MARine Ecosystem Model Intercomparison Project (MAREMIP)

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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

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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

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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

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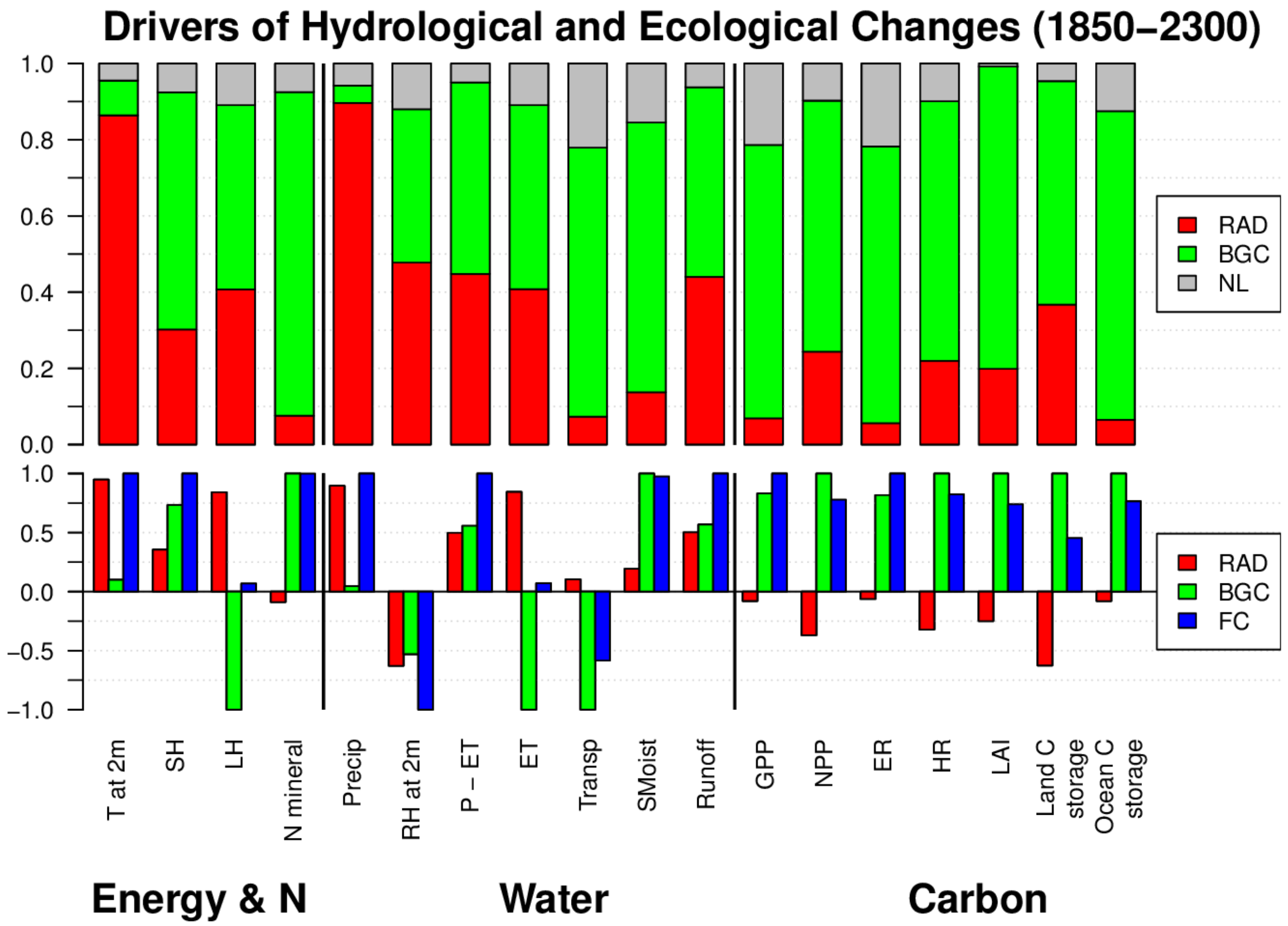
Quantifying feedbacks between the global carbon cycle and Earth's climate system is important for predicting future atmospheric CO_2 levels and informing carbon management and energy policies. We applied a feedback analysis framework to three sets of Historical (1850-2005), Representative Concentration 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)
RAD
BGC
NL
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?

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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).

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

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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

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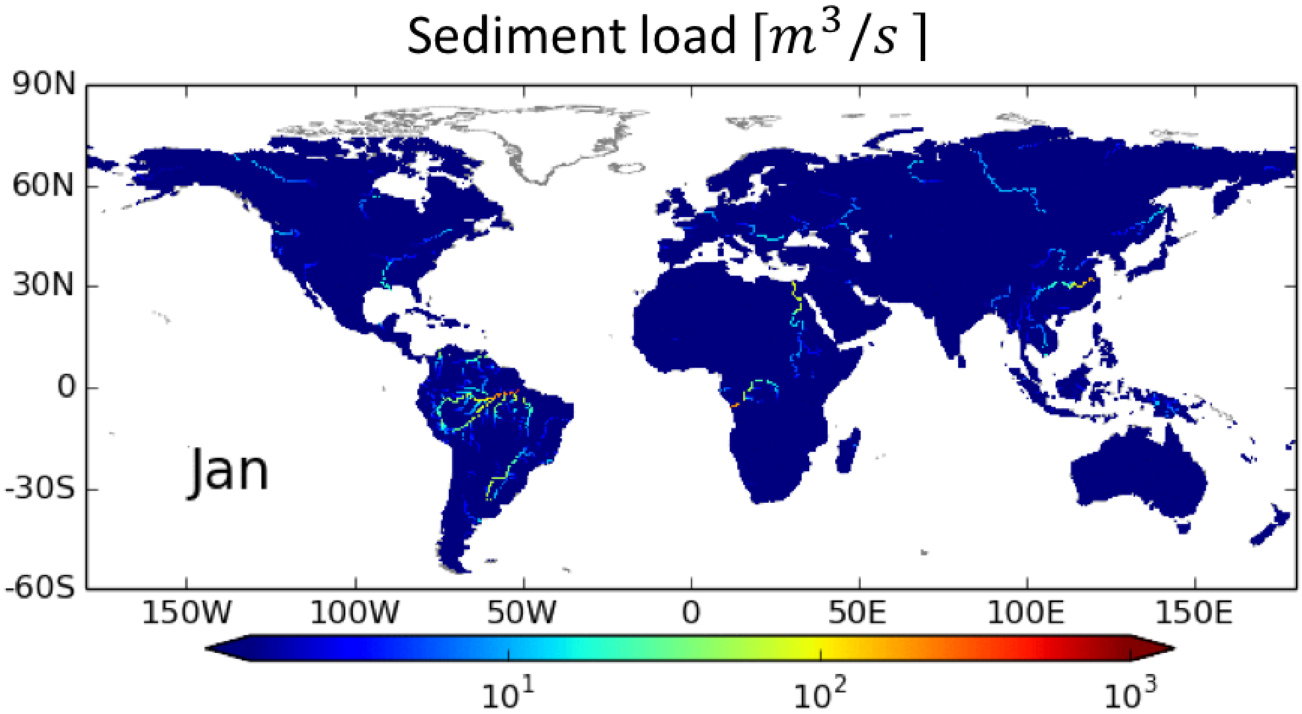
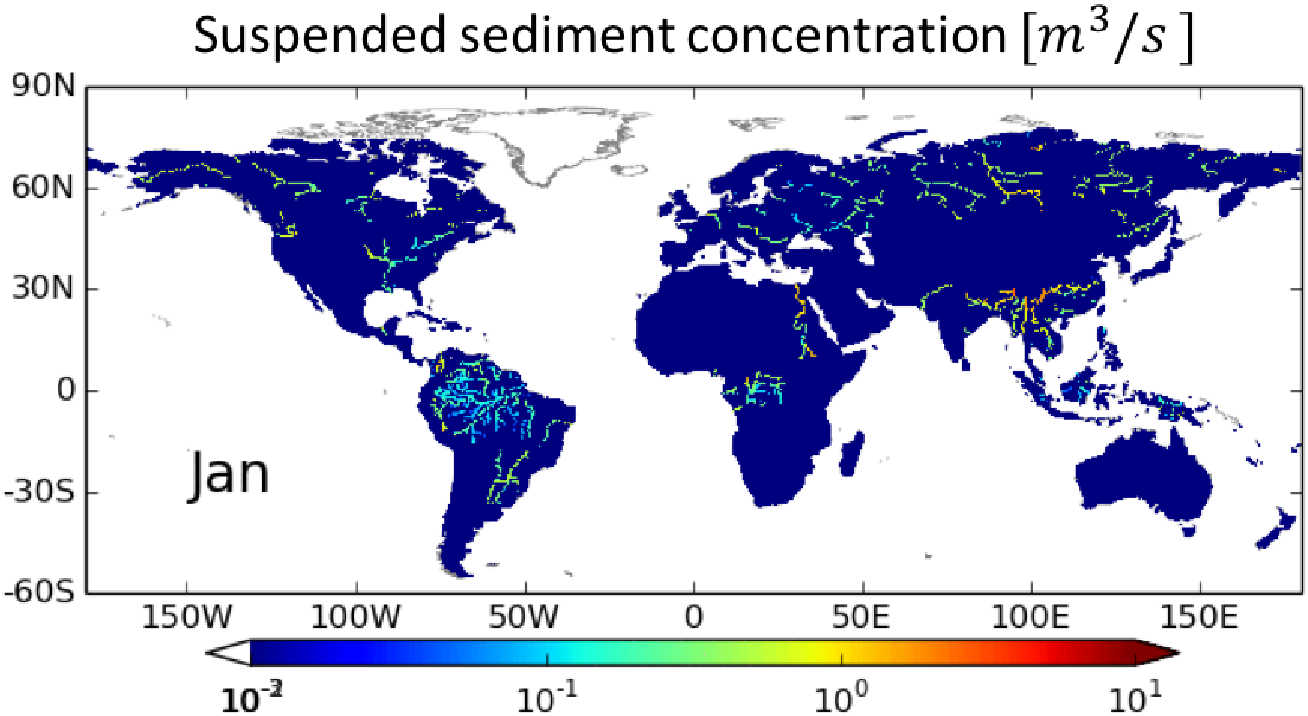
There have been a number of studies about sediment transport processes in particle scale to basin scales, but only few studies so far in a global scale. Particularly, there is no study that utilizes a single model to simulate sediment transport in all rivers in the globe. Furthermore, this sort of model 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

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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

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

THE CARBON BALANCE OF THE TERRESTRIAL BIOSPHERE IN THE TWENTIETH CENTURY

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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

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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

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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

