Carbon cycle and climate change, a tale of increasing emissions and uncertain sinks

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On behalf of Chapter-6

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About Carbon Biogeochemistry & the Climate Change Initiative

Benjamin Poulter, Natasha MacBean, Patricia Cadule, many collaborators
Never forget this: CO₂ remains in the atmosphere long after emissions.
CO$_2$, CH$_4$ and N$_2$O increase in the Industrial Era

Ice core records

Atmospheric monitoring
Since 1750, human activities have emitted $555 \pm 85$ PgC from fossil fuel burning and land use change.

Fossil fuel CO$_2$ emissions were 9.5 PgC yr$^{-1}$ in 2011, 54% above their 1990 level.

On average over the past 50 years, a fraction of $44 \pm 6$% of emissions remains in the atmosphere, increasing the Earth’s greenhouse effect.
Current land / ocean carbon flux anomalies
(from atmospheric CO2 inversion)

Global

North Hemis.

Tropics

South Hemis.
Comparison of CMIP5 Land/Ocean C fluxes with GCP

Ocean C flux (PgC/yr)

Land C flux (PgC/yr)

Chapter - 9
Projecting future changes with Earth System Models

Concentration driven
Policy relevant objectives

Emission driven
Free running coupled climate – carbon system

Used in AR5: CMIP5

Used in AR4: C4MIP
Simulated historical and future land and ocean carbon storage using CMIP5 models

Historical

RCP future pathways

Very large uncertainty on projected changes in land carbon storage
Compatible emissions for the RCP pathways

Uncertainties in modeled land and ocean carbon storage translate into uncertain compatible emissions.
Observed Emissions and Emissions Scenarios

Emissions are on track for 3.2–5.4°C “likely” increase in temperature above pre-industrial
Large and sustained mitigation is required to keep below 2°C

Linear interpolation is used between individual data points
Source: Peters et al. 2012a; CDIAC Data; Global Carbon Project 2013
Positive carbon climate feedbacks confirmed in AR5

Climate change will affect carbon cycle processes in a way that will exacerbate the increase of CO₂ in the atmosphere (*high confidence*)
Response to atmospheric CO$_2$ only
Response to climate change only

Source: Ciais et al. 2013 IPCC AR5

models do not include the release of permafrost C

decreasing sink

increasing sink

land

ocean
Ocean acidification

Uptake of carbon will increase ocean acidification: Virtually certain Aragonite vulnerable in parts of the Arctic & some coastal upwelling systems within 1 decade, in parts of the Southern Ocean within 1-3 decades

Further research need:
How will ocean acidification affect marine ecosystem services?
Further research need: How will ocean deoxygenation affect marine ecosystem services?
Future of the assessment: land-use emissions scenarios & evaluation

Land use emissions were not separated from net land flux in ESM for CMIP5.
All RCP pathways have low land use emissions.
Future of the assessment: land-use emissions scenarios & evaluation

Deforestation rate $(10^3 \text{ km}^2 / \text{yr})$

Green: RCP8.5 scenario over Amazon
Blue & Orange: Brazilian projections (LUCCME in blue and SIMAMAZONIA)

Soares Filho et al., 2006

Research needs:
Understand differences between global and regional land use scenarios
Reconcile food security scenarios (MA, FAO) with climate scenarios (IPCC)
Future of the assessment: land-use emissions scenarios & evaluation

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Future of the assessment: Nutrient limitation on terrestrial C storage

Offline model with N & P limitations

Only 1-2 Earth System Models included N-limitations in CMIP5 and found a smaller sink response to CO$_2$ and climate

Goll et al. 2012
Evaluation of C-N 11 terrestrial models using Free-Air CO2 Enrichment experiment: Net Primary Production

NPP (control CO2)

NPP (double CO2)

Observed Models

Zaehle et al. 2014
Future of the assessment: CH₄ and N₂O climate feedbacks

Feedbacks that were not included in CMIP5 models:
- Climate sensitivity of wetland CH₄ emissions
- Stability of ocean CH₄ hydrate pools
- Response of soil N₂O emission processes to climate and elevated CO₂
- Response of ocean N₂O emissions to changes in O₂ & circulation
Future of the assessment: ‘cold’ carbon processes, permafrost C

1670 Pg C
In permafrost

An Earth System Model with permafrost carbon processes was driven by RCP emissions
Result: higher projected warming (0.13 to 1.7°C) and CO₂ release (70 to 500 PgC)
Key « missing » processes: soil ice, soil C vertical distribution, soil C pools
decomposition rates [C:N], fire & thermokarst

Mc Dougall et al. 2013
Carbon vs physical parameters uncertainty

Sensitivity analysis with 1 ESM (HadCM3 – SRES-A1B) varying
Atmospheric physics parameters
Terrestrial carbon cycle parameters

Booth et al. 2012
Links with CCI projects?

Models need to be evaluated/optimized (especially for critical “long term C-cycle” processes)

- Need comprehensive global data-sets

- Need monitoring strategies to monitor Carbon fluxes and stocks

- Need coherent data sets linking Carbon, Water, other nutrients cycles
Need for more atmospheric CO2 data!

Regional fluxes from atmospheric CO2 inversions (flux anomalies PgC/yr)

- a) N. America
- b) Europe
- c) N. Asia
Need for more atmospheric CO2 data!

Regional fluxes from atmospheric CO2 inversions (flux anomalies PgC/yr)

Potential of satellite data:
- In-situ network may be limited
- Large potential of satellite data but « any bias » is critical!

CCI-GHG project

Global satellite observations
Global information on near-surface CO₂ & CH₄

Upper layer CO₂ & CH₄

SCIAMACHY/ENVISAT
TANSO/GOSAT
New land cover map (CCI) vs Old Olson land cover Map

Land surface model (ORCHIDEE)

LAI Diff : CCI - Olson

Atmospheric transport model

Significant impact on the simulated atm [CO2] at Point Barrow
Crucial need to monitor forest biomass content!

- IPCC model uncertainties are not decreasing
- Need Biomass data to validate global model simulations
- Current estimates from Remote Sensing still need to be improved!

(Note: paper in review in GEB: “Markedly divergent estimates of Amazon forest carbon density from ground plots and satellites”)
Comparison of CMIP5 land C stocks with “ref data”

Vegetation Carbon (PgC)

Soil (+ litter) Carbon (PgC)

Reference

Anav et al. 2013
Data Assimilation to better constrain model parameters

- Assimilation into LSM (ORCHIDEE) → Parameter optimisation
- Potential large decrease of land carbon storage (mainly from soil)

"CMIP5 – RCP8.5"
Conclusions, future challenges

Few good guys
- CO₂ fertilization of NPP (−)
- CO₂ driven ocean uptake (+)
- Longer northern growing seasons (+)
- Land management (−)

(-/+): Level of understanding in parenthesis

Many potentially bad guys
- Intense land use scenarios (−−)
- Permafrost C emissions (−−)
- Wetland emissions increase (−−)
- Fire emissions increase (−−)
- Emerging Nutrient limitations (−−)

CCI should focus on data stream to inform on the « long-term » carbon cycle…
Carbon - Biogeochemistry and CCI projects

Case of Amazon forest potential dieback

Remote sensing observations informed modelers to consider:
• Depth of tropical soils
• Rooting strategies
• Leaf cycle and shedding
• Forest mortality and drought
• Species diversity

New remote sensing approaches are needed:
- Sentinels and BIOMASS missions
  - Higher temporal frequency
  - Cloud/aerosol treatment
  - Spatial resolution
  - Microwave spectral resolution
Case of boreal forest changes

• 5-13 day increase in onset of boreal growing season

• Boreal forest browning detected in satellite and plot measurements

• DGVM models agree with satellite trends in growing season length

• But high disagreement in LAI dynamics

<table>
<thead>
<tr>
<th>Vegetation Type</th>
<th>Declining</th>
<th>Increasing</th>
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<tbody>
<tr>
<td>All</td>
<td>86.1 (3%)</td>
<td>266.2 (9%)</td>
</tr>
<tr>
<td>Needle-leaved Evergreen Forest</td>
<td>37.8 (6%)</td>
<td>25.9 (4%)</td>
</tr>
<tr>
<td>Sparse Deciduous Forest (mostly Larch)</td>
<td>18.1 (4%)</td>
<td>64.4 (15%)</td>
</tr>
<tr>
<td>Herbaceous or Shrub</td>
<td>4.8 (1%)</td>
<td>31.9 (6%)</td>
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Thank you for your attention

For more insights on land / ocean model simulations and atmospheric inversions: http://www.globalcarbonatlas.org/
Simulated changes in dissolved oxygen
Positive carbon-climate feedbacks means less compatible emissions.
Terrestrial Sink: DGVMs

Terrestrial sink from DGVMs is consistent with the residual sink estimated from the carbon budget
2.7±1.0 GtC/yr for 2003–2012, 1.7±1.2 GtC/yr in 2012

DGVM: Dynamic Global Vegetation Model
Source: Le Quéré et al 2013; Global Carbon Project 2013