MARine Ecosystem Model Intercomparison Project (MAREMIP)

Scott Doney[1], *Takafumi Hirata[2]

1.Woods Hole Oceanographic Institution, 2.Faculty of Environmental Earth Science, Hokkaido University

Ocean biogeochemistry is strongly influenced by the specific activity of various types of plankton. In an effort to improve the representation of marine ecosystems, ocean biogeochemistry models have evolved to include a growing number of organisms aggregated according to their functionality into "Plankton Functional Types" (PFTs). Such models open up new and exciting avenues of research to explore interactions between marine ecosystems and climate change on various time scales. The "MARine Ecosystem Model Intercomparison Project" (MAREMIP) aims to foster the development of models based on PFTs in order to progress towards the resolution of important scientific questions; what are the impacts of global environmental changes on marine ecosystems, including climate change, ocean acidification and changes in nutrient input? Are there possible regime shifts associated with future environmental changes? What is the role of ecosystem structure and biodiversity for biogeochemical fluxes, marine resources and climate? In this talk, we show an overview of the MAREMIP activities and science highlights.

Keywords: Marine Ecosystem, Ecosystem Model, Intercomparison

Emergence of multiple ocean ecosystem drivers in a large ensemble suite with an Earth system model

*Keith B Rodgers[1], Jonathan Lin[2], Thomas Frölicher[3]

1.AOS Program, Princeton University, Princeton, USA, 2.Princeton University, Princeton, USA, 3.ETH, Zurich, Switzerland

Marine ecosystems are increasingly stressed by human-induced changes. Marine ecosystem drivers that contribute to stressing ecosystems –including warming, acidification, deoxygenation, and perturbations to biological productivity –can co-occur in space an time, but detecting their trends is complicated by the presence of noise associated with natural variability in the climate system. Here we use large initial-condition ensemble simulations with an Earth system model under a historical/RCP8.5 (representative concentration pathway 8.5) scenario over 1950-2100 to consider emergence characteristics for the four individual and combined drivers. Using a 1-standard-deviation (67% confidence) threshold of signal to noise to define emergence with a 30-year trend window, we show that ocean acidification emerges much earlier than other drivers, namely during the 20th century over most of the global ocean. For biological productivity, the anthropogenic signal does not emerge from the noise over most of the global ocean before the end of the 21st century. The early emergence pattern for sea surface temperature in low latitudes is reversed from that of subsurface oxygen inventories, where emergence occurs earlier in the Southern Ocean. For the combined multiple-driver field, 41% of the global ocean exhibits emergence for the 2005-2014 period, and 63% for the 2075-2084 period. The combined multiple-driver field reveals emergence patterns by the end of this century that are relatively high over much of the Southern Ocean, North Pacific, and Atlantic, but relatively low over the tropics and the South Pacific. For the case of two drivers, the tropics including habitats of coral reefs emerges earliest, with this driven by the joint effects of acidification and warming. It is precisely in the regions with pronounced emergence characteristics where marine ecosystems may be expected to be pushed outside of their comfort zone determined by the degree of natural background variability to which they are adapted. The results underscore the importance of sustained multi-decadal observing systems for monitoring multiple ecosystem drivers.

Keywords: Ocean biogeochemistry, Earth system modeling, Large ensemble

Ocean carbon pumps in CMIP5 earth system models diagnosed by a vector diagram

*Akira Oka[1]

1.Atmosphere and Ocean Research Institute, The University of Tokyo

The ocean stores 60 times more carbon than the atmosphere and therefore the ocean carbon cycle has a critical role in controlling the atmospheric CO2 concentration. The ocean carbon cycle is controlled by several ocean pumps such as soft tissue (organic matter) and hard tissue (calcium carbonate) pumps. In the CMIP5 earth system models, these carbon pumps are explicitly simulated in the model and controls the level of the atmospheric CO2 concentration. In this study, four types of ocean carbon pumps (organic matter, calcium carbonate, gas exchange, and freshwater flux pumps) are defined here and a method for diagnosing effects of individual four carbon pumps on atmospheric CO2 concentration is proposed. In my method, the simulated 3-D field of dissolved carbon concentration (DIC), total alkalinity (ALK), phosphate, and salinity are used for diagnosing the strength of each carbon pump. In addition, the contributions of four carbon pump components to atmospheric CO2 are evaluated in one figure (the vector diagram); each carbon pump component is represented by one vector and its contribution to pCO2 can be measured from the difference in the contour values between the beginning and the end of the vector. The analysis is applied to the climatology and the CMIP5 earth system model simulations. Although all models reproduce the same level of the atmospheric CO2 concentration as the climatology, it is shown that contributions from four carbon pumps are not the same among models. This study demonstrates that the vector diagram analysis introduced here is a useful tool for quantifying the individual effects of the ocean carbon pumps on atmospheric CO2 concentration and also for evaluating the reproducibility of ocean carbon cycle models.

Keywords: carbon cycle, ocean carbon pump

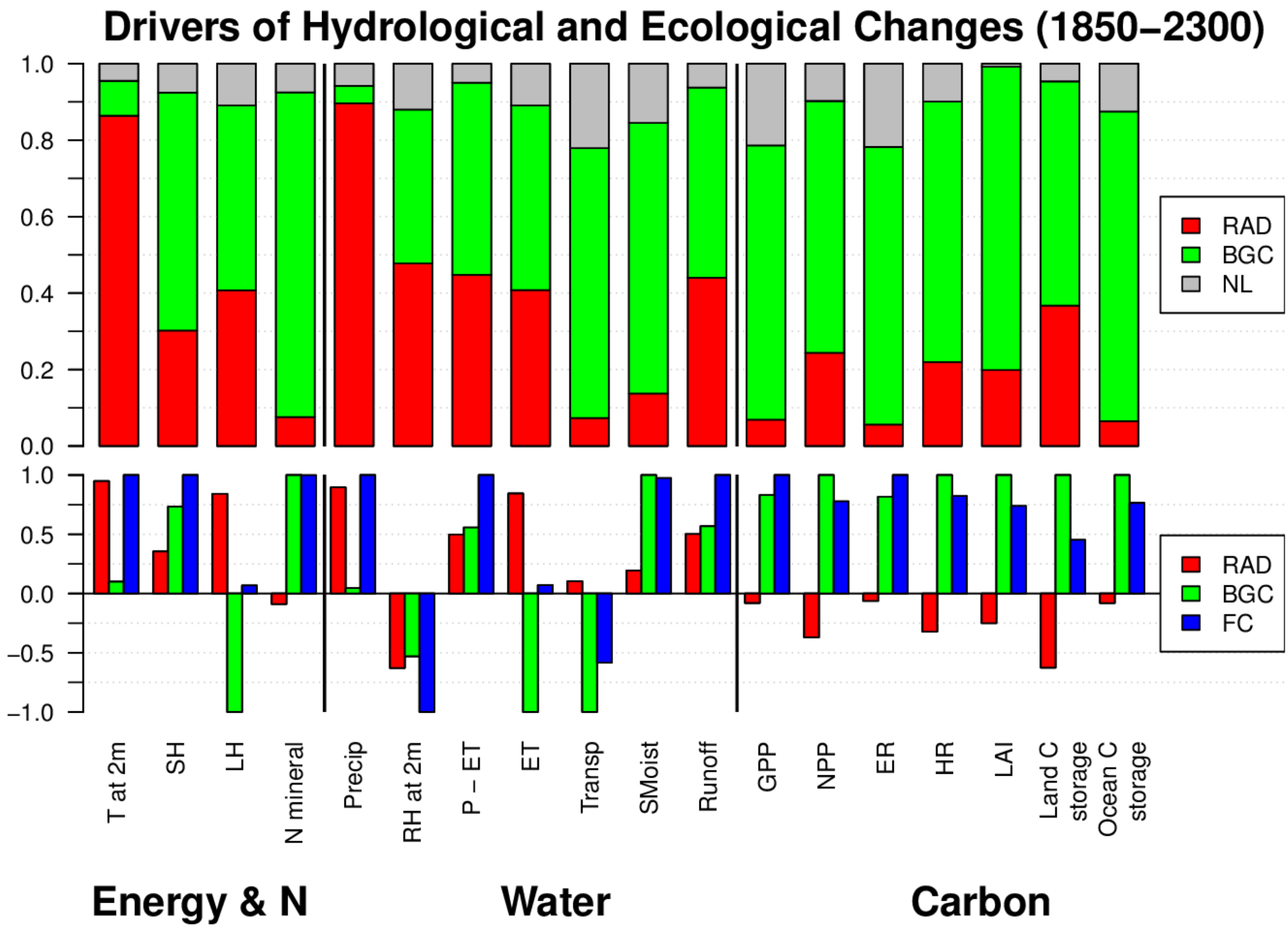
Nonlinear Interactions between Climate and Atmospheric Carbon Dioxide Drivers of Terrestrial and Marine Carbon Cycle Changes from 1850 to 2300

*Forrest M Hoffman[1], James Randerson[2], J Keith Moore[2], Michael L Goulden[2], Weiwei Fu[2], Charles D Koven[3], Abigail LS Swann[4], Natalie M Mahowald[5], Keith Lindsay[6], Ernesto Munoz[6], Gordon B Bonan[6]

1.Oak Ridge National Laboratory, 2.University of California Irvine, 3.Lawrence Berkeley National Laboratory, 4.University of Washington, 5.Cornell University, 6.National Center for Atmospheric Research

Quantifying feedbacks between the global carbon cycle and Earth's climate system is important for predicting future atmospheric CO_2 levels and informing carbon management and energy policies. We applied a feedback analysis framework to three sets of Historical (1850-2005), Representative Concentration Pathway 8.5 (2006-2100), and its extension (2101-2300) simulations from the Community Earth System Model version 1.0 (CESM1(BGC)) to quantify drivers of terrestrial and ocean responses of carbon uptake. In the biogeochemically coupled simulation (BGC), the effects of CO_2 fertilization and nitrogen deposition influenced marine and terrestrial carbon cycling. In the radiatively coupled simulation (RAD), the effects of rising temperature and circulation changes due to radiative forcing from CO_2, other greenhouse gases, and aerosols were the sole drivers of carbon cycle changes. In the third, fully coupled simulation (FC), both the biogeochemical and radiative coupling effects acted simultaneously. We found that climate-carbon sensitivities derived from RAD simulations produced a net ocean carbon storage climate sensitivity that was weaker and a net land carbon storage climate sensitivity that was stronger than those diagnosed from the FC and BGC simulations. For the ocean, this nonlinearity was associated with warming-induced weakening of ocean circulation and mixing that limited exchange of dissolved inorganic carbon between surface and deeper water masses. For the land, this nonlinearity was associated with strong gains in gross primary production in the FC simulation, driven by enhancements in the hydrological cycle and increased nutrient availability. We developed and applied a nonlinearity metric to rank model responses and driver variables. The climate-carbon cycle feedback gain at 2300 was 42% higher when estimated from climate-carbon sensitivities derived from the difference between FC and BGC than when derived from RAD. These differences are important to quantify and understand because different model intercomparison efforts have used different approaches to compute feedbacks, complicating intercomparison of ESMs over time. Underestimating the climate-carbon cycle feedback gain would result in allowable emissions estimates that would be too low to meet climate change targets. We further explored the degree to which these nonlinearities affect climate-carbon cycle feedback gain estimates in CMIP5 models at year 2100.

Keywords: carbon cycle, feedbacks, Earth system model


Drivers of Hydrological and Ecological Changes (1850–2300)
1.0
0.8
0.6
0.4
0.2
0.0
RAD
BGC
NL
1.0
0.5
0.0
–0.5
–1.0
RAD
BGC
FC
T at 2m
SH
LH
N mineral
Precip
RH at 2m
P – ET
ET
Transp
SMoist
Runoff
GPP
NPP
ER
HR
LAI
Land C storage
Ocean C storage
Energy & N
Water
Carbon

Can we bet on negative emissions to achieve the 2°C target even under strong carbon cycle feedbacks?

*Katsumasa Tanaka[1], Yoshiki Yamagata[1], Tokuta Yokohata[1], Seita Emori[1], Tatsuya Hanaoka[1]

1.National Institute for Environmetal Studies

Abstract
Given the narrowing windows of opportunities to stay below 2°C, negative emission technologies such as Bioenergy with Carbon dioxide Capture and Storage (BioCCS) play an ever more crucial role in meeting the 2°C stabilization target (Fuss et al. 2014). Negative emission technologies –if deployable at a sufficiently large scale during the second half of this century –would make the 2°C target more feasible in the midst of the slow political progress. However, such technologies are currently at their infancy and their future penetrations may fall short of the scale required to stabilize the warming (Scott et al. 2013). Furthermore, the overshoot in the mid-century prior to a full realization of negative emissions would give rise to a risk because such a temporal but excessive warming above 2°C might amplify itself by strengthening climate-carbon cycle feedbacks, which are known to be positive albeit with large uncertainties (Friedlingstein et al. 2006). When one considers other classes of carbon cycle feedbacks including those with permafrost thawing and wildfire, such a risk could be even higher. It has not been extensively assessed yet how carbon cycle feedbacks might play out during the overshoot in the context of negative emissions, while the literature on carbon cycle feedbacks has burgeoned in recent years.
This study explores how 2°C stabilization pathways, in particular those which undergo overshoot, can be influenced by carbon cycle feedbacks and asks their climatic and economic consequences. We compute 2°C stabilization emissions scenarios under a cost-effectiveness principle, in which the total abatement costs are minimized such that the global warming is capped at 2°C. We employ a reduced-complexity model, the Aggregated Carbon Cycle, Atmospheric Chemistry, and Climate model (ACC2) (Tanaka et al., 2013), which comprises a box model of the global carbon cycle, simple parameterizations of the atmospheric chemistry, and a land-ocean energy balance model. The total abatement costs are estimated from the Marginal Abatement Cost functions for CO_2, CH_4, N_2O, and BC, which are derived from Azar (2013).
Our preliminary results show that, if carbon cycle feedbacks turn out to be stronger than what is known today, it would incur substantial abatement costs to keep up with the 2°C stabilization goal. Our results also suggest that it would be less expensive in the long run to plan for a 2°C stabilization pathway by considering strong carbon cycle feedbacks because it would cost more if we correct the emission pathway in the mid-century to adjust for unexpectedly large carbon cycle feedbacks during overshoot. Furthermore, our tentative results point to a key policy message: *do not rely on negative emissions to achieve the 2°C target*. It would make more sense to gear climate mitigation actions toward the stabilization target without betting on negative emissions because negative emissions might create large overshoot in case of strong feedbacks. Our simple approach illuminates a need for investigating this issue further by using a range of models including coupled Earth System Model (ESM)-Integrated Assessment Models (IAMs).

References

Azar C., et al. (2013) Meeting global temperature targets—the role of bioenergy with carbon capture and storage. *Environmental Research Letters* 8 034004
Friedlingstein, P., et al. (2006) Climate–carbon cycle feedback analysis: results from the C4MIP model intercomparison. *Journal of Climate* 19 3337-3353
Fuss S., et al. (2014) Betting on negative emissions. *Nature Climate Change* 4 850-853

Scott V., et al. (2013) Last chance for carbon capture and storage. *Nature Climate Change* 3 105-111
Tanaka K., et al. (2013) Emission metrics under the 2°C climate stabilization target. *Climatic Change* 117 933-941

Development of Integrated Terrestrial Model: a biogeophysical land surface model with human components

*Tokuta Yokohata[1], Akihiko Ito[1], Naota Hanasaki[1], Gen Sakurai[2], Tsuguki Kinoshita[3], Toshichika Iizumi[2], Yoshimitsu Masaki[1], Tomoko Nitta[4], Yadu Pokhrel[5], Seita Emori[1]

1.National Institute for Environmental Studies, 2.National Institute for Agro-Environmental Sciences, 3.Ibaraki University, 4.Atmosphere Ocean Research Institute, University of Tokyo, 5.Rutgers University

Future climate changes possibly affect eco-system services, water resources, food production, energy supply, etc. It is important to understand the interaction between the changes in these complicated factors. In the present study, we develop an integrated terrestrial model which describes the natural biogeophysical environment as well as human activities. In the integrated model, a global vegetation model VISIT (Ito et al. 2012), water resource model H08 (Hanasaki et al. 2008, Pokhrel et al. 2012), crop growth model PRYSBI2 (Sakurai et al. 2015), and land use model TELMO (Kinoshita et al., in preparation) are coupled to a land surface model MATSIRO (Takata et al. 2003, Nitta et al. 2014), which is a component of global climate model MIROC (Watanabe et al. 2010). Output variables of each sub-model are passed to other sub-models during the time integration. The time interval of variable exchange is a few hourly or daily. For example, the crop yields [ton/ha] calculated by PRYSBI2 is used in TEMO which calculate the land use change (crop or natural vegetation area) of next year. The projected land-use map is used in all other sub-models. The water resource model H08 considers the irrigation process (water withdrawal from rivers) as well as dam operations in large rivers, which affects the state of the soil moisture and the river flows in the land surface model. We will present the state of the model development, and results from the historical and future simulation.

Keywords: Earth system model, climate change, human activity

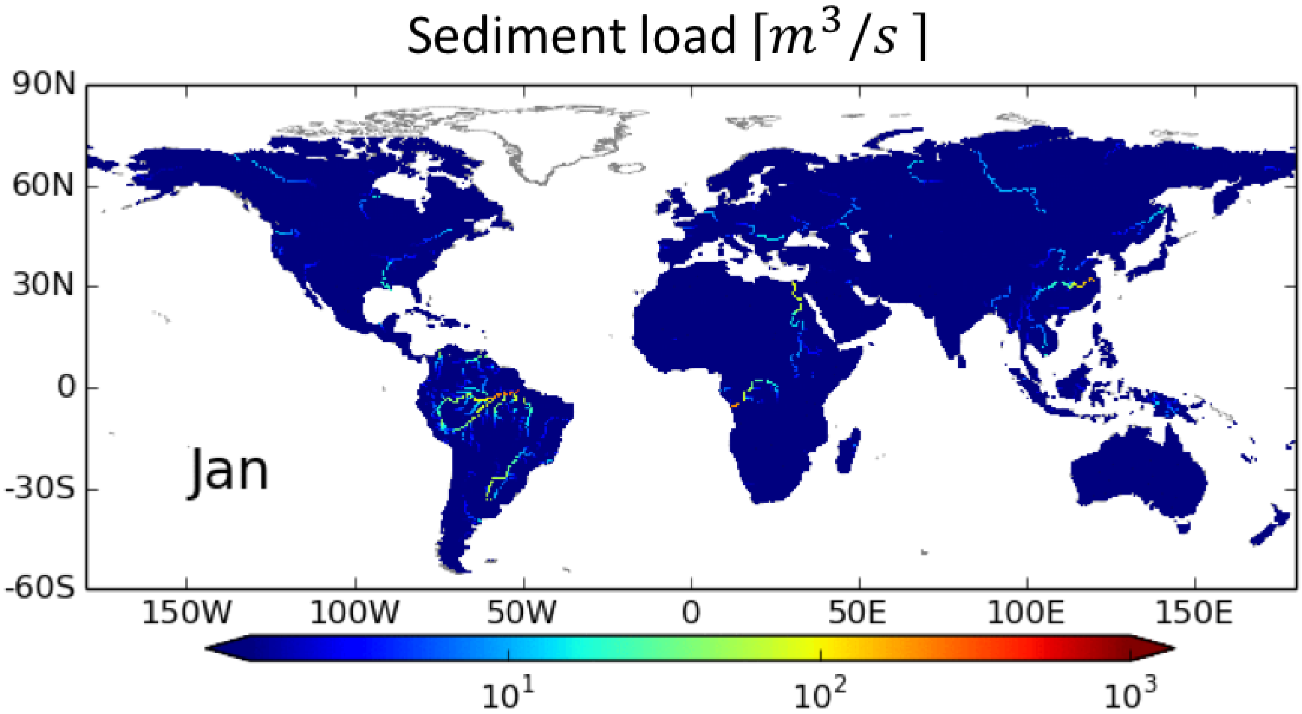
A study on spatial and temporal variability of sediment in rivers using global sediment transport model

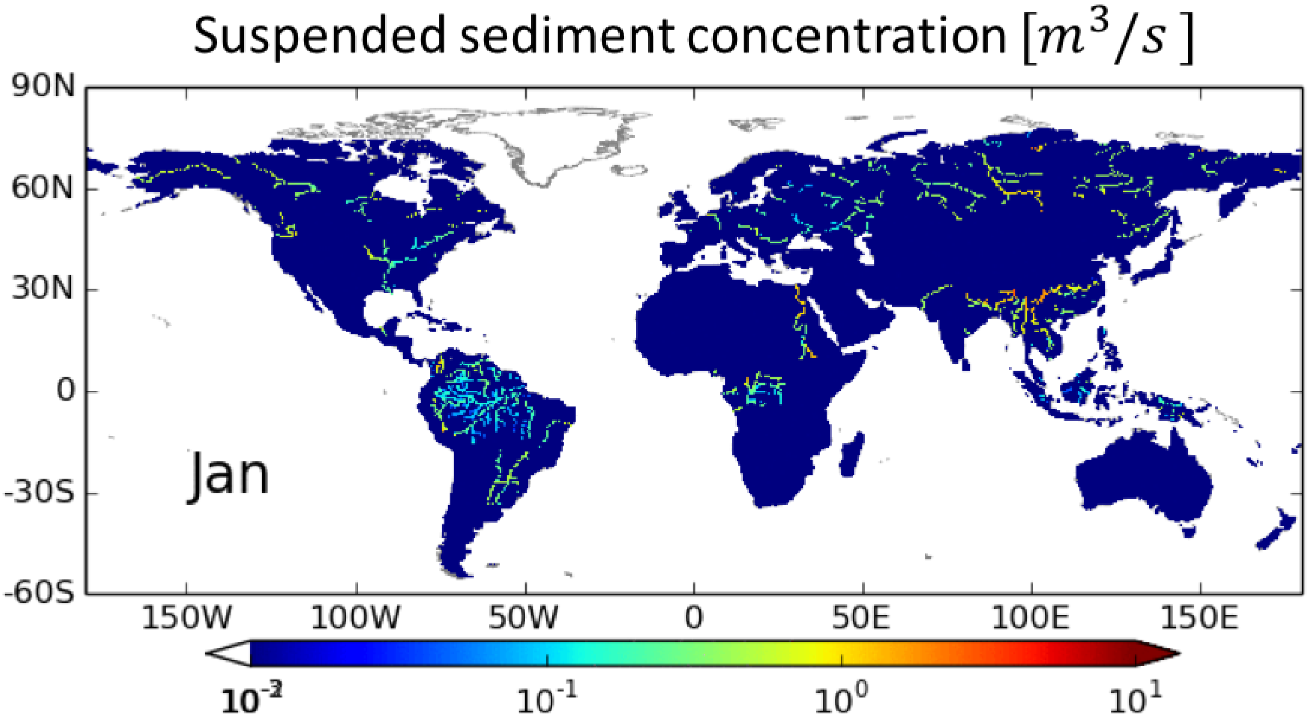
Kiyotaka Mukaida[1], *Kei Yoshimura[1]

1.Atmosphere and Ocean Research Institute, University of Tokyo

There have been a number of studies about sediment transport processes in particle scale to basin scales, but only few studies so far in a global scale. Particularly, there is no study that utilizes a single model to simulate sediment transport in all rivers in the globe. Furthermore, this sort of model should be of importance with regards to the Earth System Model (ESM) development, since ESMs are now being implemented with biogeochemical processes in the atmosphere, land, and ocean. To link between those, riverine transport process needs to be taken into account. That is our motivation to develop the global sediment transport model, CaMa-SED. In CaMa-SED, yield, erosion, transport, and sedimentation processes of soil particles are implemented. Those processes are highly dependent with soil particle diameters, so that the representative diameters of clay, silt, and sand are taken into account. Sediment yield is estimated depending on slope and precipitation rate. The horizontal transport is divided into two; suspended flow and bedload flow. Deposition and re-suspension processes are also implemented. The preliminary results show a good agreement in total sediment transport in major rivers and more importantly, reasonable characteristic of diameter-depended sediment distribution from upper to lower reaches. Furthermore, the hysteresis between river discharge and sediment transport in Amazon river was reasonably simulated. That is quite new feature of the model because the classical sediment regime, i.e., relationship between discharge and sediment, could not explain the hysteresis behavior. A set of sensitivity tests revealed that the total amount of sediment transport is highly influential to the deposition rate for smaller particles such as silt or clay.

Keywords: global sediment transport model, suspended flow, sediment regime


Sediment load $[m^3/s]$
90N
60N
30N
0
-30S
-60S
Jan
150W
100W
50W
0
50E
100E
150E
10^1
10^2
10^3


Suspended sediment concentration $[m^3/s]$
90N
60N
30N
0
-30S
-60S
Jan
150W
100W
50W
0
50E
100E
150E
10^{-2}
10^{-1}
10^0
10^1

Current state of terrestrial CO_2 exchange estimations: progresses and remaining issues

*Masayuki Kondo[1], Kazuhito Ichii[1], Prabir Patra[1], Tazu Saeki[1]

1.Department of Environmental Geochemical Cycle Research, Japan Agency for Marine-Earth Science and Technology

Terrestrial ecosystems play a critical role in formation of a feedback loop of carbon dioxide (CO_2) in atmosphere with atmospheric reservoir and climate, and thus directing a course of the future projection of climate change. The research community has spent significant efforts to understand behaviors of terrestrial ecosystems under a steady rise in atmospheric CO_2 concentration and temperature during the recent decades and deepen knowledge about the regional and global patterns of terrestrial CO_2 sinks and sources. estimate the terrestrial CO_2 exchange, while seeking consistency between simulated and observed CO_2 concentrations. The bottom-up approach estimates the terrestrial CO_2 exchange using ecosystem models, which simulate the ecosystem-scale carbon cycle by considering the internal biogeochemical mechanisms of carbon flows for each prescribed vegetation type and soil.
However, the current estimates of terrestrial CO_2 exchange by the bottom-up and top-down approaches remain inconsistent. As illustrated in the recent IPCC Assessment Report (AR5), the top-down approach tends to indicate stronger CO_2 sinks in temperate and boreal regions than the bottom-up approach does. Furthermore, the two approaches exhibited contrasting CO_2 sink–source patterns in the tropics; the bottom-up approach indicated CO_2 sinks and the top-down approach CO_2 sources. As illustrated by these inconsistencies, a consensus on the geographic distribution of the terrestrial CO_2 exchange has yet to be established among the research community.
In this study, we elaborate the current status and issues of terrestrial CO_2 flux estimations by the top-down and bottom-up approaches. Specifically, we compare the bottom-up estimate from dynamic global vegetation models that are forced by interannual variations of CO_2 concentration, climate and land use changes, with the top-down estimate from atmospheric CO_2 inversions. We show an improved level of agreement between the two estimates in relation to seasonal variability and, regional and global budgets, since the IPCC AR5. We also discuss the remaining issues causing inconsistency between the two estimates.

Acknowledgments
This research was supported by Environment Research and Technology Development Funds (2-1401) from the Ministry of the Environment of Japan and Asia-Pacific Network for Global Change Research (APN: grant#ARCP2011-11NMY-Patra/Canadell).

Keywords: Terrestrial CO2 exchange, Atmospheric CO2 inversion, Ecosystem model simulation

THE CARBON BALANCE OF THE TERRESTRIAL BIOSPHERE IN THE TWENTIETH CENTURY

*Sitch Alexander Stephen[1]

1.University of Exeter

Sitch, S. (1) and the TRENDY DGVM consortium, (1) University of Exeter, UK.
Each year a consortium of Dynamic Global Vegetation Modelling groups perform a factorial set of global simulations over the historical period, 1901 –present, to investigate the temporal and spatial trends in the land sink, and the contribution of land-use to emissions. This activity contributes the annual global carbon budget updates of the Global Carbon Project. Typical around 10 models are forced with reconstructed observed climate, global atmospheric CO_2, gridded fields of historical land-use and land cover changes (LULCC), and nitrogen deposition for a subset of models which include a fully interactive nitrogen cycle. The TRENDY project will be presented, including process developments through to the latest Trendy-v4 (1901-2014). Results are used to ascertain the individual contribution of CO_2, Climate, Land-Use and N deposition on the regional and global land carbon sink. Increasingly offline land surface simulations and coupled ESM simulations use the same land-surface components and results from each can inform the other. Both TRENDY and C4MIP have increasing interest in evaluation activities. Furthermore, observational datasets including those from remote sensing are used to evaluate model performance and help constrain the global land carbon sink over the past two decades.

Keywords: land-atmosphere interactions, DGVMs, climate-carbon cycle models

Climate-carbon cycle changes during 1000 years in doubled CO_2 concentration simulated by MIROC-ESM

*Tomohiro Hajima[1], Kaoru Tachiiri[1], Michio Kawamiya[1]

1.Japan Agency for Marine-Earth Science and Technology

Transient climate response to cumulative carbon emission, so called TCRE, is defined as the ratio of global warming to cumulative anthropogenic CO2 emission evaluated when CO2 concentration reaches the doubled CO2 level from pre-industrial state. This metric is useful because it gives us roughly estimates on future global warming induced by CO2 emission on the basis of current and future emission amounts. Since TCRE just characterizes the transient response of climate-carbon cycle, we cannot know what will happen after CO2 concentration is stabilized (or reduced) after mitigation policies adopted. To estimate the warming degree in such condition and to understand climate-carbon dynamics in the concentration-stabilized phase, we conducted simulations where CO2 concentration is abruptly doubled from pre-industrial state and fixed over 1000 years, by using an Earth system model (MIROC-ESM). We confirmed from the simulations that after 1000 years have passed, global warming and land carbon uptake almost ceased but weak carbon uptake by the ocean continues.

Keywords: carbon cycle, climate change, Earth system model, TCRE

C4MIP simulations, plans and evaluation requirements

*Chris Jones[1]

1.Met Office Hadley Centre

Climate-carbon cycle feedbacks are potentially large and play a leading order contribution in determining the atmospheric composition in response to human emissions of CO2 and in the setting of emissions targets to stabilise climate or avoid dangerous climate change. For over a decade The Coupled Climate-Carbon Cycle Model Intercomparison Project (C4MIP) has coordinated coupled climate-carbon cycle simulations and in the coming few years C4MIP will be an endorsed activity of CMIP6. It is hoped that this will encourage widespread adoption of the C4MIP set of simulations and enable increased understanding and predictability of future changes in both terrestrial and marine carbon cycle.
C4MIP has 3 key strands of scientific motivation and the requested simulations are designed to satisfy their needs: (1) pre-industrial and historical simulations (formally part of the common set of CMIP6 experiments) to enable model evaluation; (2) idealised coupled and partially-coupled simulations with 1% per year increases in CO2 to enable diagnosis of feedback strength and its components; (3) future scenario simulations to project how the Earth System will respond over the 21st century and beyond to anthropogenic activity.
In this talk I will outline some previous C4MIP results and present some key priorities for evaluation. It is clear that in biogeochemical modelling and the drive for increased complexity in ESMs, process-based model evaluation has not kept pace. As a result there is very large quantitative spread between CMIP5 carbon cycle results which hinder their usefulness. It is also the case that we have not been able to show demonstrable progress - as a coherent community - in the quality and process-realism of our modelling. There are no agreed quality criteria or metrics which measure whether our ESMs are fit for purpose or if they have improved since the last generation. It is essential that we focus our efforts in the coming years on addressing this deficiency. It is not enough that under CMIP6 there are more models within C4MIP analyses or more advanced processes. We must be able to demonstrate that we have made real progress since CMIP5 in our modelling skills, analysis techniques and our ability to constrain future projections.

There are multiple ways of evaluating carbon cycle models. Activities such as TRENDY and OCMIP (part of OMIP) will perform evaluation activities of offline land and ocean components respectively. It is the role of C4MIP to evaluate the coupled climate-carbon cycle system. Our primary simulations for this activity will be the coupled historical simulations from 1850 up to 2014. There will be two variants. Within the CMIP “DECK” (the central core of CMIP6) all models will perform a “concentration driven” historical run. This means the atmospheric concentration of CO2 is prescribed to follow the historical record. The second variant, which is required for all models contributing to C4MIP is a parallel “emissions driven” historical simulation in which CO2 emissions are prescribed to the model and the models simulate the time evolution of CO2 concentration.

In order to fully exploit these simulations we need to be prepared with some top-level evaluation criteria (e.g. as presented by Anav et al 2013); some rigorous process-based criteria and metrics (such as sensitivity of stores and fluxes to environmental drivers); carefully assembled and processed observational datasets; carefully defined model diagnostic outputs. Here I will briefly outline these requirements in the hope of stimulating discussion to move our plans forward ahead of model simulations being started by the end of 2016.

Keywords: Carbon cycle, CMIP, evaluation

Millennium-scale changes in ocean carbon cycle under global warming

*Akitomo Yamamoto[1], Ayako Abe-Ouchi[1], Yasuhiro Yamanaka[2]

1.Atmosphere and Ocean Research Institute, The University of Tokyo , 2.Graduate School of Environmental Science, Hokkaido University

The oceanic uptake of anthropogenic CO_2 from the atmosphere is expected to persist for a thousand years or more. Understanding the oceanic carbon uptake is essential for predicting the air-borne fraction of CO_2 emissions and thus degree of climate change. Warming of ocean surface waters and changes in the ocean circulation and biological pump would reduce the oceanic uptake of CO_2, which is known as climate-carbon cycle feedback.
In this study, we simulate multimillennium changes in ocean carbon cycle under quadrupling of atmospheric CO_2, using GCM (MIROC) and an offline biogeochemical model. We also carry out a number of sensitivity runs in order to isolate the individual feedback mechanisms.
The oceanic uptake is 2050 Pg C, and the reduction of uptake due to global warming is about 30% at the end of simulation. These values are comparable to the previous studies (Plattner et al, 2001; Schmittner et al, 2008). The increase in SST and weaker soft-tissue pump are the dominant mechanisms of climate-carbon cycle feedback. Important biological mechanisms are reduction in new production due to reduced nutrient supply and increase in remineralization rate due to seawater warming.
I will also discuss the effect of ocean circulation change on the oceanic uptake.

Keywords: ocean carbon cycle, multi-millennium simulation, climate-carbon cycle feedback

Global-scale swamp forest modelling using satellite-based elevation and forest datasets

*Dai Yamazaki[1]

1.JAMSTEC Japan Agency for Marine-Earth Science and Technology

Swamp forest (seasonally flooded forest) has different characteristics to usual non-flooded forest in terms of carbon pool and nutrient flux. Swamp forest exists in wide climate regions from boreal to tropical regions, but its global distribution is not well studied because satellite observation of inundated forest floor is disturbed by vegetation canopy. Here, we propose a method to estimate the global distribution of swamp forest by global river model simulations using satellite elevation and forest datasets. Digital Elevation Models (DEMs) based on satellite radar or stereoscopy have elevation biases due to forest canopy that impede the simulation of swamp forest hydrodynamics. We removed the elevation biases by combining ICESat forest height data and Landsat forest density data. The simulation with the bias-corrected DEM shows good agreement to L-band radar observation of swamp forest inundation in the Amazon basin, which suggests the potential of the proposed method for estimating swamp forest distribution.

Keywords: Swamp Forest, Global Motel, Flooding

Earth system and climate modeling activities toward CMIP6 in Japan: a review

*Michio Kawamiya[1]

1.Japan Agency for Marine-Earth Science and Technology

There are three groups in Japan planning to contribute to Coupled Model Intercomparison Project (CMIP6): Meteorological Research Institute (MRI) of Japan Meteorological Agency (JMA); Team MIROC, which is a joint effort among JAMSTEC, the University of Tokyo, and NIES; and NICAM development team consisting of UT, RIKEN and JAMSTEC. The first two groups are joining most of the endorsed MIPs with their different model versions combined, while the NICAM team joins CMIP6 in a more selective manner due to the immense computer resource requirement. The third generation of the Earth Simulator, whose theoretical computational speed is 1.3PFlops, will be used for most of the CMIP6 experiments, while the K computer may be utilized for some NICAM experiments. Many activities in Japan for CMIP6 are supported by SOUSEI project funded by MEXT, which is coming to an end in March, 2017. A forum has been set up to involving both scientists and funding agency to discuss overall direction of climate science beyond SOUSEI project.

Keywords: Earth system model, Climate projection, CMIP6

Effect of bias in Leaf Area Index to climate in MIROC-ESM

*Kaoru Tachiiri[1], Tomohiro Hajima[1]

1.Japan Agency for Marine-Earth Science and Technology

Leaf Area Index (LAI) is not only an important factor to determine the amount of photosynthesis, but also a key variable to represent ground surface condition which gives significant impact to atmosphere through biophysical processes such as albedo and transpiration. In this study, we first compared the present-day LAI in Earth System Models (ESMs) with remote sensing data and confirmed the significant overestimation by ESMs, which is pointed out by some existing studies. In order to investigate the effect of the bias, we next compared two pre-industrial control experiments: an ordinary control experiment in which LAI is prognosed by the terrestrial ecosystem component of the ESM, and an experiment in which LAI is replaced with dataset made from remote sensing data (the pre-industrial state was estimated by retuning the cultivated areas to natural vegetation). The result shows a significant temperature difference between the two cases, and by analysis of the related variables we concluded that the difference is caused by albedo change due to the change in snow depth/coverage in May-June and in the sea ice coverage in winter.

Keywords: Leaf Area Index, bias, MIROC-ESM, climate

Socio-economic implications of stabilization scenarios from MIROC-ESM

*Diego Silva[1], Kaoru Tachiiri[1]

1.Project Team for Risk Information on Climate Change, Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

Setting a target for stabilization of climate in the long-term requires significant reductions in greenhouse gas (GHG) emissions at global scale. This involves important transformations in the society, basically affecting the future patterns of energy consumption and production, as well as the patterns of land use. Moreover, the cost for achieving such climate target may be considerable, thus, requiring an optimal allocation of efforts that minimizes the economic impact. This study presents the socio-economic implications of emission scenarios aiming at long-term climate stabilization, estimated with an integrated assessment model (IAM). Emission scenarios are obtained from the earth system model (ESM) Model for Interdisciplinary Research on Climate (MIROC-ESM). The outcomes on supply and demand of energy, land use, and mitigation costs are presented.
The emissions scenarios considered are consistent with the representative concentration pathway (RCP), and aim at a global radiative forcing by 2100 of around 4.5 W/m^2 (RCP4.5) and 2.6 W/m^2 (RCP2.6). The Global Change Assessment Model (GCAM) is applied to study the developments in energy, land use and emissions throughout the 21st century. GCAM is an IAM based on a partial equilibrium approach, which resolves the balance in supply and demand across the energy, land use and agricultural sectors.
Compared to the standard RCPs, the emission scenarios from MIROC-ESM presented lower levels of allowable anthropogenic CO_2 emissions for the same climate target. This is an outcome of the stronger feedback between the carbon-cycle and the climate, and the higher value for climate sensitivity assumed in MIROC-ESM in contrast to the climate model used in the development of RCPs. As a consequence, the changes in the energy and land systems are more drastic, while the cost of mitigations is higher. These differences are greater in the second half of the century.

Keywords: MIROC-ESM, stabilization scenario, integrated assessment model

Mineral aerosol as a source of iron for the marine ecosystems in the Southern Ocean

*Akinori Ito[1], Jasper F. Kok[2]

1.Japan Agency for Marine-Earth Science and Technology, 2.University of California, Los Angeles

Atmospheric deposition of dust source materials is a significant source of exogenous iron (Fe) in marine ecosystems. Especially, the Southern Ocean is the most biogeochemically important ocean because of its large spatial extent and its considerable influence on the global carbon cycle. However, there is large uncertainty in our estimate of the dust emissions in the Southern Hemisphere. Here, we implement a newly developed dust emission scheme into a global atmospheric chemistry transport model to produce better agreement with measurements of Fe loading over the oceans.

Keywords: Aerosols , Global Biogeochemical Cycles, Atmospheric chemistry transport model

On constraining the strength of the terrestrial CO_2 fertilization effect in an Earth system model

*Vivek Arora[1], John Scinocca[1]

1.Canadian Centre for Climate Modelling and Analysis, Environment and Climate Change Canada

Earth system models (ESMs) explicitly simulate the interactions between the physical climate system components and biogeochemical cycles. Physical and biogeochemical aspects of ESMs are routinely compared against their observation-based counterparts to assess model performance and to evaluate how this performance is affected by ongoing model development. Here, we assess the performance of version 4.2 of the Canadian Earth system model against four, land carbon cycle focused, observation-based determinants of the global carbon cycle and the historical global carbon budget over the 1850-2005 period. Our objective is to constrain the strength of the terrestrial CO_2 fertilization effect which is known to be the most uncertain of all carbon cycle feedbacks. The observation-based determinants include (1) globally-averaged atmospheric CO_2 concentration, (2) cumulative atmosphere-land CO_2 flux, (3) atmosphere-land CO_2 flux for the decades of 1960s, 1970s, 1980s, 1990s and 2000s and (4) the amplitude of the globally-averaged annual CO_2 cycle and its increase over the 1980 to 2005 period. The optimal simulation that satisfies constraints imposed by the first three determinants yields a net primary productivity (NPP) increase from ~ 58 Pg C yr^{-1} in 1850 to about ~ 74 Pg C yr^{-1} in 2005; an increase of ~ 27 % over the 1850-2005 period. The simulated loss in the global soil carbon amount due to anthropogenic land use change over the historical period is also broadly consistent with empirical estimates. Yet, it remains possible that these determinants of the global carbon cycle are insufficient to adequately constrain the historical carbon budget, and consequently the strength of terrestrial CO_2 fertilization effect as it is represented in the model, given the large uncertainty associated with LUC emissions over the historical period.

Keywords: Earth system models, CO2 fertilization effect, Land carbon uptake

Multi-model analysis of ocean acidification in the subsurface layers of the North Pacific

*Michio Watanabe[1], Michio Kawamiya[1]

1.Japan Agency for Marine-Earth Science And Technology

Ocean acidification is one of the major threats for marine calcifying organisms such as precious corals. They live in the mesophotic waters at a depth of 80–300 m near Japan and are known as habitat-forming species with an important structural role in mesophotic habitats of continental slopes, sustaining biodiversity hotspots. Using the outputs of projections under the highest emission scenario of the Representative Concentration Pathways performed by Earth System Models (ESMs), we evaluate the ocean acidification rates in the middle layers of the North Pacific, where the strongest sink of atmospheric CO_2 is found in the mid-latitudes. The mixed layer depth in the Kuroshio Extension region reaches ~200 m during winter due to the strong wind forcing and cooling. Consequently, the low potential vorticity (PV) water mass called the Subtropical Mode Water is formed. This mode water shows large dissolved inorganic carbon (DIC) concentration increase, and is advected southwestward, so that, in the Izu-Ogasawara region, DIC concentration increases and ocean acidification occurs faster than in adjacent regions. The ESMs simulate that pH in the middle layers of the Izu-Ogasawara region decreases by 0.3~0.4 from 2006 through 2100. We find that the ESMs with a deeper mixed layer during winter in the Kuroshio Extension region show the large increase in DIC concentration within the Izu-Ogasawara region. For a reliable projection of the ocean acidification in the middle layers of the Izu-Ogasawara region, an ESM should well reproduce the mixed layer deepening during winter in the Kuroshio Extension region.

Keywords: ocean acidification, CMIP5, Earth System Model

Measurements of Gaseous Nitrous Acid (HONO) Emission from Activated Sludge and Denitrifying Bacteria

*Chika Minejima[1], Tomoyuki Miyashita[1]

1.International Christian University

Introduction

Gaseous nitrous acid (HONO) is known as a precursor of OH radicals, a strong oxidant in the atmosphere. Up to 34 % of OH radical is produced from HONO in a city and a rural area[1)]. Therefore HONO is an important species to know OH radical behaviors.

The high HONO concentration have been observed during daytime in spite of the HONO photolysis. There are several known HONO sources: gas phase reactions, heterogeneous reactions and combustion process. Also, HONO emission from soil by the equilibrium between gaseous nitrous acid and aqueous nitrous acid in the soil and the direct emission by nitrifying bacteria have been observed[2)3)]. In the soil, there are not only nitrifying bacteria but denitrifying bacteria. However the emission by denitrifying bacteria is not studied.

The research purpose is to determine whether or not denitrifying bacteria in the activated sludge emits HONO directly.

Experimental

HONO emissions from activated sludge in aerobic condition and anaerobic condition were measured. Also HONO emission from the sterlized supernatant solution was measured. HONO emissions from biological process and chemical process were compared. Activated sludge in Duran bottle was purged with air or N_2 for 1 day to 4 days and HONO was captured with a filter pack. The sludge was aerobic with air purge and anaerobic with N_2 purge. Duran bottle and filter packs were covered with tin foil to avoid HONO photodissociation. Dissolved Oxygen was measured to keep the condition of activated sludge and pH was stabilized at 7.8-8.1 by adding 0.1 M HCl solution or 50 g/L $NaHCO_3$ solution not to decrease the bacteria’s activity. The flow speed was controlled at 2 L/min with mass flow controllers.

Also, activated sludge and its sterilized supernatant solution were purged with room air and N_2 at 22 ℃. Also the activated sludge was purged with N_2 at 27, 32 ℃. The activated sludge in a Duran bottle was put in the water which is controlled with a heat controller to stabilize the temperature of activated sludge. In these experiments, three filter packs were placed for each experiment. Air or N_2 was purged in 4.5 L/min because three filter packs were prepared and the purged gas was controlled to flow through each filter pack in 1.5 L/min. The NO_2^- concentrations of the sludge and supernatant were measured before these experiments with the pack test. The purging time was 8 hours in order to keep controlling pH.

Results and Discussion

In this experiment, HONO emissions from the sludge were observed at anaerobic condition. The contribution of biological process was more than 90%. However, calculated activation energy from temperature dependent experiment was much bigger than that of the denitrifying bacteria. Thus, there is a possibiliy that denitrifying bacteria reduce NO_3^- to NO_2^- and the increase in NO_2^- concentration increased the HONO emission from the chemical process. Also, NO_2^- concentration in the sludge should be measured more accurately because it has influence on HONO emission.

Reference

1) Wong *et al.*, *Atmos. Chem. Phys.*, **11**, 3595-3609 (2011).
2) Su, et al., *Science,* **333**, 1616-1618 (2011).
3) Oswald, et al. *Science* **341**, 1233-1235 (2013).

Keywords: nitrous acid, atmosphere, soil

IMPACT OF BIOGEOPHYSICAL AND BIOGEOCHEMICAL PROCESSES AND THEIR INTERACTIONS ON PERMAFROST SOIL CARBON STOCKS

*Jain K Atul[1], Shijie Shu[1], Rahul Barman[1], Bassil El-Masri[1]

1.Department of Atmospheric Science, University of Illinois

One of the major challenges in more detailed Earth system models (ESMs) is the treatment of the biophysical and biogeochemical processes and feedbacks and their impact on soil organic carbon (SOC), in the Northern high latitudes (NHL) permafrost region. . This is because a larger suite of active terrestrial processes coupled with scarcity of observational data introduce many challenges for modelling these processes. Nonetheless, several studies in the recent past have demonstrated improved permafrost modelling capabilities by incorporating soil/snow processes that critically influence the ground energetics in these environments, such as: deep soil layers and organic soils, and the effects of wind compaction and depth hoar formations, and structural properties of vegetation (phenology, assimilated vegetation C allocation to leaves, stems, and roots and root dynamics) However, no study has yet evaluated the combined effects of the improvements of these biogeophysical and biogeochemical processes for the entire NHL.

We use a land surface model, the Integrated Science Assessment Model (ISAM), to investigate the effects of feedbacks between the biogeochemical (C and N) and biogeophysical (water, and energy) processes on the model estimated soil organic carbon (SOC) for the NHL permafrost region. We not only focus on recent model improvements in the biogeophysical processes that are deemed important for the high latitude soils/snow and ppermafroest SOC; such as deep soil column, modulation of soil thermal and hydrological properties, wind compaction of snow, and depth hoar formation; but also biogeochemical processes that are important for soil biogeochemistry; such as dynamic phenology and root distribution, litter carbon decomposition rates and nitrogen amount remaining. We select multiple sites to evaluate the modeled processes. We then carried out several model simulations to study the effects of feedbacks between biogeochemical and biogeophysical processes on SOC in NHL.

After accounting for dynamic biogeochemical processes, ISAM is able to capture permafrost extend and and the carbon stored in NHLs, as well as the seasonal variability in leaf area index (LAI), and root distribution in the soil layers and the root response of soil water uptake and transpiration. The evaluation of the model results suggest that without accounting these processes, modelled growing season length (GSL) for NHL was almost two times higher as compared to measurements. To quantify the implication of these processes on the carbon and water fluxes, we compared the results of two different versions of ISAM, dynamic version which accounts for dynamic processes ($ISAM_{DYN}$) and static version which do not account for dynamic processes ($ISAM_{BC}$), with measurements from12 eddy covariance flux sites. The results show that $ISAM_{DYN}$, unlike $ISAM_{BC}$, is better able to capture the seasonal variability in GPP and energy fluxes. Our modelling analysis shows that by including the biophysical processes in addition to biogeochemical processes, the modelled NHL permafrost carbon increased by 30% from 328 to 447 GtC in the top one meter of soil which is in better agreement with observational estimates of 495 GtC (Northern Circumpolar Soil Carbon Database). Even though the inclusion of these processes generally reduced vegetation productivity and litter production due to a decrease in soil temperature and liquid water content, increased soil carbon stocks highlight the dominance of soil water/temperature stress on decomposition processes. While continued improvements are required in the treatment of biogeochemistry, here we demonstrate the importance of soil/snow biogeophysical and biogeochemical processes in modelling permafrost carbon stocks, as important drivers of soil biogeochemical processes.

Keywords: Permafrost Soil Carbon, Land Surface Model, Biogeophysics, Biogeochemistry