Eos

Inventorying Earth's Land and Ocean Greenhouse Gases

A new special collection in AGU journals will present findings from the Second REgional Carbon Cycle Assessment and Processes (RECCAP2) study with a decade of data on greenhouse gas growth.

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The second phase of the REgional Carbon Cycle Assessment and Processes study (RECCAP2) considers all three major greenhouse gases and looks at ten land regions and five ocean regions that together cover the entire globe. Credits (top to bottom): Babak Farrokhi (CC BY 2.0); Vlad Hilitanu (public domain); Schäferle / 94 images (public domain)

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Immediate and rapid reductions in greenhouse gas emissions are needed to avoid the worst of climate change. The second REgional Carbon Cycle Assessment and Processes (RECCAP2) study is providing accurate scientific data on sources a

land and ocean regions. A new special collection of papers published across several AGU journals, will present these findings that can be used to inform national and international policymaking and action to slow and stabilize the growth rate of greenhouse gases in the atmosphere and associated climate warming.

A decade of record growth in greenhouse-gas concentrations (2010-2019)

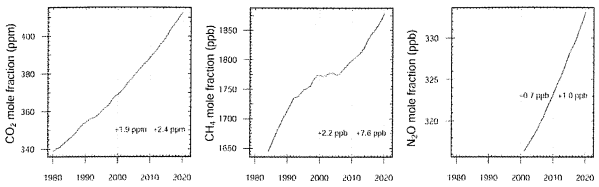
To support the development of pathways to net-zero emissions, the **second phase of the Global Carbon Project's REgional Carbon Cycle Assessment and Processes study (RECCAP2)**, was launched to provide much needed regionally and temporally resolved greenhouse gas (GHG) growth rate information.

The growth rate of greenhouse gases in the atmosphere is determined by the balance of emissions and removals from natural processes and human activities. With concentrations of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) currently at record high levels, sustained emission reductions need to begin immediately.

The **2015 Paris Agreement** and the **2021 Conference of Parties (COP26)** outlined a clear pathway to reach net-zero emissions, which is necessary to stay within the temperature change thresholds of 1.5°C and 2.0°C. Yet emission growth is headed in the wrong direction: between the decades 2000-2009 and 2010-2019 the average annual global growth rate increased from 1.9 to 2.4 ppm yr^{-1} for CO_2, 2.2 to 7.6 ppb yr^{-1} for CH_4, and 0.7 to 1.0 ppb yr^{-1} for N_2O (see Figure 1).

In 2020, and despite a temporary decrease in economic activity due to the ongoing coronavirus-19 (COVID-19) pandemic that led to a 5.4% reduction in CO_2 fossil fuel emissions (**Le Quéré et al., 2021**), the growth of atmospheric CO_2 remained similar to that of an El Niño year (+2.4 ppm), and the growth for CH_4 and N_2O was the largest ever observed, +15.7 and 1.4 ppb, respectively.

Figure 1: Global annual concentrations of CO_2, CH_4 and N_2O in the marine boundary layer. The rate of growth between 2000-2009 and 2010-2019 has accelerated for all three gases (Canadell, in press). Data from the National Oceanic and Atmospheric Administration (NOAA), https://gml.noaa.gov, accessed on January 15, 2022.



Attributing the growth of greenhouse gases to emissions and removals

The REgional Carbon Cycle Assessment and Processes study (RECCAP2) is currently in its second phase. A series of studies related to quantifying greenhouse-gas (GHG) emissions and removals for the land and ocean will be published in a **forthcoming AGU Special Collection**, with papers in the journals ***Global Biogeochemical Cycles***, ***AGU Advances***, ***JGR: Biogeosciences***, and ***JGR: Oceans***.

Following on the success of **RECCAP1**, which quantified CO_2 sources and sinks for the 1990-2009 period, the RECCAP2 activity will cover emissions and removals for all three major greenhouse gases extended to include the time period since 2010. In RECCAP2, CO_2, CH_4 and N_2O budgets will be developed for ten land regions and five ocean regions that together cover the entire globe and several 'special focus' areas (see Figure 2), including updated estimates for four integral components of the Land-Ocean-Aquatic Continuum (LOAC).

A particularly unique feature of RECCAP2 is the use of multiple state-of-art independent methods to estimate GHG fluxes that include atmospheric inversions, land-surface models, ocean biogeochemical models, data-products based on ship-observations, remote-sensing based products, and national greenhouse gas inventories. Together, these different estimates of emissions and removals provide an opportunity to identify areas of uncertainty and also to support the planning of future research campaigns that would help reduce this uncertainty.

Combined, the integration of the individual land and ocean regions to global fluxes provides additional perspective on how well we can balance emission sources with their sinks (see **Ciais et al., 2021**) with relevance to informing the mitigation targets adopted by the Paris Agreement (**Deng et al., 2021**).

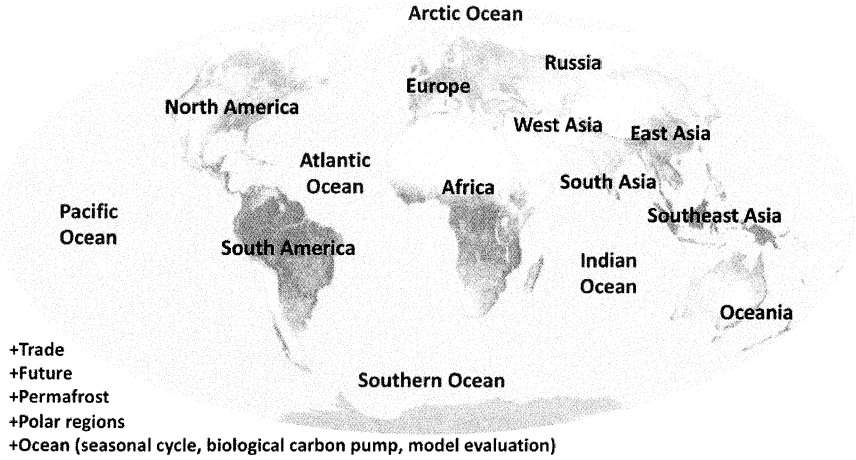


*Figure 2: The RECCAP2 land (10), ocean (5) and special topic areas to be included in the special collection. Additional estimates associated with the four LOAC sub-groups are developed for each team to use and to help reconcile top-down and bottom-up methodologies (**Kondo et al., 2021**).*

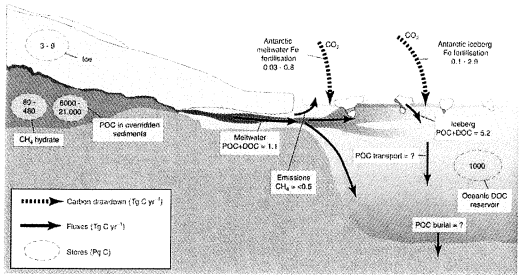
RECCAP2, an international effort with broad focus

RECCAP2 kicked off in 2019 in Gotemba, Japan, and currently includes over 150 participants from more than 20 countries around the world, representing a range of career stages, and covering areas of expertise from termite biology to making observations of greenhouse gases from space.

In addition to the ten land and five ocean regions shown in Figure 2 and included in the first RECCAP activity, RECCAP2 includes three new land studies that focus on the permafrost region, polar biogeochemistry, and future-climate feedbacks, as well as three new ocean studies that focus on the changing seasonality in the carbon cycle, the biological carbon pump and model evaluation.

The permafrost and polar regions are of special interest given how rapidly temperature in the high latitudes are changing and the need to assess whether the frozen carbon and nitrogen stored in permafrost is beginning to thaw and be released as CO_2, CH_4 and N_2O. For polar regions, a wealth of new literature is providing insight into changes in polar biogeochemistry as the ice sheets retreat with warming (Figure 3).

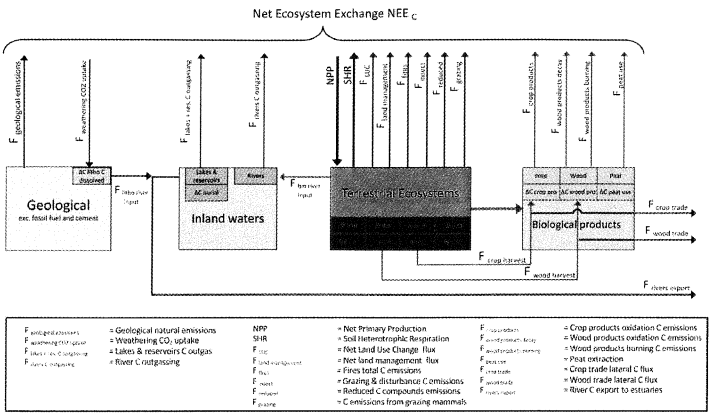
*Figure 3: A new polar regions study will be included in RECCAP-2 to contribute to our understanding of polar biogeochemistry as ice sheets retreat with warming (figure from **Wadham et al., 2019**).*



Cross-cutting activities, include a permafrost themed **Intersectoral Impact Model Intercomparison Project**, integration of the results from the **Global Carbon Budget** (**Friedlingstein et al., 2021**), the **Global Methane Budget** (**Saunois et al., 2020**), and the **Global Nitrous Oxide Budget** (**Tian et al., 2021**).

Another novelty in RECCAP2 is renewed focus on lateral biogeochemical fluxes that result from aquatic processes (transport, emissions and burial), and from the trade of agricultural commodities and wood products. Lateral exchanges of carbon were shown to be a key component of reconciling top-down with bottom-up methodologies in RECCAP1 (**Ciais et al., 2021**). Four sub-groups are working on updating the different components of the Land-Ocean-Aquatic-Continuum (LOAC; inland waters, estuaries and coastal wetlands, continental shelf, and lateral fluxes), and another group on trade fluxes. Guidelines on how to integrate and reconcile bottom-up and top-down estimates of terrestrial CO_2 fluxes including their definitions has been provided by **Ciais et al., 2022**), see Figure 4 for CO_2.

Figure 4: Definitions and terminology for the CO_2 emissions and terrestrial removals has been provided based on experience of the first RECCAP activity (Ciais et al., 2022).



Greenhouse gas budgeting to meet science and policy needs

Since the first RECCAP activity, new demands and expectations for greenhouse-gas accounting have emerged, with a need for budgets to inform more directly on the development of climate-mitigation targets and to also contribute to monitoring potential climate-carbon feedbacks in a rapidly warming world.

The **Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change**, published in the summer of 2021, made clear that "...human influence has warmed the atmosphere, ocean and land. [and that] Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred." The AR6 also provided a roadmap for avoiding 1.5°C or 2.0°C given the emergent relationship between cumulative greenhouse gas emissions and global temperature change, also known as the transient climate response to cumulative carbon emissions. This emissions roadmap quantifies, with 50 percent confidence, the 'remaining carbon budget' as 500 $GtCO_2$ and 1350 $GtCO_2$ to stay within 1.5°C and 2.0°C, or roughly 10 to 30 years at the current rate of CO_2 emissions (IPCC, in press).

In 2023, as mandated by the Paris Agreement, the first **Global Stocktake (GST)** will take place to assess global progress in reducing GHG emissions, with the preparation for the GST beginning in early 2022 through a series of Technical Dialogs.

RECCAP2 roadmap

The **RECCAP2 Special Collection** will provide a comprehensive view of the three main greenhouse gases for 2010-2019 for all land and ocean regions, including

the exchange of GHG in aquatic transport and economic trade. The new analysis provided by this series of publications will play a critical role in national and international synthesis reports, as well as contribute to providing a global aggregate view of climate mitigation as required by the Global Stocktake.

RECCAP2 comes at a time where immediate and rapid reductions in greenhouse-gas emissions are needed to avoid the worst of climate change and provides a framework for the international community to contribute to the science that will foster the success of the Paris Agreement.

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