Controversies at the interface of carbon and climate

SIO 209, Fall 2015
Tuesday 2:30-3:45pm

Organizers:

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Course Goals and Structure:

Predictions of climate change depend not only on how much fossil carbon is emitted, but also on how much of these emissions accumulate in the atmosphere as opposed to the land biosphere and ocean reservoirs. It is challenging to predict how the partitioning of fossil carbon into each reservoir will continue or change in the future and therefore how it will affect key components of the climate system (ocean deoxygenation, marine productivity etc.). This reading seminar will explore controversies in the future of natural and human carbon emissions, feedbacks and impacts. Discussion will center on: What processes, interactions, and feedbacks control the level of CO_2 in the Earth's atmosphere, what effect will these have on the climate system, and what considerations should be made to minimize adverse societal impacts?

The course will center on reading and discussing scientific literature. For each class meeting, we will discuss 2-3 short journal articles (approx. 12 pages in total) on a controversial aspect of carbon-climate interactions. The class will divide into small groups at the beginning of each meeting to discuss questions about the papers, which we will prepare ahead of time. About halfway through the session, the small groups will reorganize into one large group and report on what they discussed, allowing further discussion by the whole group. This seminar will not involve presentations of papers to the rest of the group by individual participants.

Readings and discussion questions will be posted on the web at ted.ucsd.edu. The site will be updated each Monday for that week's readings and discussion questions. If you would like to participate but not officially enroll in the class, let us know and we can give you access to the website.

Assessment:

The course is available for one credit, and will be graded Satisfactory/Unsatisfactory (S/U) only. Students are encouraged to sign up for the course even if you will be away part of the quarter for field work, conferences etc...

Week 1, Jan 10: Organizational meeting

Week 2, Jan 17: Model projections of carbon-climate feedbacks

- Do models agree on the sign and the magnitude of the climate-carbon cycle feedback? Are climatic feedbacks projected to have a stronger effect on the land or ocean CO2 sink? Which has a larger uncertainty, land or ocean, according to the models? Do you think the real effect could be outside the range predicted by models?
- The two papers mention using observed climatic and CO_2 variability on El Nino/La Nina and glacial/interglacial time periods to test the modeled climate-carbon cycle interactions. Consider the value and the limitations of this approach.
- In your opinion, what are the most important research directions that need to be pursued in carbon-climate interactions?

Friedlingstein, P., and Prentice, I. (2010), Carbon-climate feedbacks: a review of model and observation based estimates, *Current Opinion in Environmental Sustainability*, 2, 251-257.

Joos, Fortunat. (2015) "Global Warming: Growing Feedback from Ocean Carbon to Climate." Nature 522, 295–96. doi:10.1038/522295a.

Cox, Peter M., David Pearson, Ben B. Booth, Pierre Friedlingstein, Chris Huntingford, Chris D. Jones, and Catherine M. Luke. "Sensitivity of Tropical Carbon to Climate Change Constrained by Carbon Dioxide Variability." Nature 494, no. 7437 (February 21, 2013): 341–44. doi:10.1038/nature11882.

Week 3, Jan 24: Are natural CO_2 sinks already decreasing?

- Summarize the mechanism for the stalling of the ocean sink proposed by Le Quere. How strong is the evidence? If true, what is needed for the mechanism to continue?
- What are the terms in the atmospheric CO_2 budget considered by Ballantyne?
- Are you surprised that the airborne fraction has remained relatively constant since 1960? Do you think land and ocean sinks will continue to keep up with CO2 emissions?
- Weigh the evidence for both Le Quere and Ballantyne. Are they equally compelling? Could they both be right?

Ballantyne, A. et al. (2012), Increase in observed net carbon dioxide uptake by land and oceans during the past 50 years, *Nature*, 488, 70-72, doi:10.1038/459909a

~~(Optional) Law, R. M., Matear, R. J., & Francey, R. J. (2008). Comment on "Saturation of the Southern Ocean CO2 Sink Due to Recent Climate Change." *Science*, *319*(5863), 570a–570a. doi:10.1126/science.1149077~~

(Optional) Zickfeld, K., Fyfe, J. C., Eby, M., & Weaver, A. J. (2008). Comment on "Saturation of the Southern Ocean CO2 Sink Due to Recent Climate Change." *Science*, *319*(5863), 570b–570b. doi:10.1126/science.1146886

(Optional) Le Quere, C., Rodenbeck, C., Buitenhuis, E. T., Conway, T. J., Langenfelds, R., Gomez, A., et al. (2008). Response to Comments on "Saturation of the Southern Ocean CO2 Sink Due to Recent Climate Change." *Science*, *319*(5863), 570c–570c. doi:10.1126/science.1147315

Mikaloff-Fletcher, S. E. "An Increasing Carbon Sink?" Science 349, no. 6253 (September 11, 2015): 1165–1165. doi:10.1126/science.aad0912.

Landschützer, Peter, Nicolas Gruber, F. Alexander Haumann, Christian Rödenbeck, Dorothee C. E. Bakker, Steven van Heuven, Mario Hoppema, et al. "The Reinvigoration of the Southern Ocean Carbon Sink." Science 349, no. 6253 (September 11, 2015): 1221–24. doi:10.1126/science.aab2620.

Week 4, Jan 31: Climate change and marine productivity

- What is the effect of marine productivity in projections of ocean CO_2 uptake, and how does it compare to physical effects? Would you characterize the interaction of marine productivity and climate change as a strong two-way coupling/feedback, or a stronger one-way forcing of climate on productivity?
- Behrenfeld et al. show a remarkable correspondence between anomalies in temperature and chlorophyll/productivity in low and mid-latitudes. Do you think that their results show a compelling long-term trend that is indicative of the effects of global warming?
- These papers have focused on warming and stratification. What are some other potential effects of climate change on marine productivity? For example, last week we discussed potential enhancements in upwelling in the Southern Ocean, which have also been proposed for eastern boundary current upwelling systems due to strengthening coastal winds.

Broecker, W. S. (1991). Keeping global change honest. *Global Biogeochemical Cycles*, *5*(3), 191–192.

Joos, F., Plattner, G.-K., Stocker, T. F., Marchal, O., & Schmittner, A. (1999). Global warming and marine carbon cycle feedbacks on future atmospheric CO_2. *Science*, *284*, 464–467.

Doney, S. C. (2006). Plankton in a warmer world. *Nature*, *444*, 695–696. doi:10.1029/2003GB002134

Behrenfeld, M. J., O'Malley, R. T., Siegel, D. A., McClain, C. R., Sarmiento, J. L., Feldman, G. C., et al. (2006). Climate driven trends in contemporary ocean productivity. *Nature*, *444*(7120), 752–755. doi:10.1038/nature05317

(Optional) Doney, S. C., Ruckelshaus, M., Emmett Duffy, J., Barry, J. P., Chan, F., English, C. A., et al. (2012). Climate Change Impacts on Marine Ecosystems. *Annual Review of Marine Science*, *4*(1), 11–37. doi:10.1146/annurev-marine-041911-111611.

Week 5, Feb 7: Carbon bombs

- How much carbon is there in the arctic soil carbon reservoir? Is it physically vulnerable to climate change or human activity? Is there evidence that it is biochemically labile (i.e. will ancient organic matter or soil carbon be converted to CO_2 or CH_4)? What other processes may compensate to decrease the positive feedback? What features of the models need to be improved?
- What evidence is there of methane hydrate destabilization or release in the modern environment? Where did that methane go?
- Do these processes represent a tipping point in the climate-carbon system that we won't be able to come back from? How do we evaluate the risks on different time scales? If detected early enough, can anything be done to stop the feedback?

van Huissteden, J., & Dolman, A. J. (2012). Soil carbon in the Arctic and the permafrost carbon feedback. *Current Opinion in Environmental Sustainability*, *4*(5), 545–551. doi:10.1016/j.cosust.2012.09.008

Phrampus, B. J., & Hornbach, M. J. (2012). Recent changes to the Gulf Stream causing widespread gas hydrate destabilization. *Nature*, *490*(7421), 527–530. doi:10.1038/nature11528

Mienert, J. (2012). Signs of instability. *Nature Geoscience*, *490*, 491–492.

(Optional) Schuur, E. (2011), High risk of permafrost thaw, *Nature*, 480, 32–33.

(Optional) Etiope, G. (2012). Climate science: Methane uncovered. *Nature Geoscience*, *5*(6), 373–374. doi:10.1038/ngeo1483

(Optional) Kort, E. A., Wofsy, S. C., Daube, B. C., Diao, M., Elkins, J. W., Gao, R. S., et al. (2012). Atmospheric observations of Arctic Ocean methane emissions up to 82 degree north. *Nature Geoscience*, *5*(5), 318–321. doi:10.1038/ngeo1452.

Week 6: Climate change and natural variability: the warming hiatus.

Meehl, Gerald A., Julie M. Arblaster, John T. Fasullo, Aixue Hu, and Kevin E. Trenberth. "Model-Based Evidence of Deep-Ocean Heat Uptake during Surface-Temperature Hiatus Periods." Nature Climate Change 1, no. 7 (September 18, 2011): 360–64. doi:10.1038/nclimate1229.

Chen, X., and K.-K. Tung. "Varying Planetary Heat Sink Led to Global-Warming Slowdown and Acceleration." Science 345, no. 6199 (August 22, 2014): 897–903. doi:10.1126/science.1254937.

Trenberth, Kevin E., and John T. Fasullo. "Tracking Earth's Energy." Science 328, no. 5976 (April 16, 2010): 316–17. doi:10.1126/science.1187272.

Week 7, Feb 21: Warming by CO_2 and short-lived greenhouse gases

- Matthews and Caldeira show an approximately linear relationship between warming and cumulative CO_2 emissions, suggesting that warming is not sensitive to the CO_2 emissions pathway. Describe how this linear relationship comes about. Are there processes that could lead to enhanced warming or other adverse effects that might be missed by only considering cumulative CO_2 emissions?

- What are the advantages and disadvantages of reducing CO_2 emissions compared to other GHGs or aerosols?
- Do you think the near-term focus should be placed on mitigation of short-lived GHGs or on mitigation of CO_2?

Zaelke, D. J., & Ramanathan, V. (2012). Going Beyond Carbon Dioxide. *The New York Times*, published December 6, 2012.

Matthews, H. D., & Caldeira, K. (2008). Stabilizing climate requires near-zero emissions. *Geophysical Research Letters*, *35*(4), L04705. doi:10.1029/2007GL032388.? Stocker, Benjamin D., Raphael Roth, Fortunat Joos, Renato Spahni, Marco Steinacher, Soenke Zaehle, Lex Bouwman, Xu-Ri, and Iain Colin Prentice. "Multiple Greenhouse-Gas Feedbacks from the Land Biosphere under Future Climate Change Scenarios." Nature Climate Change 3, no. 7 (July 2013): 666–72. doi:10.1038/nclimate1864.

Week 8, Feb 28: Is it too late to limit warming to 2°C or less? Targets?

- According to Stocker (2013) what would be required to stabilize temperatures at 2°C? Explain the options for Global Mitigation Schemes (GMS) and how they are related to cumulative CO_2 emissions.
- What is Victor's objection to focusing on cumulative emissions? Is it purely political or does it also have scientific merit?
- In light of the various readings, what do you think makes the most sense for a target? 2°C? Cumulative emissions? Peak atmospheric CO_2 concentration?

Victor, D. (2009), Global warming: why the 2°C goal is a political delusion, *Nature*, 459, 909, doi:10.1038/459909a

Stocker, T. (2013), The closing door of climate targets, *Science*, in press, doi:10.1126/science.1232468

Monastersky. (2009). A Burden Beyond Bearing. *Nature*, 1–4.

(Optional) Meinshausen, M. et al. (2009), Greenhouse-gas emission targets for limiting global warming to 2°C, *Nature*, 458, 1158-1162, doi:10.1038/nature08017

Steinacher, Marco, Fortunat Joos, and Thomas F. Stocker. "Allowable Carbon Emissions Lowered by Multiple Climate Targets." Nature 499, no. 7457 (July 11, 2013): 197–201. doi:10.1038/nature12269.

Week 9, Mar 7: Ocean deoxygenation

- Describe the different processes acting to reduce dissolved oxygen concentrations off of Oregon. How do they relate to climate change? What are the effects on marine ecosystems?
- What are some of the challenges in detecting oxygen declines?
- How can future deoxygenation be prevented? Do you think further deoxygenation is already committed by historical GHG emissions and warming?

Deutsch, Curtis, William Berelson, Robert Thunell, Thomas Weber, Caitlin Tems, James McManus, John Crusius, et al. "Centennial Changes in North Pacific Anoxia Linked to Tropical Trade Winds." Science 345, no. 6197 (August 8, 2014): 665–68. doi:10.1126/science.1252332.

Helm, Kieran P., Nathaniel L. Bindoff, and John A. Church. "Observed Decreases in Oxygen Content of the Global Ocean" Geophysical Research Letters 38, no. 23 (December 2011): n/a – n/a. doi:10.1029/2011GL049513.

Stramma, L., G. C. Johnson, J. Sprintall, and V. Mohrholz. “Expanding Oxygen-Minimum Zones in the Tropical Oceans.” Science 320, no. 5876 (May 2, 2008): 655–58. doi:10.1126/science.1153847.

? Deutsch, C., H. Brix, T. Ito, H. Frenzel, and L. Thompson. “Climate-Forced Variability of Ocean Hypoxia.” Science 333, no. 6040 (July 15, 2011): 336–39. doi:10.1126/science.1202422.

(Optional) Keeling et al., 2010?

Week 10: Land northern carbon sink

Graven et al.

Week Climate modeling and projections ?

Other topics considered but not covered:

What is the magnitude of CO_2 fertilization?

Thompson, S. et al. (2004), Quantifying the effects of CO2-fertilized vegetation on future global climate and carbon dynamics. *Geophysical Research Letters*, 31(23), L23211. doi:10.1029/2004GL021239

Norby, R. et al. (2010), CO_2 enhancement of forest productivity constrained by limited nitrogen availability. Proceedings of the National Academy of Sciences, 107(45), 19368–19373. doi:10.1073/pnas.1006463107/-/DCSupplemental

Ridley, M., The greening of the planet, *Wall Street Journal*, 5 January 2013.

Is a high climate sensitivity probable?

Knutti, R. and Hegerl, G. (2008), The equilibrium sensitivity of the Earth's temperature to radiation changes, *Nature Geoscience*, 1, 735 - 743 doi:10.1038/ngeo337

Schmittner, A. et al. (2011), Climate Sensitivity Estimated from Temperature Reconstructions of the Last Glacial Maximum, *Science*, 334, 6061, 1385-1388, doi: 10.1126/science.1203513

What will be the effect of changes in fuel supply?

Schrag, D. (2012), Is shale gas good for climate change? *Daedalus*, 141(2), 72–80, doi:10.1162/ DAED_a_00147.

Murray, J. and D. King (2012), Climate policy: Oil's tipping point has passed, *Nature*, 481, 433–435, doi:10.1038/481433a.