海洋生態系モデル相互比較計画
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.

キーワード：海洋生態系、生態系モデル、相互比較
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

CMIP5モデルにおける海洋炭素ポンプの診断

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.

キーワード：炭素循環、海洋炭素ポンプ
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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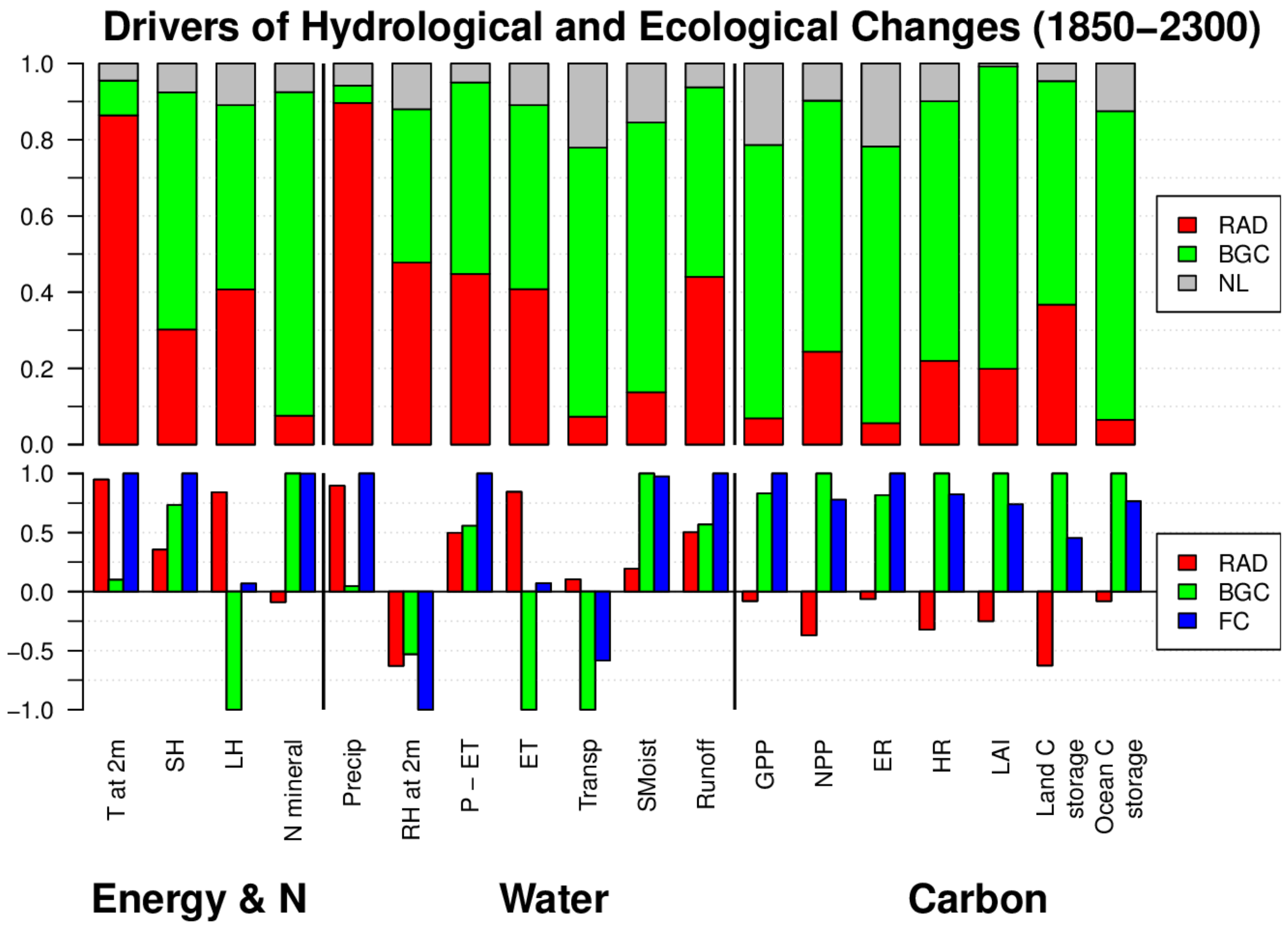
Quantifying feedbacks between the global carbon cycle and Earth's climate system is important for predicting future atmospheric CO_2 levels and informing carbon management and energy policies. We applied a feedback analysis framework to three sets of Historical (1850-2005), Representative Concentration 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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陸域統合モデル：陸面・水資源・作物・土地利用結合モデルの開発
Development of Integrated Terrestrial Model: a biogeophysical land surface model with human components

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*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]

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将来の気候変動は、食料生産･水資源･エネルギー･生態系サービスなどの要素に大きな影響を与えると考えられるが、それぞれの要素に与える影響は密接に関連するため、要素間の相互作用を考慮することが必要不可欠である。これまでの研究では、気候変動が食料･水･エネルギー･生態系のそれぞれに対して及ぼす影響の評価は行われてきたが、これら全体を陸域における自然–人間活動をシステムとして総合的にとらえて影響評価を行うことが、重要な課題である。そこで本研究では、気候変動が土地･水･農業･生態系に及ぼす影響を総合的に評価できる「陸域統合モデル」を開発する。モデルでは、全球気候モデルMIROC (Watanabe et al. 2010) の一要素である陸面モデルMATSIRO (Takata et al. 2003, Nitta et al. 2014) に、陸域生態系モデル VISIT (Ito and Inatomi 2012)、水資源モデルH08 (Hanasaki et al. 2008, Pokhrel et al. 2012)、作物モデルPRYSBI2 (Sakurai et al. 2015)、土地利用モデルTELMO (Kinoshita et al., in preparation) が結合されたモデルである。モデルでは、各サブモデルで計算された出力変数が、関係する別のモデルに数時間あるいは一日の時間ステップで渡され、時間発展する。たとえば、作物モデルPRYSIBI2で計算された穀物収量は、土地利用モデルTELMOに渡され、翌年の土地利用変化が計算される。予報された土地利用変化は、すべてのサブモデルで利用される。また、水資源モデルH08では灌漑プロセス（河川からの取水）、ダム操作を考慮しており、その結果が陸面モデルの土壌水分や河川流量に影響を与える。発表では、モデル開発の現状と、過去再現実験および将来予測実験の結果を報告する。

キーワード：地球システムモデル、気候変動、人間活動
Keywords: Earth system model, climate change, human activity

全球土粒子輸送モデルを用いた河川内の土砂分布の時空間変動に関する研究

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

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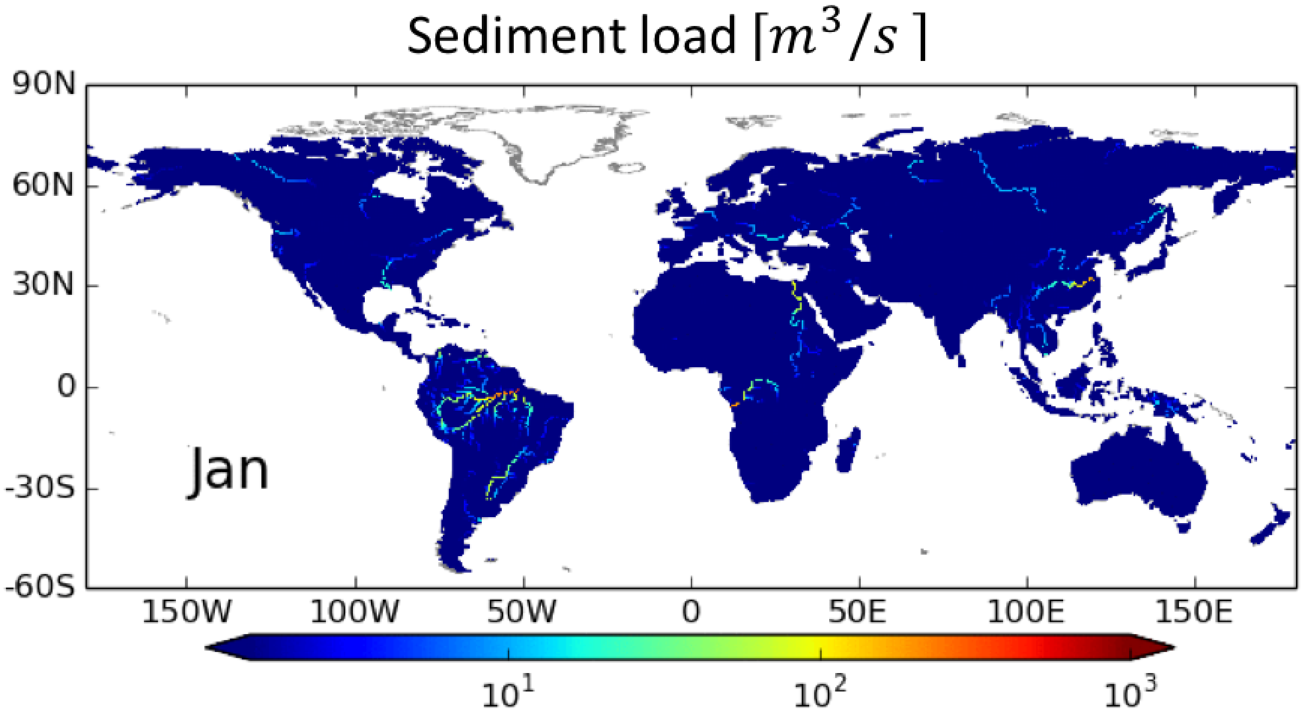
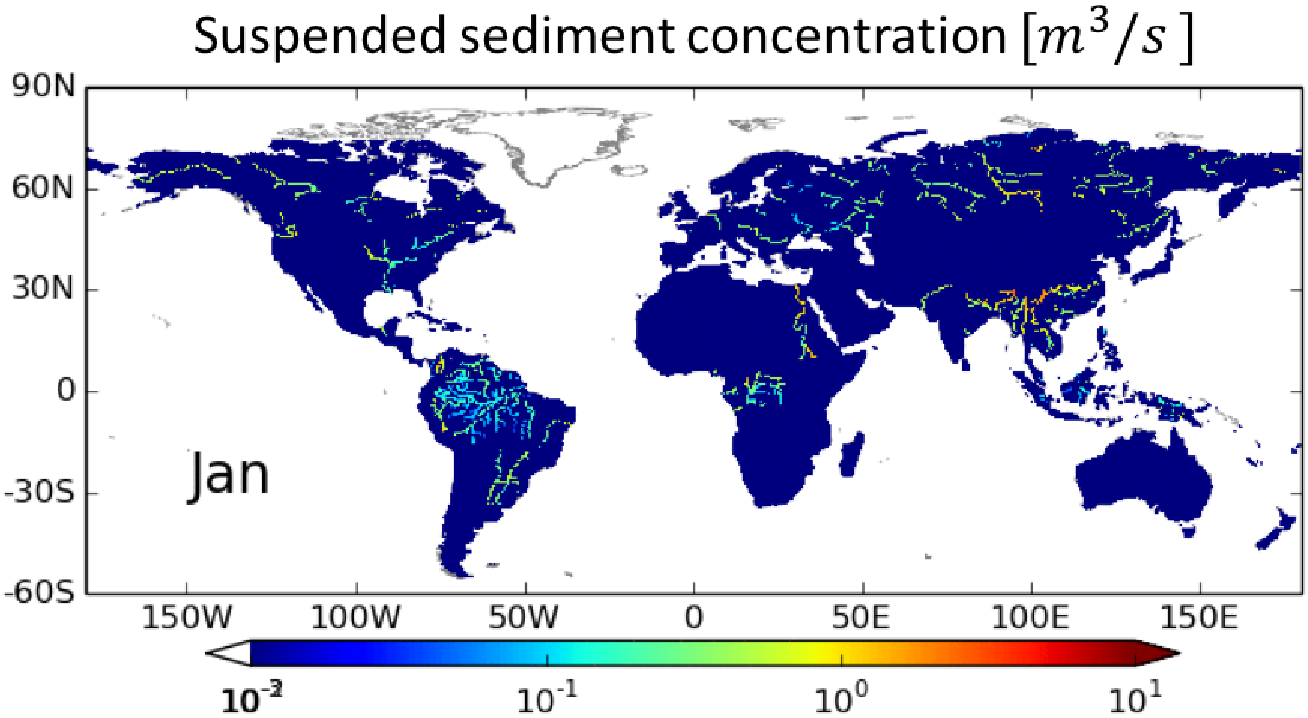
土砂の輸送量の研究は、個々の粒子の振る舞いの詳細な実験による観察やある対象地域における浸食量、堆積量を見積もるなど様々なスケールで行われてきた。個々の研究においては粒径分布や土地利用、土壌の種類など様々な要因について輸送量の時間変動への影響を示唆している。全球スケールにおいては、流域の大まかな気候区分や地形情報を用いて年々変動を表現する経験式を作成することが現在行われて来ている。それに対して本研究においては大河川において土砂動態の時間的変動、空間的変動の理解、再現、予測へとつなげていくために、現状をうまく説明する経験式を推定する立場とは別の、物理過程に従う物質の体積輸送により把握するという立場に立ったアプローチを取る。本研究においては全球スケールの土砂動態を表現するために、物理的過程に基づいて水の流下を計算する全球河川モデルCaMa-Flood (Yamazaki et al. 2011)に、浸食、運搬、堆積の現象に基づいた土砂の輸送過程を導入し、全球土砂輸送モデルCaMa-SEDを開発した。土砂生産過程においては、降水量と傾斜を用いて土砂生産量を推定し、モデルの中で土砂の運搬に関しては流水と同じように移流方程式を用いて掃流輸送と浮遊輸送の二つの輸送形態を計算過程として用い水平方向の移動を表現し、鉛直方向の移動としては河床への沈降量と河床からの巻き上げ量の変数を与えた。ストレージとして浮遊土砂量と堆積土砂量を逐次計算することによって各構成要素の輸送量への寄与を計算することができる。粒径別の計算結果によって河川の上流部から流下した土砂が輸送され粒径の大きいものから先に堆積していく作用による土砂輸送量の空間分布が計算可能となり、細粒分が河口での土砂量を支配していることを示した。生産、運搬、堆積の物理過程に基づいた計算を用いた感度実験の結果により、土砂輸送量に関して沈降速度の感度が高いことが分かった。河口への輸送量が多い粘土、シルト分において沈降速度が非常に小さいため一度浮遊した土砂が沈降しないことに由来する。定点観測データとの比較により、レジーム則や従来の全球河川モデルでは表現できなかった流量と濃度のピークタイミングのずれであるヒステリシス効果を表現することが可能になった。

キーワード：全球土砂輸送モデル、浮遊輸送、レジーム則
Keywords: global sediment transport model, suspended flow, sediment regime


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


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

陸域CO_2交換量推定の現状と課題
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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キーワード：陸域CO2交換量、大気CO2インバージョン、陸域生態系モデル
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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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

地球システムモデルMIROC-ESMを用いた2倍増CO_2濃度下における気候-炭素循環の1000年数値積分
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.

キーワード：炭素循環、気候変動、地球システムモデル、人為CO2排出に対する気候の過渡的応答
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 CO_2 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 CO_2 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 CO_2 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 CO_2 emissions are prescribed to the model and the models simulate the time evolution of CO_2 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

