The Global Carbon Cycle: Research, Infrastructure, and Capacity Needs

Global carbon dioxide budget (gigatonnes of carbon per year) 2006-2015

Fossil fuels & industry 9.3 ± 0.5
Atmospheric growth 4.5 ± 0.1
Land-use change 1.0 ± 0.5
Land sink 3.1 ± 0.9
Ocean sink 2.6 ± 0.5

Geological reservoirs

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The central objective of the North American Carbon Program is to measure and understand the sources and sinks of Carbon Dioxide (CO$_2$), Methane (CH$_4$), and Carbon Monoxide (CO) in North America and in adjacent ocean regions.
Fundamental Science Questions (U.S. CCSP 2011)

1) How do natural processes and human actions affect the carbon cycle, on land, in the atmosphere, and in the oceans?

2) How do policy and management decisions affect the levels of the primary carbon-containing gases, carbon dioxide and methane, in the atmosphere?

3) How are ecosystems, species, and natural resources impacted by increasing greenhouse gas concentrations, the associated changes in climate, and by carbon management decisions?
The Global Carbon Project (GCP) was established in 2001 in recognition of the large scientific challenges and critical nature of the carbon cycle for Earth’s sustainability.

The scientific goal of the project is to develop a complete picture of the global carbon cycle, including both its biophysical and human dimensions together with the interactions and feedbacks between them.
Global CO₂ emissions from fossil fuel use have flattened, in part from declining coal use in China and the U.S.

36.3 ± 1.8 GtCO₂ in 2015, 63% over 1990: 2016 estimate: 36.4 ± 2.3 GtCO₂

Source: CDIAC; Le Quere 2016; Jackson et al 2016; Global Carbon Budget 2016
CO₂ emissions in the U.S. have declined for a decade (black line). Energy efficiency (purple, e.g., buildings and cars) and switching coal for natural gas, wind, and solar (orange; carbon intensity) are offsetting GDP growth (green).
Fate of anthropogenic CO$_2$ emissions (2006-2015)

Sources = Sinks

34.1 GtCO$_2$/yr  
91%

16.4 GtCO$_2$/yr  
44%

3.5 GtCO$_2$/yr  
9%

11.6 GtCO$_2$/yr  
31%

9.7 GtCO$_2$/yr  
26%

Atmospheric concentration

The atmospheric concentration growth rate has increased steadily. The large growth in 1987, 1998, & 2015 reflects strong El Niños, which weaken the global land sink. Preliminary data suggest the atmospheric growth rate was even bigger in 2016 and thus, the land sink was likely small.

Source: NOAA-ESRL; Global Carbon Budget 2016
Remaining uncertainty in the global carbon balance

The remaining uncertainty is the carbon left after adding independent estimates for total emissions, the atmospheric growth rate, and model-based estimates for the land and ocean carbon sinks.

Source: Le Quéré et al 2016; Global Carbon Budget 2016
An ensemble of tools and data to estimate the global methane budget

**Bottom-up budget**

- Atmospheric observations
- Emission inventories
- Biogeochemistry models & data-driven methods
- Methane sinks
- Inverse models

**Top-down budget**

**Atmospheric observations**
- Ground-based data from observation networks (AGAGE, CSIRO, NOAA, UCI, LSCE, others).
- Satellite data (SCIAMACHY, GOSAT)

**Emission inventories**
- Agriculture and waste related emissions, fossil fuel emissions (EDGARv4.2, USEPA, GAINS, FAO).
- Fire emissions (GFED3 & 4s, FINN, GFAS, FAO).
- Biofuel estimates

**Biogeochemistry models & data-driven methods**
- Ensemble of 11 wetland models, following the WETCHIMP intercomparison
- Model for Termites emissions
- Other sources from literature

**Methane sinks**
- ACCMIP CTMs intercomparison.
- Soil uptake & chlorine sink taken from the literature

**Inverse models**
- Ensemble of 30 inversions (diff. obs & setup)

**Suite of eight atmospheric inversion models**
- TM5-4DVAR (JRC & SRON), LMDZ-MIO, PYVAR-LMDz, C-Tracker-CH₄, GELCA, ACTM, TM3, NIESTM)
Observed Concentrations Compared to IPCC Projections

Source: Saunois et al. 2016 ERL (Fig 1)
• 60% of global methane emissions come from tropical sources
• Anthropogenic sources drive 60% of global emissions.

Source: Saunois et al. 2016 ERL (Fig 2)
Global emissions:
- 559 TgCH₄/yr [540-568] for TD
- 734 TgCH₄/yr [596-884] for BU

TD and BU estimates generally agree for wetland and agricultural emissions.

Estimated fossil fuel emissions are lower for TD than for BU approaches.

Large discrepancy between TD and BU estimates for freshwaters and natural geological sources (“other natural sources”)

Source: Saunois et al. 2016, ESSD (Fig 5)
Figure 2: 12-month running mean of annual methane emission anomalies (TgCH₄·yr⁻¹) inferred by the ensemble of inversions (mean as the solid line and min/max range as the shaded area). (Saunois et al., unpublished)
Scaling Emissions (e.g., activity factors, land classifications and areas, etc.) remains problematic

- Land classifications and area (e.g., wetlands, permafrost, and potential double counting)
- New emissions estimates from freshwater and coastal systems are really high in places.
- BU emissions are often higher than TD, and more likely to over-estimate, but TD inversions should clarify assumptions of baselines and latitudinal transport
- We have some common uncertainties and opportunities across CO₂, CH₄, CO, and N₂O
New Effort in the Global Nitrous Oxide Budget

• New activity (not “carbon”, but...)
• Finalizing consortium of BU and TD contributors.
• Leaders, Hanqin Tian (USA) and Rona Thompson (Norway).
• Expected first budget in 2018.
REgional Carbon Cycle Assessment and Processes

Land
L1  Africa
L2  Arctic tundra
L3  Australia
L4  Europe
L5  North America
L6  Russia
L7  South America
L8  East Asia
L9  Southeast Asia
L10 South Asia

Oceans
O1  Pacific
O2  Atlantic and Arctic
O3  Southern Ocean
O4  Indian

Global
• Fossil Fuel Emissions
• Land Use Change emissions
• Riverine transport
• Atmospheric inversions
• Marginal seas
• Interior ocean
• Air-sea flux
• Coastal zones
RECCAP-2

• Currently exploring the feasibility of RECCAP-2.
• Large interest from research community to:
  – Update budgets from RECCAP-1 (end years 2009-11)
  – Incorporate more data products. Take advantage of new developments using complex empirical models
  – Take advantage of new assimilation techniques
  – Continue capacity building in countries and regions
• With initial support from ESA, RECCAP seeks sponsors for the activity.
How will we integrate Mexico more effectively into NACP?

~8 abstracts for research in Mexico at this meeting, almost exclusively for forests and soils, with a few coastal studies.
What role will stakeholder engagement and co-design play in future NACP research?
Some possible directions for research

1. Continue exploring short-term inter-annual and decadal variability in the carbon cycle for fundamental understanding (larger and smaller land sinks; greening of the biosphere, atmospheric growth rate, etc.).

2. Analyze decadal variability in the carbon cycle to understand when we can expect to see the effects of climate mitigation in the atmospheric record.

3. Emphasize carbon-climate feedbacks at lower stabilization scenarios (1.5°C, 2°C, 2.5°C). We have typically studied more extreme warming scenarios and larger potential feedbacks. This emphasis will also require new carbon-cycle work on negative emissions.

4. Constrain the factors responsible for the rapid rise in atmospheric methane, particularly the relative importance of wetlands and food production.

5. Integrate N₂O into carbon cycle science where possible. N₂O may be increasing even in regions where N fertilization use has apparently declined.