *Tansley review Integrating the evidence for a terrestrial carbon sink caused by increasing atmospheric CO₂*. <https://doi.org/10.1111/nph.16866>.
- Wieder, W. R., Cleveland, C. C., Smith, W. K., & Todd-Brown, K. (2015). Future productivity and carbon storage limited by terrestrial nutrient availability. *Nature Geoscience*, 8(June). <https://doi.org/10.1038/ngeo2413>.
- Zhou, T., Northwest, P., Haddeland, I., Resources, N. W., Directorate, E., Nijssen, B., & Land-surface, E. (2016). *Human induced changes in the global water cycle* (Issue September). <https://doi.org/10.1002/9781118971772.ch4>.