Changing CO₂ seasonal amplitude: A synthesis

Ralph Keeling
Scripps Inst. Oceanography
Barrow seasonal amplitude trend

"Kelley" data

NOAA data
Fall/winter bump, evidence for increased respiration (Piao et al., 2008, Nature)

Ciais/Piao et al. next paper?


zero-crossing advancing

Amplitude increase

Figure from Graven et al. Science 2013
Graven et al 2013, Science study

Compared airborne campaign data from ~1960 (IGY) and ~2010 (HIPPO)
Major conclusions:

% Changes in middle troposphere were larger than at either Barrow or Mauna Loa!

Longer growing season alone cannot explain changes. Uptake in mid summer must also have increased.
Relevance of crop changes

Crop trends account for ~50% of amplitude trend at Mauna Loa and global average CO2

Account for 17 to 25% of amplitude trend detected from airborne data
How do models compare?

It depends on what signal is compared to!

(1) Mid-troposphere 50-year trend

(2) Surface stations in network since ~1980 (satellite era)

(3) Mauna Loa or global average CO$_2$
## How do models compare?

<table>
<thead>
<tr>
<th>Publication</th>
<th>Model(s)*</th>
<th>Mid trop 1960-2010</th>
<th>Surface stations since ~1980</th>
<th>Mauna Loa or global avg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graven et al. (2013)</td>
<td>CMIP5</td>
<td>All models too low</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forkel et al. (2016)</td>
<td>LPJml</td>
<td></td>
<td>partial success</td>
<td></td>
</tr>
<tr>
<td>Thomas et al. (2016)</td>
<td>MsTMIP</td>
<td>All models too low</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wenzel et al. (2016)</td>
<td>CMIP5</td>
<td></td>
<td>partial success</td>
<td></td>
</tr>
<tr>
<td>Ito et al. (2017)</td>
<td>MsTMIP</td>
<td></td>
<td>partial success</td>
<td></td>
</tr>
</tbody>
</table>

*All model studies suggest a larger role for changes in photosynthesis than respiration in driving amplitude changes.*
Models capture greening but not amplitude increases (Thomas et al., 2016)
How is amplitude change related to northern land sink?

- Randerson (GBC, 1997) Amplitude increase consistent with ~2 Pg northern sink if driven by increase in NPP and passive respiration response.
- Welp et al. (Biogeosciences, 2016) resolve changes in amplitude and sink from inversions, 1985-2012.
  - Boreal zone: strengthening annual sink (0.2 Pg/yr over 25 yrs)
  - Arctic: No annual trend (to within 0.1 Pg yr).
- Commane et al. (PNAS, 2017) show Alaska trending towards stronger net source.
Welp et al (Biogeosciences, 2016)
Possible drivers of increases in June/July net CO$_2$ uptake:

(1) Warming-effect on photosynthesis (growing season, nitrogen, etc.)
(2) Leaf-level CO$_2$ fertilization effect
(3) Changes in vegetation: cover, structure, leaf area (woody encroachment, treeline migration)
(4) Changes in disturbance, especially fire
(5) Shifts in evergreen/deciduous
Some needs/objectives

Datasets:
• maps of deciduous vs evergreen fractions over time
• tree & understory cover over time
• snow depth over time
• stand age over time
• consistent long-term fire databases/records

Modelling:
• robust long-term inversions
• better constraints on long-term CO$_2$ fertilization responses
• warming effects on nutrient availability
• better representation of drought stress (esp. late summer)
• better phenology
Ongoing ABoVE efforts

Brendan Rogers et al. - Develop data driven model of seasonal amplitude changes

Colm Sweeney et al. - Atmospheric measurements and synthesis

Welp/Keeling et al. – Relationship between seasonal changes in CO$_2$ and $\delta^{13}$C

Roedenbeck/Keeling et al – Synthesis inversion from 1955 using T-based regression

Emily Wilson et al. – Miniaturized CO$_2$ and CH$_4$ column measurements (laser heterodyne)
Ongoing research by Brendon Rogers et al

Provide a bottom-up, data-constrained, hypothesis-driven modeling assessment of increasing CO₂ amplitudes

- Synthesis of in situ CO₂ fluxes
- Gridded monthly flux products
- Landsat-based deciduous fraction
- Time series of Plant Functional Types
- AVHRR-based fire history for Siberia
- Circumpolar records of fire disturbance
Mini-LHR Update
For more info contact: Emily Wilson/614
Emily.L.Wilson@nasa.gov, 301-614-6730

Overview: The mini-LHR is a miniaturized laser heterodyne radiometer that measures column CO$_2$ and CH$_4$ (precision 1 ppm CO$_2$, 10 ppb CH$_4$ for one hour data products for clear sky conditions)

Status:
• Analysis software uses Planetary Spectrum Generator and MERRA data. More info: https://psg.gsfc.nasa.gov, contact Geronimo Villanueva, geronimo.l.villanueva@nasa.gov.
• Mini-LHR is now completely solar powered and fits on a backpack for access to remote areas.
• Side-by-side comparison with TCCON at Armstrong planned late spring 2018.
• Current instrument cost is ~$10K. It is not commercially available yet – but we are building the first 20 for teams to test.

Look for column CO$_2$ and CH$_4$ data sets coming to our webpage (https://mini-lhr.gsfc.nasa.gov/) in Spring 2018:
- Hi-SEAS (https://hi-seas.org/), & MLO
- Bonanza Creek Research Forest
- Edinburgh Scotland (Royal Observatory)
- Amazon river basin
OCS seasonal cycles - work in progress by Abhishek Chatterjee
Thank You