MECHANISMS AND DRIVERS OF CO_2 AND CH_4 FLUX VARIABILITY ON REGIONAL TO GLOBAL SCALES

June 12, 2020, *8:30-11:15 am MDT*

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<u>Session Overview:</u> Carbon cycle processes in climate prediction models can have large uncertainties due to carbon flux variability driven by environmental changes. Terrestrial, oceanic, and anthropogenic factors all contribute to changes in atmospheric CO_2 concentration over days to decades, and understanding the integration of forcings and feedbacks across scales is key to modeling current and predicting future changes in the carbon cycle.

Session Chair: Aleya Kaushik

All times below are in Mountain Daylight Time (UTC -6).

Time	Title / Abstract	Presenter & Affiliation
08:30-08:35	**Opening Remarks**	**James Butler, NOAA GML**
08:35-08:50	**Thawing permafrost, landscape change, and consequences for northern ecosystem carbon cycling**	**Merritt Turetsky** INSTAAR, CU Boulder
08:50-09:05	**Process-based mapping of global wetland carbon isotopic signatures of methane**	**Youmi Oh** Purdue University
09:05-09:20	**Global methane budget and trend in 2010-2017: comparative and joint inversions of suborbital (ObsPack) and satellite (GOSAT) observations**	**Xiao Lu** Harvard University
09:20-09:35	**Sources of Uncertainty in Regional and Global Terrestrial CO_2 Exchange Estimates**	**Ana Bastos** Max Planck Institute for Biogeochemistry, Jena, Germany
09:35-09:45	**Break/Discussion**	
09:45-10:00	**Toward understanding biospheric gross carbon fluxes: sources and sinks of carbonyl sulfide**	**Huilin Chen** University of Groningen, Netherlands
10:00-10:15	**The near-infrared reflectance of vegetation: what canopy structure can tell us about terrestrial gross primary productivity**	**Grayson Badgley** Columbia University
10:15-10:30	**Measuring and modeling the impact of droughts on the Amazon carbon cycle**	**Wouter Peters** Wageningen University, Netherlands
10:30-10:45	**Recent changes of the Amazon Carbon Cycle**	**Emanuel Gloor** University of Leeds, UK
10:45-11:00	**Outsized contribution of the semi-arid ecosystems to interannual variability in North American ecosystems**	**Brendan Byrne** NASA Jet Propulsion Laboratory
11:00-11:15	**Wrap-up/Discussion**	

SESSION ABSTRACTS

MECHANISMS AND DRIVERS OF CO₂ AND CH₄ FLUX VARIABILITY ON REGIONAL TO GLOBAL SCALES

08:30-08:45   Merritt Turetksy, Director, INSTAAR

<u>Title</u>: **Thawing permafrost, landscape change, and consequences for northern ecosystem carbon cycling**

<u>Abstract</u>: Permafrost thaw is altering northern ecosystems and the services they provide at scales ranging from local subsidence to global climate feedbacks. In ice-rich permafrost, thermokarst initiation and spread rates are increasing with rising mean annual air temperatures, summer precipitation, changes in wildfire, and human land use. This presentation will outline empirical and modeling approaches to better understand the consequences of thermokarst on landscape change and carbon cycling. Using a combination of empirical datasets and conceptual modeling, I will explore how thermokarst development (formation, stabilization, re-accumulation of permafrost in some conditions) affects carbon storage and release of CO_2 and CH_4.

<u>Bio</u>: Merritt has more than 20 years of experience working in boreal and arctic ecosystems. Her work contributes to theoretical predictions of ecosystem structure and function, but it also applies to regulation of carbon in a global change world. She is passionate about northern ecosystems and the people who depend on them. She has provided leadership to the Permafrost Carbon Network, NASA's ABoVE campaign, and the recently formed Canadian Permafrost Network. She sits on the executive committees of several international research networks and was selected in recent years as a AAAS Leshner Science Engagement Fellow. She currently sits on the National Academies' Polar Research Board.

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08:45-09:00   Youmi Oh, Purdue University

<u>Title</u>: **Process-based mapping of global wetland carbon isotopic signatures of methane**

<u>Abstract</u>: To effectively use measurements of $\delta^{13}C$ of atmospheric CH_4 to constrain emissions of CH_4 by source sector in atmospheric transport model studies, the spatial and temporal distribution of source isotopic signatures must be known. But currently, such information on $\delta^{13}C$ of CH_4 ($\delta^{13}C$-CH_4) emitted by wetlands is limited. Observations show a latitudinal gradient in wetland $\delta^{13}C$-CH_4 source signatures with higher values in tropics and lower values in the Arctic. Here we incorporated a carbon isotope-enabled module into an extant biogeochemistry model to mechanistically simulate the spatial and temporal variability of global wetland $\delta^{13}C$-CH_4. The new model explicitly considers isotopic fractionation during methane production, oxidation, and transport processes. The model is then parameterized for low and high pH conditions of boreal, temperate, and tropical wetland ecosystems using observed data from field studies and extrapolated to global wetland ecosystems for 1984 to 2016. We estimate a flux-weighted global wetland $\delta^{13}C$-CH_4 of -60.78‰ with its seasonal and inter-annual variability. We find that the new model matches field chamber observations 35% better in terms of RMSE compared
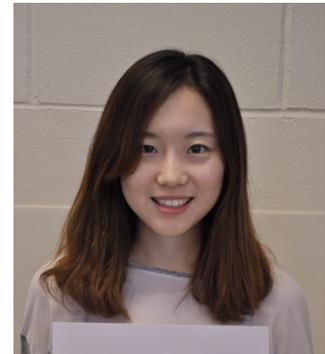
to an empirical wetland δ^{13}C-CH$_4$ map. The model also reasonably reproduces the regional heterogeneity of wetland δ^{13}C-CH$_4$ in Alaska, consistent with vertical profiles of δ^{13}C-CH$_4$ from NOAA aircraft measurements. Furthermore, we show that the latitudinal gradient of atmospheric δ^{13}C-CH$_4$ simulated by a chemical transport model using the new wetland δ^{13}C-CH$_4$ map reproduces the observed latitudinal gradient based on NOAA/INSTAAR global flask-air measurements. We believe this study is among the first to use a process-based biogeochemistry model to map the global distribution of wetland δ^{13}C-CH$_4$, which will significantly help atmospheric chemistry transport models partition global methane emissions.

Bio: Youmi studies how climate change can alter atmosphere - biosphere interactions. She uses numerical modeling and Isotope Ratio Mass Spectrometry, and do field works for my research. She is currently a Ph.D candidate in the department of Earth, Atmospheric, and Planetary Sciences at Purdue University.

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09:00-09:15   Xiao Lu, Harvard University

Title: Global methane budget and trend in 2010-2017: comparative and joint inversions of suborbital (ObsPack) and satellite (GOSAT) observations

Abstract: We use satellite (GOSAT) and suborbital (ObsPack) observations of atmospheric methane in a joint global inversion of methane sources, sinks, and trends for the 2010-2017 period. The inversion is done by analytical solution to the Bayesian optimization problem, yielding closed-form estimates of information content to assess the consistency and complementarity (or redundancy) of the satellite and suborbital datasets. We find that GOSAT and ObsPack are to a large extent complementary, with GOSAT defining the global methane budget, but ObsPack being more important for northern mid-latitudes and for relaxing global error correlations between methane emissions the methane sink (OH concentrations). Our joint GOSAT+ObsPack inversion finds that oil/gas emissions are underestimated in the US and Canada relative to the values reported by these countries to the United Nations Framework Convention on Climate Change (UNFCCC) and used here as prior estimates, while coal emissions in China are overestimated. Wetland emissions in North America are much lower than in the mean WetCHARTs inventory used as prior estimate. The correction for boreal wetlands is largest in May-June when snow may suppress emissions. Oil/gas emissions in the US increase over the 2010-2017 period but decrease in Canada and Europe. The joint GOSAT+ObsPack inversion yields the global methane emissions and loss of 539 and 515 Tg a^{-1} a^{-1} averaged over 2010-2017, and methane lifetime against OH oxidation of 11.5 years.
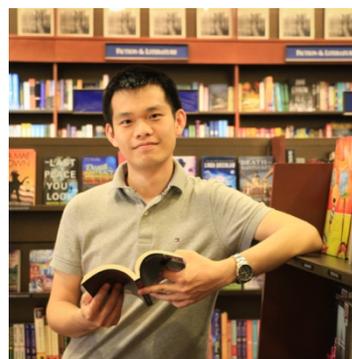
Bio: Xiao Lu is a postdoctoral research fellow in Harvard University, working with Prof. Daniel Jacob at the Atmospheric Chemistry Modeling Group. He received his Ph.D. from Peking University in 2019. His research interests mainly focus on tropospheric ozone and methane.

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09:15-09:30   Ana Bastos, Max Planck Institute for Biogeochemistry, Jena, Germany

Title: Sources of Uncertainty in Regional and Global Terrestrial CO_2 Exchange Estimates

Abstract: Global carbon budgets can be estimated as the balance between carbon sources and sinks. These terms are normally calculated from a combination of observations, observation-based and modelled datasets, and lead to a "budget imbalance," that results from uncertainties in the different components. To address this problem, I will show results from a recent study analyzing the mismatch between "top-down" (atmospheric inversions) and "bottom-up" estimates (models) of land carbon fluxes. The study is motivated by the following questions:
i) which regions contribute the most to uncertainty in the global land carbon sink?
ii) can we identify key processes explaining the mismatch between different datasets?
iii) what improvements/future developments are needed to reduce uncertainty in the global land sink?

Bio: Ana obtained her PhD in Geophysical and Geoinformation Science by the University of Lisbon, PT, in 2015, in which she studied the links between atmospheric and ocean variability and anomalies in the terrestrial carbon cycle, combining satellite-, measurement- and model-based estimates of terrestrial CO_2 fluxes and ecosystem productivity. As a Post-Doc at the Laboratoire des Sciences du Climat et de l'Environnement (2015-2018) and a Scientific Researcher at the Geography Department of the Ludwig-Maximilians University in Munich (2018-2020), she studied the gap in the CO_2 budget estimates during the 20th century and contribution of inter-annual to decadal variability in climate and changes in land-use to the uncertainty in the terrestrial global CO_2 budget. Recently, she moved to the Max-Planck Institute for Biogeochemistry Jena where she is starting a group focusing on the impacts of climate variability and natural disturbances on terrestrial ecosystems. She is currently part of the Steering Committee of the "REgional Carbon Cycle Assessment and Processes (RECCAP-2) promoted by the Global Carbon Project.

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09:45-10:00   Huilin Chen, University of Groningen, Netherlands

Title: Toward understanding biospheric gross carbon fluxes: sources and sinks of carbonyl sulfide

Abstract: Carbonyl sulfide (COS or OCS) may be a useful tracer for estimating gross primary production (GPP), because it provides an opportunity to partition net ecosystem exchange of the land biosphere into GPP and respiration fluxes. However, the ability of using COS to constrain GPP is limited by our understanding of the sources and sinks of COS. I will present our recently observation-based COS fluxes in a boreal forest in Finland and in an urban area in the Netherlands. At the boreal forest site (Hyytiala), we found that the nighttime COS uptake was 21% of the total daily COS uptake during the late growing season, and the leaf relative update ratio (LRU) of COS/CO2 varies with light due to the differential light responses of COS and CO2 uptake, and with vapor pressure deficit (VPD) in the peak growing season, indicating a humidity-induced stomatal control. Furthermore, the COS sources that are inferred from COS concentration measurements from the Groningen urban area will also be shown. To this end, GPP estimates will be significantly affected if the different environmental responses of COS and CO2 uptake and possible sources of COS are not taken into account.

Bio: Dr. Huilin Chen is an associate professor at the centre for isotope research of the University of Groningen in the Netherlands. His research interest is in atmospheric greenhouse gases and related tracers, and more specifically in using innovative tracers and measurement techniques to advance our understanding of the sources and the sinks of greenhouse gases and help mitigating greenhouse gas emissions. He received his PhD at the Max Planck Institute for Biogeochemistry in Jena, Germany in 2010. Following a two year NRC postdoc at NOAA GMD, he started a tenure-track position in the Netherlands in 2013, and became an associate professor in 2018.

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10:00-10:15   Grayson Badgley, Black Rock Forest Consortium, Lamont-Doherty Earth Observatory, Columbia University

Title: The near-infrared reflectance of vegetation: what canopy structure can tell us about terrestrial gross primary productivity

Abstract: Quantifying photosynthesis at the global scale is a long-standing goal of ecology, with implications for our understanding of global change, biodiversity, and agriculture. While the biochemistry of photosynthesis at the leaf-level is well characterized, canopy and regional estimates of gross primary production (GPP) remain highly uncertain. I will share ongoing work to infer GPP at these scales using tower- and satellite-based measurements of the near-infrared reflectance of vegetation (NIRv). I will discuss how NIRv relates to canopy structure and demonstrate that NIRv provides a tight constraint on the amount of sunlight captured by plants. I will also touch on how NIRv might be integrated into terrestrial ecosystem models both to parameterize canopy biochemical variables and to explore the theoretical relationship between canopy structure and whole-plant photosynthetic capacity.

Bio: Grayson is a plant physiologist studying photosynthesis at the global scale. His research combines ecological theory, plant ecophysiology, and remote sensing to understand how plants allocate limited resources and what these decisions tell us about plant function. A native Idahoan, Grayson received his PhD from Stanford in 2019 (working with Joe Berry and Chris Field) and is currently a postdoctoral researcher at the Black Rock Forest Consortium in Cornwall, NY.

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10:15-10:30   Wouter Peters, Wageningen University, Netherlands

Title: Measuring and modeling the impact of droughts on the Amazon carbon cycle

Abstract: The Amazon basin is warming rapidly and has suffered a number of major droughts in the past two decades. This caused ecohydrological changes in the rainforests as well as in the adjacent Cerrado regions, typically leading to increased carbon release from deforestation and agricultural fires. In addition, carbon uptake by vegetation is reduced as plants experience heat stress, and moisture stress in the canopy and in the soil. Major questions remain on how large the impacts are, which processes contribute and in which synchronicity, and also whether the reported drought impacts are temporary, or part of larger ecological shifts in the basin. To help answer some of the open questions, we perform stable isotope measurements on the aircraft samples collected by INPE that are measured on

MAGICC, since 2016. We measure ratios of $\delta^{13}C$, $\delta^{18}O$, and uniquely also $\Delta^{17}O$ in CO_2 from this network, aiming to trace gross primary production and changes in water-use efficiency across the basin. In this presentation, we will show some of the data gathered over the past years, and use two recent drought events to illustrate our current capacity to capture drought impacts also using numerical models. We report on a newly detected drought that occurred in the dry season of 2016, as a legacy effect of the 2015/2016 El Nino drought in the basin. The dry season event occurred without anomalous atmospheric forcing, proceeded without excessive biomass burning, but manifested itself as reduced in gross- and net carbon uptake by vegetation, sparking a number of questions about longer-term impacts of more frequent drought events in the Amazon.

Bio: Wouter works at Wageningen University in the Netherlands where he leads a group on numerical modeling of the carbon cycle in the atmosphere and biosphere. Following his initial contributions to the design and first prototype of NOAA's CarbonTracker data assimilation system, he continued his research in Europe where he extended CarbonTracker to also include isotope ratios, Lagrangian transport models, fossil fuel models, and combustion tracers. To broaden his agenda beyond numerical modeling, he also became affiliated with the Centre for Isotope Research at the University of Groningen in 2012, where he conducts the experimental work on isotope ratios that is part of his Amazon project, funded by a 5-year European Research Commission grant.

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10:30-10:45   Emanuel Gloor, University of Leeds, UK

Title: Recent changes of the Amazon Carbon Cycle

Abstract: Amazonia hosts the largest tropical forests, large parts of it are seasonally flooded and because it is a major air upwelling region it is an important component of the global hydrological cycle. Changes to its forests may therefore influence future levels of atmospheric CO_2 and CH_4 as well as tropical atmospheric circulation. An indicator of these large-scale roles is the strong influence of year to year variation of carbon exchange between Amazonia on global atmospheric CO_2 variation. Development of Amazonia has led to substantial destruction of these forests. These developments have decreased from approximately 2006 onwards but have recently increased again. One effect is a substantially more rapid increase in temperatures in the Southern part of tropical South America. Amazonian old-growth forests have also been a slight buffer to warming as these forests have gained carbon until recently, possibly in response to a CO_2 growth stimulus. I will give a brief overview of the Amazon carbon cycle and its recent changes and sensitivity to climate change based on remote sensing, forest inventories, tree ring studies and atmospheric greenhouse gas data.

Bio: Emanuel studied physics at ETH Zurich, Switzerland followed by a PhD in Environmental Sciences at EAWAG, Zurich. After that he was a Post Doc at Princeton University with Jorge Sarmiento and Stephen Pacala, followed by a Post at Max-Planck Institute Jena. Since 2005 he is at University of Leeds, UK where he teaches and does research as a Professor. His research interests are the global carbon cycle and biogeochemical cycles related to it. Over recent years he has been strongly involved in the greenhouse gas sampling program of the Amazon led by Luciana Gatti, INPE Sao Jose dos Campos as well as forest monitoring programs which aim to understand the sensitivity of the tropical South American Carbon Cycle to ongoing changes.

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10:45-11:00   Brendan Byrne, NASA Jet Propulsion Laboratory

Title: Outsized contribution of the semi-arid ecosystems to interannual variability in North American ecosystems

Abstract: Across North America, interannual variability (IAV) in gross primary production (GPP) and net ecosystem exchange (NEE), and their relationship with environmental drivers, are poorly understood. Here, we examine IAV in GPP and NEE and their relationship to environmental drivers using two state-of-the-science flux products: NEE constrained by surface and space-based atmospheric CO_2 measurements over 2010-2015 and satellite up-scaled GPP from FluxSat over 2001-2017. We show that the arid western half of North America provides a larger contribution to IAV in GPP (104% of east) and NEE (127% of east) than the eastern half, in spite of smaller magnitude of annual mean GPP and NEE. This occurs because anomalies in western North America are temporally coherent across the growing season leading to an amplification of GPP and NEE. In contrast, IAV in GPP and NEE over eastern North America are dominated by seasonal compensation effects, associated with opposite responses to temperature anomalies in spring and summer.

Bio: Brendan Byrne is a NASA Postdoctoral Program Fellow in the Carbon Cycle & Ecosystems Group at JPL. He received his Ph.D. in atmospheric physics from the University of Toronto. His research focuses on using measurements of atmospheric CO_2 to infer fluxes of CO_2 between the biosphere and atmosphere.

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