Understanding the Causes and Implications of Enhanced Seasonal CO$_2$ Exchange in Boreal and Arctic Ecosystems (Rogers CARBON 2016)

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Increasing seasonal cycle amplitude (or “The hyperventilating biosphere”)

Randerson et al. (1997)

Graven et al. (2013)
Increasing seasonal cycle amplitude (or "The hyperventilating biosphere")

Graven et al. (2013)

Randerson et al. (1997)
Models attribute to climate change & CO₂ fertilization

Similar findings by Zhao et al. (2016), Thomas et al. (2016), Ito et al. (2017), Piao et al. (2017), and others
But model performance is…”iffy”

- Cannot represent observed amplification

Thomas et al., 2016
But model performance is...”iffy”

- Cannot represent observed amplification
- Overestimate LAI and greening

Murray-Tortora et al., 2013
But model performance is…”iffy”

- Cannot represent observed amplification
- Overestimate LAI and greening
- Misrepresent impact of warming on CO₂ uptake (e.g., Zhu et al., 2019)

Murray-Tortora et al., 2013
But model performance is...”iffy”

- Cannot represent observed amplification
- Overestimate LAI and greening
- Misrepresent impact of warming on CO$_2$ uptake (e.g., Zhu et al., 2019)
- Argued that CO$_2$ fertilization can only explain minor fraction (e.g., Kohlmaier et al., 1989; Randerson et al., 1997; Girardin et al., 2011)

Murray-Tortoralo et al., 2013
Changing vegetation distributions are a factor
Changing vegetation distributions are a factor in climate change and CO₂ fertilization as shown by Welp et al., 2006. The change in photosynthetic functional types (PFTs) is almost equally as important as climate change and CO₂ fertilization (Forkel et al., 2016).
Changing PFTs almost equally as important as climate change and CO$_2$ fertilization (Forkel et al., 2016)

Major component of PFT changes due to wildfire
The dark horse of winter respiration

Natali et al., in press

Welp et al., 2016
And gosh darn it, the continents behave differently!!
Approach

New / improved data products
Better use of existing products
Improved modeling approaches

Data-driven modeling approach
Hypothesis-driven
Bottom-up and top-down approaches
Multiple co-benefits to NASA & scientific community
Approach

Summer productivity
- Climate
- CO₂ fertilization
- Vegetation distributions (fire & non-fire)
- N cycling
- Permafrost dynamics
- Physiology

Winter respiration
- Climate
- Vegetation distributions
- Snow cover & depth
- Productivity (labile substrates)
New data products
Deciduous fraction

Ground samples and mid-summer clear pixel availability for Landsat 7 ETM+ and Landsat 8 OLI (2013–2018)

Massey et al. (in prep)
New data products
Deciduous fraction

Fort Greely, AK

Massey et al. (in prep)
New data products

Siberian historical fire scars

Soja et al. (in prep)
New data products

In-situ CO$_2$ flux synthesis

- Working with broader arctic-boreal flux community
- Two workshops in 2018
- Aggregating, standardizing, and synthesizing CO$_2$ flux observations from EC towers & chambers
- Previous literature, available repositories, and community contributions
- Site list and mapping tool soon to be archived
Modeling approaches

Flux upscaling

Machine learning

Soil Temp
Landcover
Air Temp
LAI
Tree cover
GPP
Sand
SOC
Moisture
Moisture-JJ
Clay

Winter CO₂ Flux Total

Oct - Apr

η CO₂-C m⁻² yr⁻¹

≥ 200
180
160
140
120
100
80
60
40
20

Natali et al. (in press)
Modeling approaches
Coupling observational products & data-driven models

Inputs
- Climate
- Vegetation type (fire & non-fire)
- Tree cover
- Snow cover

Models
- Our upscaling model
- FluxCom
- CLM-SP
- Polar VPRM

Individual & combined influences on seasonal CO₂ fluxes
Primary issues

- Too productive in high latitudes & no latitudinal gradient (arctic shrubs and grasses much too productive).
- Large dead zones (visible with PFT-specific output).
- Phenology biases:
  - Late onset bias for shrubs and deciduous trees.
  - Early onset and peak GPP bias for needleleaf evergreen.
  - Late offset bias for All PFTs.
Modeling approaches
Community Land Model

Model development (mechanistic approach)

- Improved temperature scaling of photosynthetic parameters ($V_{cmax}$ & $J_{max}$).
- Improved allocation parameters.
- Onset based on soil temperature, air temperature, and snow depth.
- Offset based on latitudinal gradient in daylight length.
- Other bug fixes.

Birch et al. (in prep)
Modeling approaches
Atmospheric Transport

CAMS & CarbonTracker inversion products $\rightarrow$ GEOS-Chem atmospheric transport model

Lin et al. (in review)
Modeling approaches
Atmospheric Transport

CAMS & CarbonTracker inversion products → GEOS-Chem atmospheric transport model

Lin et al. (in review)
Future directions

• Data products mostly finalized. In process of publishing & archiving

• Next year focused on conducting & analyzing model experiments

• Our focus is on the CO$_2$ amplitude phenomenon, but our research & data products should be useful for a variety of other NASA investigations and the scientific community