The Airborne Measurements of Methane Fluxes (AIRMETH) 
Arctic Campaign

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Background

Global CH4 budget for the past three decades [$Tg(CH_4) yr^{-1}$]

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[IPCC, The Fifth Assessment Report AR5]

- Wetlands are the dominant natural source of CH$_4$ over the globe
- Still large range of wetland emission estimates
- Permafrost wetlands not separately assessed
- Process-based models tend to be calibrated at individual wetland sites and then applied across the globe
- Spread in top-down approach is due to a lack of observations
Background

Global CH4 budget for the past three decades [Tg(CH$_4$) yr$^{-1}$]

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<tr>
<th>Tg(CH$_4$)yr$^{-1}$</th>
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Eddy Covariance & Chamber measurements

- Continuous in-situ observations of the surface-atmosphere exchange
- Well suited for local process studies and for investigating the temporal variability of fluxes

But:
- Rare in the Arctic permafrost zone
- Site selection is bound by logistical constraints among others
- These observations cover only small areas that are not necessarily representative of the region of interest
Airborne Flux Measurements

AIRMETH 2012, North Slope of Alaska, 28 June - 2 July 2012
24 flight hours out of Barrow / 3500 km / 40 vertical profiles

- Closing the gap between tower and satellite measurements
- Assessing heterogeneity of sources and sinks

But:
- Expensive and provide a snapshot at a particular time
Research Aircraft POLAR5

Los Gatos RMT-200
$\text{CH}_4$, precision: 3 ppb @ 10 Hz

messWERK GmbH
3D wind, precision: 0.1 m/s @ 100Hz
Temperature, precision: 0.01 K @ 100 Hz

- Inertial Navigation System
- GPS
- Radar altimeter
- Laser altimeter
- Radiation thermometer
- Pyranometer
- Pyrgeometer
- Total Temperature Sensor
- Humidity / Temperature sensors
- Photo / Video cameras
Workflow

Aims
• Link the measurement to surface properties
• Land cover specific CH$_4$ flux
• Maps of the predicted CH$_4$ fluxes
• CH$_4$ budget and budget uncertainty
Workflow

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**Low-level flights**
- 3D location
- 3D wind vector
- $\text{CH}_4$ concentration
- Humidity
- Air pressure & temperature
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- Spatially resolved turbulence statistics
- Spatially resolved turbulent fluxes
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- Spatially resolved contributions of land cover, LST, EVI, NDVI, albedo to each observation of CH$_4$ flux
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Machine learning
- Environmental response functions
Atmospheric Scales

Excluded 20 runs (~1600 km) of 44 (~3500 km)

- above surface layer (> 10% boundary layer height) measured flux not representative of surface flux
- below mechanical blending height $z_{blend}$ turbulence not representative of mechanical setting in entire source area

\[ z_{blend} = \frac{u_* L_{hetero}}{U C_{blend}} \]  

[Mahrt 2000, Bange 2007]
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[Mahrt 2000, Bange 2007]
Wavelet Analysis

- Spatially resolved turbulence statistics and LE, H, CH$_4$
- Large contribution from structures >1 km
- Mesoscale transport is not “visible” in flux tower measurements
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Footprint Analysis

Footprint model of Kljun et al. (2004)

80% cum. footprint distance:

- 250–8400 m, median 800 m
- Spatially resolved contribution of land cover, LST, NDVI, EVI etc to each flux observation
Turbulent CH$_4$ Fluxes

- Purple: 95% confidence interval, grey: 1 $\sigma$ random sampling error
- Color scale: dominant LST and NDVI in each 100 m slice

QA / QC tests:
- Steady state tests [Foken and Wichura, 1996; Vickers and Mahrt, 1997]
- ITC test [Foken, 2008]
- Rejection of fluxes below 95% detection limit
Machine Learning

Boosted Regression Trees

- ML approach tries to learn the response by observing inputs and responses and finding dominant patterns (regression tree)
- Boosting combine large numbers of relatively simple tree models adaptively, to optimize predictive performance
Boosted Regression Trees

\[ \text{CH}_4 \text{ flux [mg m}^{-2} \text{ hr}^{-1}] \]

<table>
<thead>
<tr>
<th>Aircraft measured</th>
<th>LTFM predicted</th>
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<tbody>
<tr>
<td>-2</td>
<td>2</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
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<tr>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>8</td>
</tr>
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\[ f(x) = 0.03 + 0.99x \]

MAD(res) = 3%

\[ R^2 > 0.99 \]
Environmental Mean Response Functions

- $F_{\text{CH}_4 \text{ mass - Fit}_F}$
- $F_{\text{LST MODIS}}$ (9.6%)
- $F_{\text{mix}}$ (8.3%)
- $F_{\text{R SW down}}$ (9.4%)
- $F_{\text{uv met}}$ (7.8%)
- $F_{\text{NDVI MODIS}}$ (7.6%)

Map of predicted CH$_4$ Flux

Median measured CH$_4$ flux along transects: 13.1 mg/m$^2$/day
Median predicted CH$_4$ flux across the area: 18.9 mg/m$^2$/day
Anaktuvuk River Fire

Credit: Bureau of Land Management, Alaska Fire Service

July – September 2007

Credit: Courtesy of Jim Laundre, Marine Biological Laboratory

NASA-MODIS image

June 14, 2008
Future Plans

Seasonality of drivers
Future Plans

Seasonality of drivers

Temporal maps of predicted CH$_4$ flux
Future Plans

Seasonality of drivers

Land cover & soil type specific CH$_4$ budget and budget uncertainty

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<th>Land cover</th>
<th>CH$_4$ [mg/m$^2$/hr]</th>
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<tr>
<td>Wetlands</td>
<td>0.8</td>
</tr>
<tr>
<td>Shrub</td>
<td>0.3</td>
</tr>
<tr>
<td>Sedge</td>
<td>0.6</td>
</tr>
<tr>
<td>...</td>
<td>0.4</td>
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Temporal maps of predicted CH$_4$ flux
Summary

- Airborne flux data covering extensive areas of terrestrial permafrost
- Wavelet decomposition yields high spatial resolution of the flux observations
- Footprint modelling to map spatially resolved contribution of environmental drivers
- Boosted regression trees to link the methane exchange to meteorological and biophysical drivers in a high latitude permafrost areas
- Environmental response functions assist bridging observational scales:
  - isolate and quantify relevant land-atmosphere exchange processes
  - extend airborne flux measurements to regional scale
  - estimate land cover specific emission factors
  - assess the spatial representativeness of flux tower measurements
Acknowledgments

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