Time & Location: Tuesday/Thursday, 12:30 – 1:50 PM
Meeting Location: Liberal Arts (Eck) 204
Professor: Cory Cleveland **Email:** Cory.Cleveland@umontana.edu
Course Web Site: UM Moodle
Office hours: By appointment via email

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 of 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 one of many possible climate change solutions in small groups, with each group 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 present your topic and/or lead the class in discussion. Your group presentation should take up ~30 minutes of class time, but you should leave some time for discussion. There will be two group presentations per day.

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 (AR6) Report, published in 2021. Most of the IPCC reading is from Climate Change 2021: The Physical Science Basis. However, we will also read the Summary for Policymakers sections from all three Working Groups. All can be downloaded via the link above.

Recommended Text: Blockstein D.E. and Wiegman L. (2010). The Climate Solutions Concensus: What We Know and What to do About it. Island Press, Washington. ISBN. **ISBN-13:** 978-1597266741 (available online). The relevant chapters are also in the course reading folder on Moodle.

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/save them, read them, bring them with you to class every day (as paper or electronic copies), and be prepared to discuss them. Periodically, I will prepare quizzes that cover the reading. All readings are available on the course Moodle site.

Other Resources: The second half of the course is structured around the information on the Project Drawdown website. Please bookmark this link for easy reference.

Grading:

Grades will be assigned based on the following percentages:

Midterm exams (2): 40%
In-class quizzes, participation, homework, etc.: 20%
Climate change solutions final project outline: 5%
Climate change solutions presentation (1 per group): 15%
Climate change solutions essay (1 per group): 20%
Note: There is no final exam in this course.

(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 the Office for Disability Equity. If you think you may have a disability adversely affecting your academic performance, and you have not already registered with DSS, please contact ODE in Aber Hall 116 or 406.243.4216. I will work with you and DSS to provide an appropriate modification.

Course Withdrawal Deadlines:

Please refer to the UM Registrar's Office website for course withdrawal deadlines.

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. Please read it and be familiar with its content. Academic misconduct includes plagiarism. Don't plagiarize someone else's work, period.

Preliminary Class Schedule (subject to change)

Mtg #	Date	Topic	Required Reading	Recommended Reading/Preparation
Part I		**Climate & the Global C Cycle**		
1	1/18	Course Overview & Intro to the Science of Climate Change: Richard Alley	Alley (2003)	W. Schlesinger: New Perspectives on Biogeochemical Cycles
2	1/23	Decoding the Weather Machine, Part 1	Ruddiman Ch. 2	
3	1/25	Decoding the Weather Machine, Part 1	Ruddiman Ch. 2	
4	1/30	Intro to Climate Change	Ruddiman Ch. 2	Bloom Ch. 1
5	2/1	Intro to Climate Change and Links to Biogeochemistry	Arneth et al. (2010)	IPCC 2021 WG1 – Summary for Policy Makers; IPCC 2021 WG1 Full Report (Intro 5.1)
6	2/6	The Pre-industrial C Cycle; **Symposium/Paper topics DUE**	Schlesinger Ch. 8.09 (pp. 425-454); Canadell 5.2 – 5.5	Falkowski et al. (2000)
7	2/8	The Modern C Cycle	Friedlingstein et al. 2019; Ciais 6.3	Bloom Ch. 4
8	2/13	C Cycling in the Oceans	Schlesinger Ch. 8.05; Canadell 5.2 – 5.5	Falkowski et al. (1998)
9	2/15	The C Cycle on Land (part 1)	Schlesinger Ch. 8.06; Canadell 5.2 – 5.5	Solomon et al. (2009)
10	2/20	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)
11	2/22	**Midterm Exam 1**		
Part 2		**Climate and Other Biogeochemical Cycles**		
12	2/27	CO_2 and the Biosphere	Bloom Ch. 5	Walker et al. (2020)
13	2/29	Climate Change & The Biosphere	Bloom Ch. 6; Pecl et al. (2017)	Holden et al. (2018)
14	3/5	The Hydrologic Cycle	Schlesinger Ch. 10; Douville 2021 (8.1 – 8.5)	Zhou et al. (2016)
15	3/7	The N Cycle	Schlesinger Ch 8.12; Schlesinger Ch. 8.08 (pp.	Suddick et al. (2013)

			350-361); Erisman et al. (2011)	
16	3/12	The P Cycle and S Cycles	Schlesinger Ch. 8.13 (585-593)	Wieder et al. (2015) Charlson et al. (1987) Robock (2002)
17	3/14	**Midterm Exam 2**		
18	3/19	**Spring Break**		
19	3/21	**Spring Break**		
Part 3				
20	3/26	Intro to Part III/Review	Projects, presentations, etc.	
21	3/28	Climate Change Solutions: Project Drawdown and the Drawdown Roadmap	Pacala and Socolow (2004)	
22	4/2	Natural Climate Solutions **Essay outlines due**	Griscom et al. 2017; Anderson et al. (2019)	Mitigate, Adapt, or Suffer
23	4/4	Climate Change Solutions: Can We Cool the Planet?	Pacala & Socolow (2004)	Blockstein & Wiegman (2010); IPCC: IPCC 2022 WG3 Summary for Policy Makers
24	4/9	The Science of Geoengineering Solutions	Neimeier & Tilmes (2017); Caldeira et al. 2013	David Keith: A Critical Look at Geoengineering
25	4/11	Climate Change: The Six Americas	The Six Americas in 2020	Climate Change: The Six Americas
26	4/16	Climate Change Solutions	Student Presentations	
27	4/18	Climate Change Solutions	Student Presentations	
28	4/23	Climate Change Solutions	Student Presentations	
29	4/25	Climate Change Solutions	Student Presentations	
30	4/30	Climate Change Solutions	Student Presentations	
31	5/2	Climate Change Solutions; **Final papers due**	Student Presentations	

Important Due Dates:

Symposium Topics: 2/6 **Essay Outlines: 4/2** **Final Papers: 5/2**

Supplemental Reading: Available as PDFs for download on Moodle.

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

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

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

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.

Canadell, J.G., P.M.S. Monteiro, M.H. Costa, L. Cotrim da Cunha, P.M. Cox, A.V. Eliseev, S. Henson, M. Ishii, S. Jaccard, C. Koven, A. Lohila, P.K. Patra, S. Piao, J. Rogelj, S. Syampungani, S. Zaehle, and K. Zickfeld, 2021: Global Carbon and other Biogeochemical Cycles and Feedbacks. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. P.an, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelek.i, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 673–816, doi:10.1017/9781009157896.007.

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.

Douville, H., K. Raghavan, J. Renwick, R.P. Allan, P.A. Arias, M. Barlow, R. Cerezo-Mota, A. Cherchi, T.Y. Gan, J. Gergis, D. Jiang, A. Khan, W. Pokam Mba, D. Rosenfeld, J. Tierney, and O. Zolina, 2021: Water Cycle Changes. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1055–1210, doi:10.1017/9781009157896.010.

Erisman, 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 Environmenal 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. et al. (2023). *Global Carbon Budget 2023*. 1783–1838. https://www.globalcarbonproject.org/

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. Proceedings of the National Academy of Sciences USA 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, 2021: Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 3−32, doi:10.1017/9781009157896.001.

IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp. doi:10.1017/9781009157896.

IPCC, 2022: Summary for Policymakers [P.R. Shukla, J. Skea, A. Reisinger, R. Slade, R. Fradera, M. Pathak, A. Al Khourdajie, M. Belkacemi, R. van Diemen, A. Hasija, G. Lisboa, S. Luz, J. Malley, D. McCollum, S. Some, P. Vyas, (eds.)]. In: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.001

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 CO 2. 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.

Symposium Topics

Group Number	Forests	Sector(s)	Group Members	Symposium Day & Time (TBD)
1	Temperate Forest Protection/Restoration	Land Sinks		
2	Tropical Forest Protection/ Restoration	Land Sinks		
3	Natural Forest Management	Food, Agriculture, and Land Use		
4	Improved Plantation Management, Multi-strata Agroforestry, Tree Intercropping	Food, Agriculture, and Land Use		
5	Fire Management	Food, Agriculture, and Land Use		
	Agriculture and Grasslands			
6	Biochar Production and Use	Food, Agriculture, and Land Use/Engineering		
7	Soil Nutrient Management	Food, Agriculture, and Land Use		
8	Grazing – Feed, Animal Management, Legumes, Manure Management	Food, Agriculture, and Land Use		
9	Conservation/Organic Agriculture	Food, Agriculture, and Land Use		
	Wetlands			
10	Coastal/Peat Protection/Restoration, Improved Rice	Food, Agriculture, and Land Use/Land Sinks		
	Food System			
11	Reduced Food Waste/Diet/Composting	Food, Agriculture, and Land Use		
	Geoengineering			
12	Atmospheric Solar Radiation Management (Aerosols)	Engineering		