What satellites tell us about the global carbon budget

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Overview

Different satellites are used to infer different aspects of the global carbon budget.

To varying degrees they provide:
- Gross fluxes vs. net annual changes
- Attribution
- Full carbon accounting
Overview

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- To varying degrees they provide:
  - Gross fluxes vs. net annual changes
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  - Full carbon accounting

Terrestrial emphasis.
Questions:

What is the annual carbon budget?
- Atmosphere, fossil fuels, oceans, land

How is the budget changing?
- Response to climate change
- Are the sinks changing?

What are the drivers of the net terrestrial flux?
Questions:

- What is the annual carbon budget?
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- How is the budget changing?
  - Response to climate change
  - Are the sinks changing?

- What are the drivers of the net terrestrial flux?  [Attribution]
Five approaches with satellites

- GOSAT and OCO
- “Greenness” for GPP, NPP (?), NEP (??)
- Change in forest area
  - Co-located with aboveground carbon density
- Changes in aboveground C density
Issues

- Gross fluxes vs. net annual changes
- Attribution
- Full carbon accounting
1. **GOSAT and OCO**

- All 4 carbon reservoirs
- Daily to monthly budget
- A net flux (partial gross)
- Some attribution
  - spatial
  - land vs. ocean
- Model of atmospheric transport?
2. “Greenness” for GPP, etc.

- Land, ocean (?)
  - NDVI, ocean color
- Gross fluxes
  - Ocean: ~100 PgC/yr - diffusion
  - Land: ~120 PgC/yr - photosynthesis
- Respiration?
2. “Greenness” for GPP, etc.

- Land, ocean (?)
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- Respiration?

Land and ocean *net* fluxes are 1-2 PgC/yr
3. Change in forest area

- Carbon density?
- Carbon model required
  - For different carbon pools
  - For time lags (legacy effects)
- Attribution?
  - Management vs. natural
Carbon sources and sinks on land result from \textit{two} processes

1. Direct human effects (management)
   - Croplands, pasturelands
   - Forestry
Carbon sources and sinks on land result from two processes

1. Direct human effects (management)
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2. Indirect and natural effects
   - Environmentally induced changes in metabolism
Perturbation of Global Carbon Budget (1850-2006)

Le Quéré, unpublished; Canadell et al. 2007, PNAS
Changes in Land Use (LULCC)
Response Curves

Living Biomass

Wood Products

Slash

Soil Carbon

Total Carbon

Annual net flux

Years

MgC/ha

Bookkeeping
Annual emissions of carbon

Graph showing the annual emissions of carbon from 1850 to 2010, with two lines indicating land-use change and fossil fuels.
## Uncertainties in estimates of flux from LULCC

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<thead>
<tr>
<th>Uncertainty</th>
<th>PgC yr(^{-1})</th>
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<td>Tropical peatlands</td>
<td>+0.3 ± 0.1</td>
<td>SE Asia</td>
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<td>Settled lands</td>
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<td>Woody encroachment</td>
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Houghton et al., 2012
Perturbation of Global Carbon Budget (1850-2006)

Le Quéré, unpublished; Canadell et al. 2007, PNAS
Two questions for this residual terrestrial sink:

- What causes it?
  - i.e., attribution
- Will it continue?
4. Forest area co-located with aboveground carbon density

Almost....

- Baccini et al. (2012)
- Harris et al. (2012)
4. Forest area co-located with aboveground carbon density

Other terrestrial carbon pools
- Belowground biomass
- Coarse woody debris
- Harvested products
- Soil carbon
Terrestrial pools of carbon
4. Forest area co-located with aboveground carbon density

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- Attribution
  - E.g., was deforestation caused by management or natural disturbance?
5. Changes in aboveground carbon density
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Dubayah et al. 2010
5. Changes in aboveground carbon density

- Other terrestrial carbon pools
- Attribution
- Some processes and activities missed
5. Changes in aboveground carbon density

- Other terrestrial carbon pools
- Attribution
- Some processes and activities missed
- But other processes are included!
5. Changes in aboveground carbon density

- Other terrestrial carbon pools
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- Some processes and activities missed
- But other processes are included

i.e., the Residual Terrestrial Sink
(or some part of it)
Perturbation of Global Carbon Budget (1850-2006)

CO₂ flux (Pg C y⁻¹)

- Fossil fuel emissions
- Atmospheric CO₂
- Natural effects (land)
- Ocean

Le Quéré, unpublished; Canadell et al. 2007, PNAS
The Residual Terrestrial Sink =

Net terrestrial sink - LULCC source
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Net terrestrial sink - LULCC source

Approach #5

Approach #4
Until now there has been no way to measure the residual terrestrial sink.

It has been inferred from the global carbon budget.
Until now there has been no way to measure the residual terrestrial sink.

It has been inferred from the global carbon budget.

It’s a net sink, presumably including the metabolic responses of land to CO$_2$, climate, N deposition, etc.
Questions for the Residual Terrestrial Sink

- What’s the annual carbon budget?
  - Atmosphere, fossil fuels, oceans, land
- How is the budget changing?
  - Response to climate change
  - Are the sinks changing?
  - How long will they last?
- What are the drivers of the net terrestrial flux?
Now, 2 approaches for RTS

1. Refinement of the other budget terms
   - Including the land-use term
2. Direct measurement of changes in aboveground carbon density
   a. identifying those that are LULCC
   b. and those that are not LULCC (RTS)
Summary: Five approaches with satellites

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Net flux
Gross flux
Net fluxes
Summary: Five approaches with satellites

- GOSAT and OCO
- “Greenness” for GPP
- Change in forest area
  - Co-located with aboveground carbon density
- Changes in aboveground C density*

* This approach is promising.
Thank you
The Global Carbon Budget

Global carbon dioxide budget (gigatonnes of carbon per year)

- FF: Fossil fuel & cement
  - 1990-2000: 6.4 ± 0.4
  - 2000-2008: 7.7 ± 0.5

- AG: Atmospheric growth
  - 1990-2000: 3.1 ± 0.1
  - 2000-2008: 4.1 ± 0.1

- Land use change
  - 1990-2000: 1.6 ± 0.7
  - 2000-2008: 1.4 ± 0.7

- OS: Ocean sink
  - 1990-2000: 2.2 ± 0.4
  - 2000-2008: 2.3 ± 0.5

- Land sink
  - 1990-2000: 2.6 ± 0.9
  - 2000-2008: 2.7 ± 1.0

- MS = FF-AG+LU-OS

Credit: IGBP / GCP

Global Carbon Project 2009
Tipping Points in the Carbon-Climate System

If the natural sinks on land and ocean are beginning to decline:

1. more of the carbon emitted stays in the atmosphere,
2. the rate of climatic disruption increases,
3. it is more difficult to manage the carbon cycle,
4. the carbon cycle is not behaving as the projections assumed.
...and there are two ways to do that:

- Reduce emissions
- Increase uptake by land, oceans
We could stabilize the concentration of $CO_2$ in the atmosphere quickly by:

• reducing emissions by about 50%

And we could do that by:

• managing forests
Three land management mechanisms for the near term

- Stop deforestation
- Allow existing forests to grow
- Expand the area of forests

Total CO$_2$ reduction: 3-5 BMT yr$^{-1}$
Global Carbon Budget  2000-2010

**Sources**
- Fossil fuels 7.9 ±0.5 (BMT C/yr)
- Land-use change 1.0 ±0.7

**Sinks**
- Atmosphere 4.1 ±0.2
- Oceans 2.4 ±0.5
- Residual terrestrial 2.4 ±1.0
### Global Carbon Budget 2000-2010

<table>
<thead>
<tr>
<th>Source</th>
<th>2000-2010</th>
<th>With management</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sources</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fossil fuels</td>
<td>7.9 ±0.5</td>
<td>7.9</td>
</tr>
<tr>
<td>Land-use change</td>
<td>1.0 ±0.7</td>
<td>-3 to -5</td>
</tr>
<tr>
<td><strong>Total Sources</strong></td>
<td>8.9</td>
<td>~4</td>
</tr>
</tbody>
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<td>4.1 ±0.2</td>
<td>0.0</td>
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<tr>
<td>Oceans</td>
<td>2.4 ±0.5</td>
<td>2.3</td>
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<td>Residual terrestrial</td>
<td>2.4 ±1.0</td>
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Note: The total sources are approximately 4 billion metric tons of carbon (BMT C/yr) for the period 2000-2010.