Integrating Tower EC, Remote Sensing and Ecosystem Modeling to Monitor Arctic-boreal CO₂ & CH₄ Fluxes

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Important in Rapidly Changing Arctic Environments
One accurate measurement is worth a thousand expert opinions

Grace Hopper
But the Arctic is a Big Place!

And In Situ Measurements are Expensive
We Need Repeated Measurements at Various Scales

Satellites

Airborne Remote Sensing

Flux Towers

Flux Chambers
Using a Suite of Satellite Observations to Monitor Change
Satellite Observations: Monitoring Regional Change

1,2 AMSR Surface Water

3 AMSR Non-Frozen Season

4 SSMI/MODIS Active Layer Depth

5 AVHRR/MODIS NDVI

1 Watts et al. 2014 ERL; 2 Du et al. 2016 In Press; 3 Kim et al. 2015 ERL; 4 Park et al. 2015 RSE; 5 Didan et al. 2010 IGRSS
EC Tower Flux Measurements

Critical! Needed to Calibrate/Validate Ecosystem Models
Primary Research Objectives

Use satellite remote sensing & tower EC data to:

- **Identify patterns in Arctic-boreal CO$_2$, CH$_4$ fluxes**
  - Environmental drivers of GPP vs. Reco
  - Changes in landscape carbon sink & source activity
  - High-res (daily; ≤ 9 km) carbon maps

- **Determine wetland CH$_4$ contributions**
  - Regional emission magnitudes; GHG budget impact
  - Interannual changes in wetland extent
  - Inundated landscape constraints vs. sub-surface water table & soil moisture

- **Assess regional landscape change & vulnerability**
  - Surface & soil wetting/drying vs. temperature controls
  - Active layer variability
  - Vegetation start & length of season
  - Snow cover properties & effects on carbon cycling
Integrate with Ecosystem TCF Modeling for Regional Carbon Monitoring\(^{(1,2)}\)

\[
GPP = \varepsilon \times PAR \times FPAR \\
\varepsilon = \varepsilon_{\text{max}} \times f(\text{VPD}) \times f(T_{\text{min}}) \times f(\theta) \\
R_{\text{aut}} = (1-CUE) \times GPP
\]

\[
R_{\text{het}} = f(C_{\text{pool}}, T_s, \theta)
\]

\[
R_{\text{CH}_4} = (R_0 \times \phi_s) \times C_{\text{pool}} \times Q_{10}(T_s-T_p)/10
\]

Aerobic vs Anaerobic

1\(^{\text{Watts et al. 2014 Biogeosciences}}\)  2\(^{\text{Kimball et al. 2015 SMAP L4_C User Guide}}\)
TCF (SMAP L4C) CO2 Model

$$\text{NEE}(t) = \frac{d\text{SOC}}{dt} = \text{RECO}(t) - \text{GPP}(t)$$

$$\text{RHET}(t) + \text{RAUT}(t)$$

$k_{\text{max}} \times \text{SOC}(t) \times \text{Scalars}$

$\epsilon_{\text{max}} \times \text{Fpar} \times \text{Par} \times \text{Scalars}$

Environmental Scalars: Satellite RS (e.g. SMAP, AMSR) & Reanalysis Inputs

Kimball et al. 2015  *SMAP L4_C User Guide*
TCF CH4 Model

1. Wetland CH$_4$ production

2. Three flux pathways

   • Vegetation
     
     \[ F_{plant} = C_{CH4} \times C_{p} \times S_{grow} \times \lambda \times P_{trans} \times (1 - P_{ox}) \]
     
     \[ S_{grow} = f(GPP), \quad \lambda = f(u_{m}) \]

   • Diffusion
     
     \[ F_{diff} = (C_{CH4} \times \tau \times D_{e} (C_{CH4} - Air_{CH4}) (1 - \theta)) - R_{ox} \]
     
     \[ \tau = f(T_{s}), \quad D_{e} = f(\theta), \quad R_{ox} = f(T_{s}) \]

   • Ebullition
     
     \[ F_{ebull} = (C_{e} - \phi_{s}) \times (C_{CH4} - \nu_{e}) \]

Satellite and/or Reanalysis Inputs

\[ R_{CH4} = (R_{o} \times \phi_{s})C_{met} \times Q_{10p}^{(T_{s} - T_{ref})/10} \]

CO$_2$ Model Inputs

\[ F = \text{Vegetation} \]

\[ F = \text{Diffusion} \]

\[ F = \text{Ebullition} \]

\[ F = \text{Satellite and/or Reanalysis Inputs} \]

\[ F = \text{CO$_2$ Model Inputs} \]

1Watts et al. 2014, Biogeosciences
### Climate Variability

<table>
<thead>
<tr>
<th></th>
<th>BEO/BES</th>
<th>ATQ</th>
<th>IVO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elev. (m)</td>
<td>6</td>
<td>15</td>
<td>568</td>
</tr>
<tr>
<td>MAT (°C)</td>
<td>-12.6</td>
<td>-9.7</td>
<td>-7.9</td>
</tr>
<tr>
<td>MSP (mm)</td>
<td>72</td>
<td>100</td>
<td>210</td>
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<tr>
<td>ALD (cm)</td>
<td>-36</td>
<td>-50</td>
<td>-60</td>
</tr>
</tbody>
</table>

### Vegetation Communities

**BES/BEO:** Inundated & polygonal tundra (grass, sedge, moss)

**ATQ:** Moist sedge tundra & tussock

**IVO:** Tussock tundra & dwarf shrub, moss and lichen
NASA ABoVE TCF Ecosystem Modeling

**BES**

- **Tower EC Flux**
- **TCF Model (in situ data)**
- **TCF Model (reanalysis)**

**Wet Sedge**
- NEE: $-4 \text{ g C m}^{-2} \text{ yr}^{-1}$
- $\text{CH}_4$: $3.5 \text{ g C m}^{-2} \text{ yr}^{-1}$

**IVO**

- **Non-FZN**
- **FZN**

**Tussock**
- NEE: $-12 \text{ g C m}^{-2} \text{ yr}^{-1}$
- $\text{CH}_4$: $6.5 \text{ g C m}^{-2} \text{ yr}^{-1}$
Model Scaling of Carbon Fluxes

1. Beta release of NASA SMAP L4 Carbon Maps
   - Radiometer informed soil moisture & temp.
   - 9 km spatial res. & daily NEE, GPP, Reco fluxes
   - Data from April 2015 onward

2. Off-line 1 km TCF CO$_2$ + CH$_4$ Flux Maps (In Progress)
   - Regional validation using EC tower data
     (32+ sites; 15 have CH$_4$ records)
   - Evaluation against airborne & tall tower obs., inverse models

1SMAP L4 Global Daily Carbon Products: http://nsidc.org/data/SPL4CMDL
Challenges for Regional Modeling

- **Flux tower data**
  - Accessibility (not all datasets on Fluxnet, etc.)
  - Flux processing, QC, & gap-filling
  - Sparse pan-Arctic tower network; data overlap needed
  - Limitations to tower longevity ($)

- **Modeling**
  - Arctic-boreal wetland/veg. maps; land cover classifications often inconsistent
  - Reanalysis data are spatially coarse (0.5°); 3-9 km ideal
  - Water inundation maps are coarse (e.g. 6-25 km)

- **Surface flux maps vs. atmospheric observations**
  - Available airborne observations limited in space & time
  - Regional inverse modeling (tall towers?)
  - Gauging CH$_4$ contributions from lakes & rivers
Thank You!