Carbon in Arctic Reservoirs Vulnerability Experiment - (CARVE) And Related Projects

Vaporum Inquisitor

CARVE (EV-S1)
CARVE-CAN (C13-0350)
Permafrost Vulnerability (IDS12)
CO_2 & CH_4 Fluxes (TE14-046)

Charles Miller

Charles Miller, PI
Steve Dinardo, PM
Jet Propulsion Laboratory, California Institute of Technology
and the CARVE Science Team

ABoVE STM #1 – Minneapolis MN
30 September, 2015

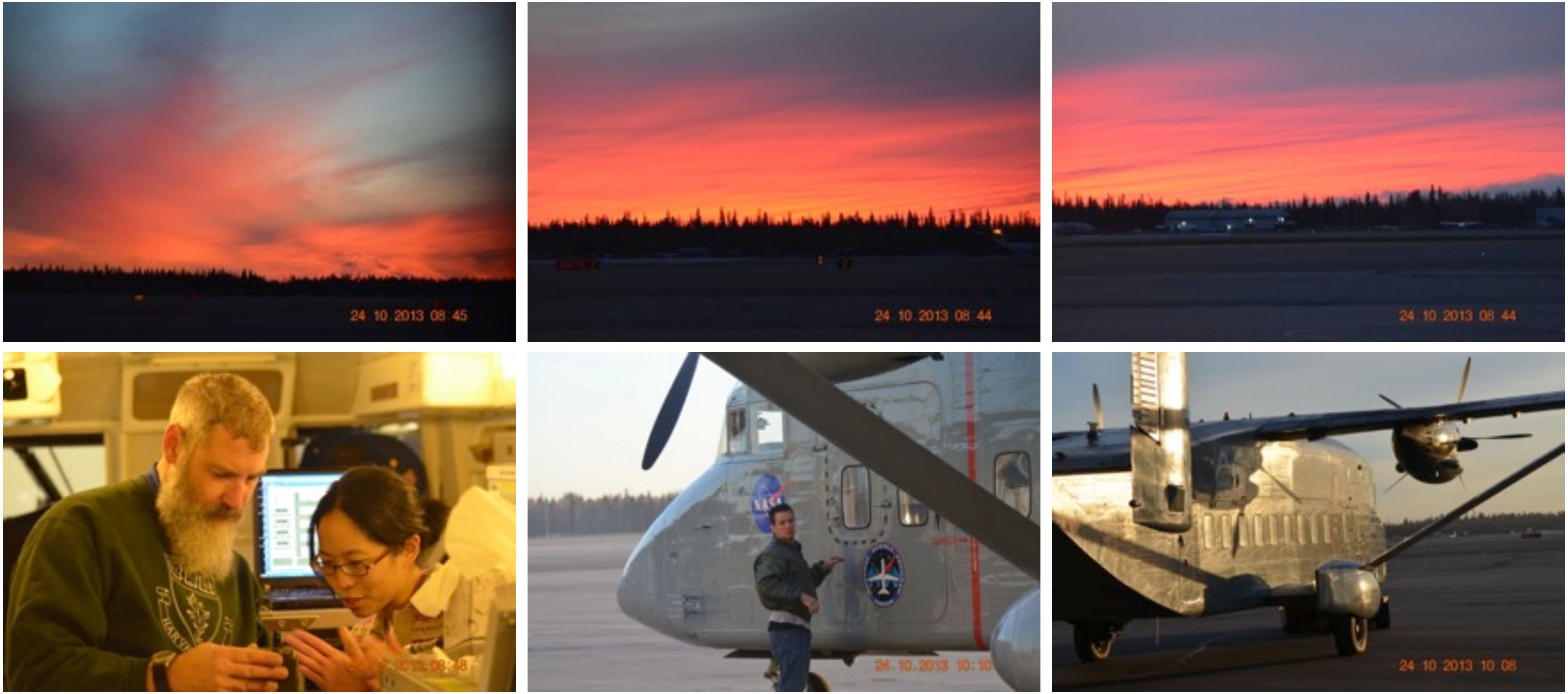
5 July 2013 CARVE Exceeds PLRA Threshold Science Requirements

29 May 2014 CARVE Achieves Baseline Science Requirements

CARVE team celebrate meeting the PLRA Baseline Requirement for 500 total science flight hours during the 29 May 2014 flight over Interior Alaska

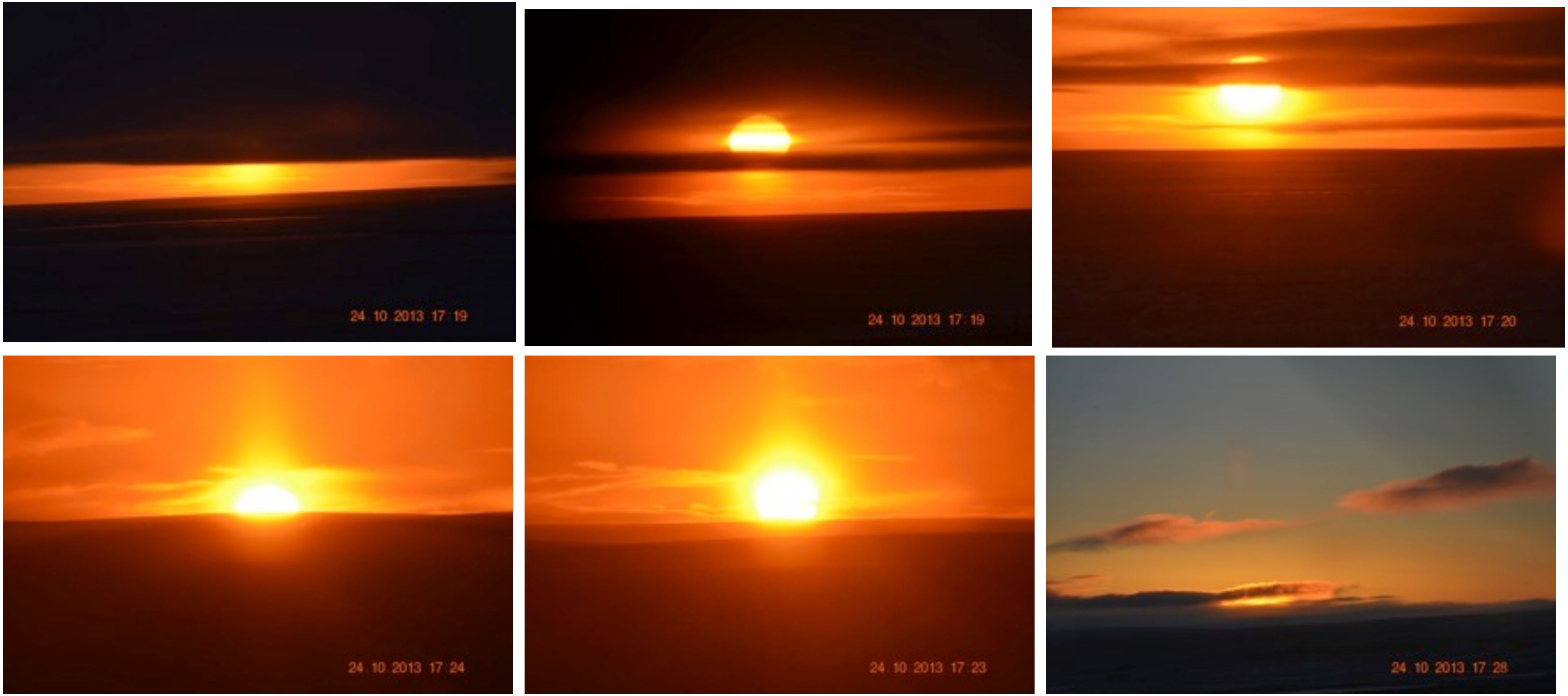
5 Aug 2015/DOY 217 CARVE Science Flight
Alaska Governor Bill Walker Visits CARVE

24 Oct 2013 (DOY 297) CARVE Science Flight
Barrow – Deadhorse – North Slope



Fairbanks Sunrise and CARVE flight preparations

24 Oct 2013 (DOY 298) CARVE Science Flight North Slope

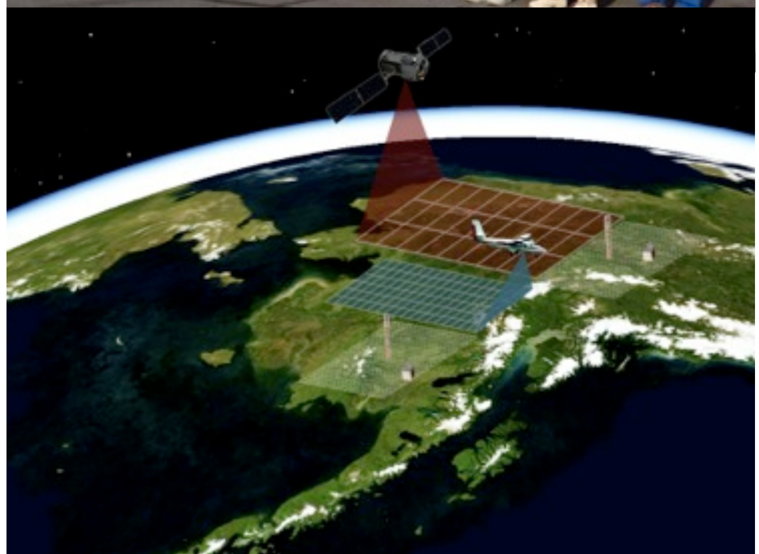


Sunset on the North Slope

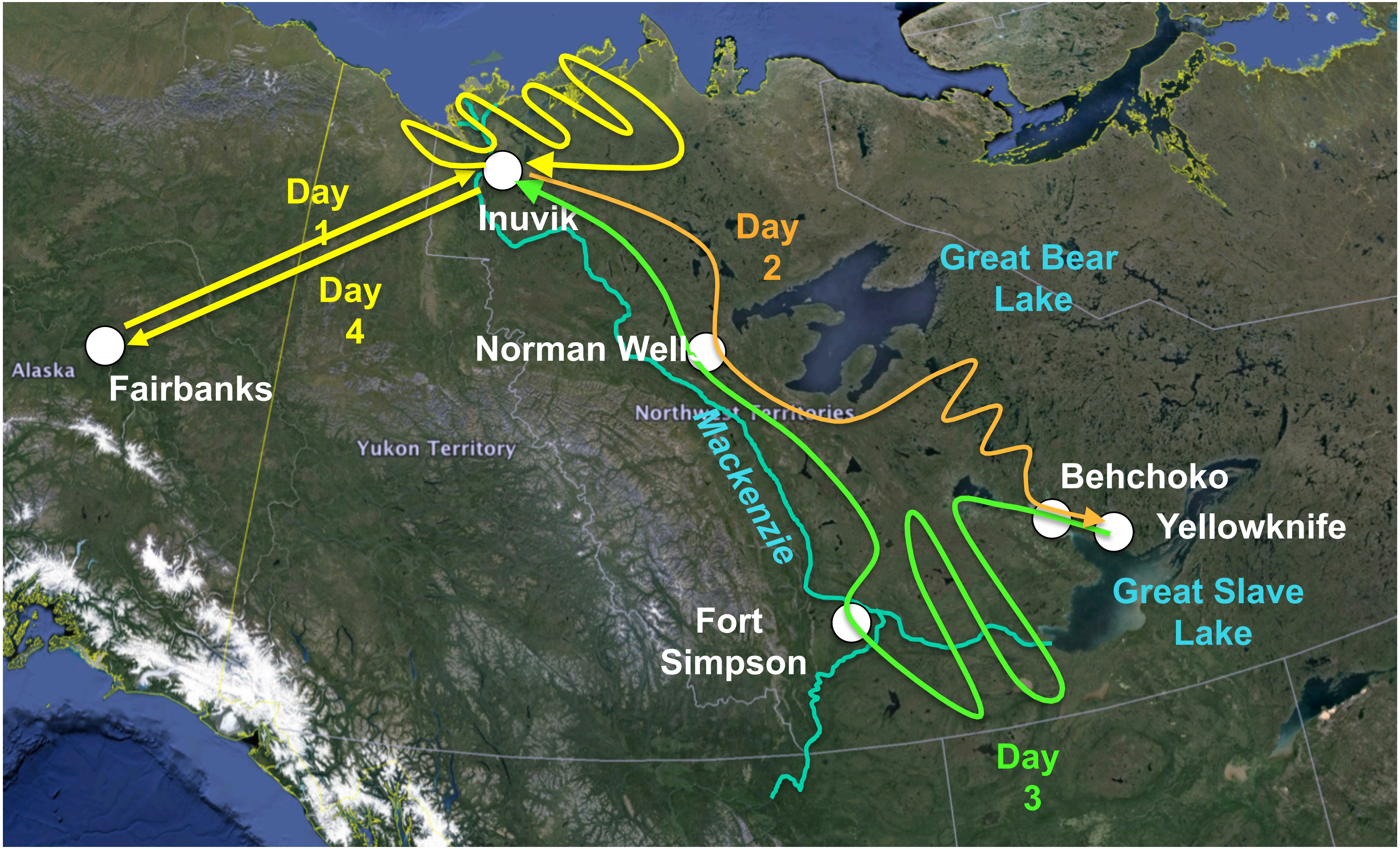
CARVE: A NASA Earth Ventures (EV-1) Airborne Sciences Investigation

CARVE
- 5-years sustained, frequent flights
- Quantify correlations between atmospheric CO_2 & CH_4 and surface state variables for the Alaskan terrestrial ecosystems

CARVE bridges critical gaps in our understanding of
- Arctic ecosystems,
- Linkages between the Arctic hydrologic and terrestrial carbon cycles,
- Feedbacks from fires and thawing permafrost



CARVE-CAN
Sampling the Mackenzie River Valley



CARVE Team

Co-Investigators

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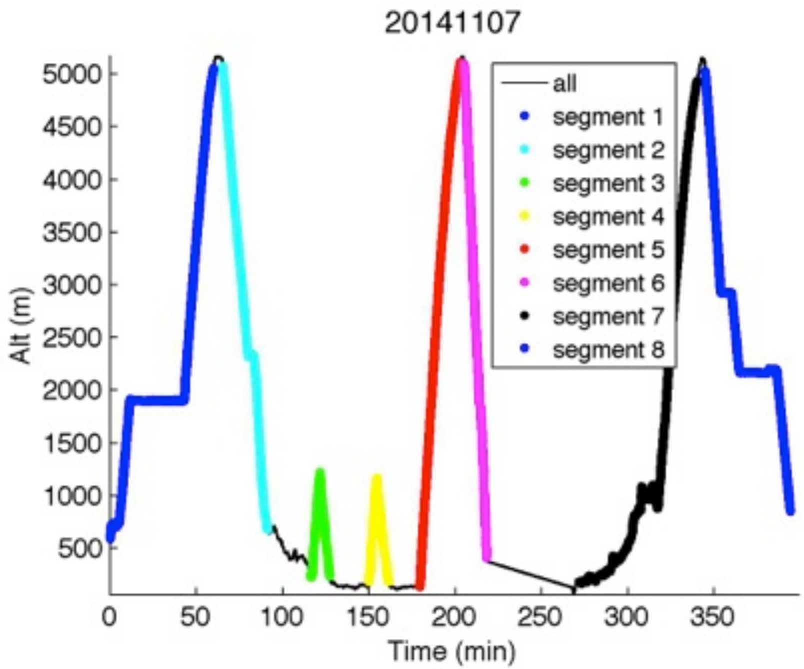
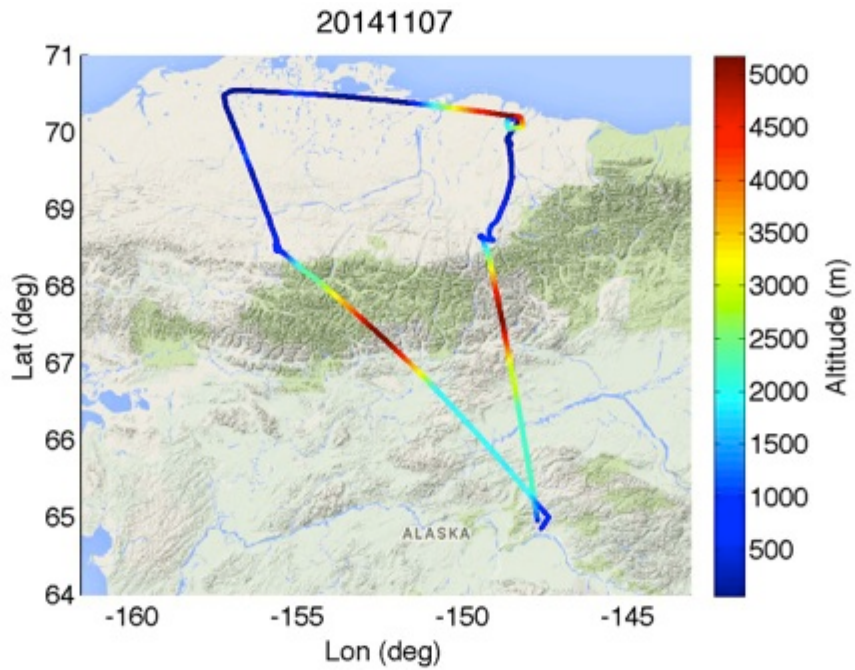
CARVE Defines A New Paradigm for Airborne CO2 and CH4 Observations

- **Fly Low:** Surveys conducted at 150 m AGL with frequent vertical profiles to characterize the PBL height and regional budgets





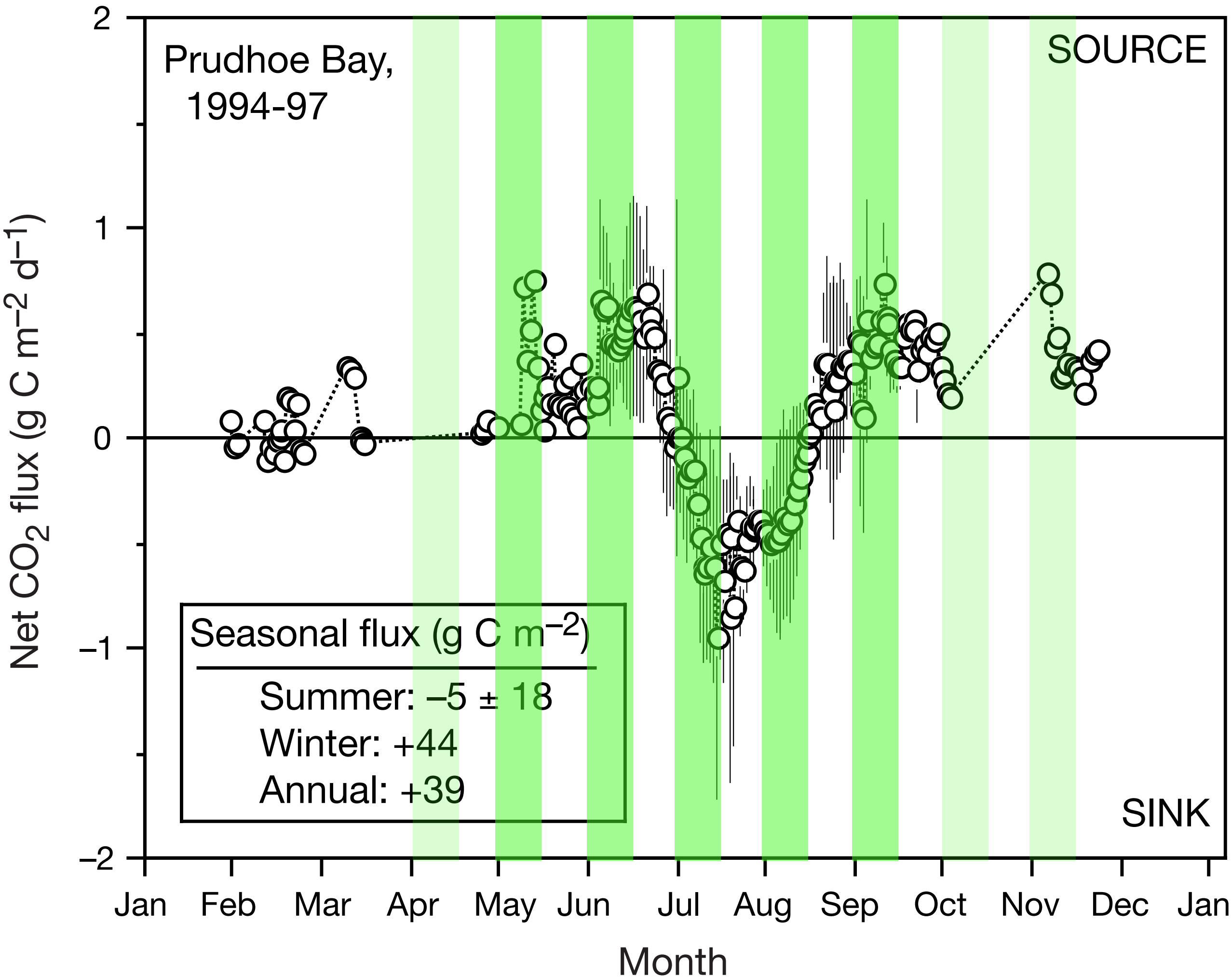
- **Frequent, Sustained Observations:** flight campaigns 2 weeks/month provided multiple revisits to key sites each month during the growing season and revealed details of the rapidly changing environment

CARVE Campaigns Capture Freeze-Thaw, Summer Drawdown, and Fall Refreeze

CARVE

Arctic carbon cycle is compressed into ~90 day thawed season

CARVE campaigns are timed to capture the critical growing season events required to reconstruct the annual Alaskan C cycle



Oechel et al., Nature 406, 978-80 (2000)

CARVE Operations Strategy: Frequent & Sustained Observations

May – September 2012

32 flights & ~200 Science flight hours

- 2 weeks/month each month
- 4-10 flights/campaign

2012 Conditions

- Climatologically 'average' year
- Average thaw and re-freeze dates
- Cool summer
- Record summer sea ice minimum

CARVE 2012 Flight Tracks

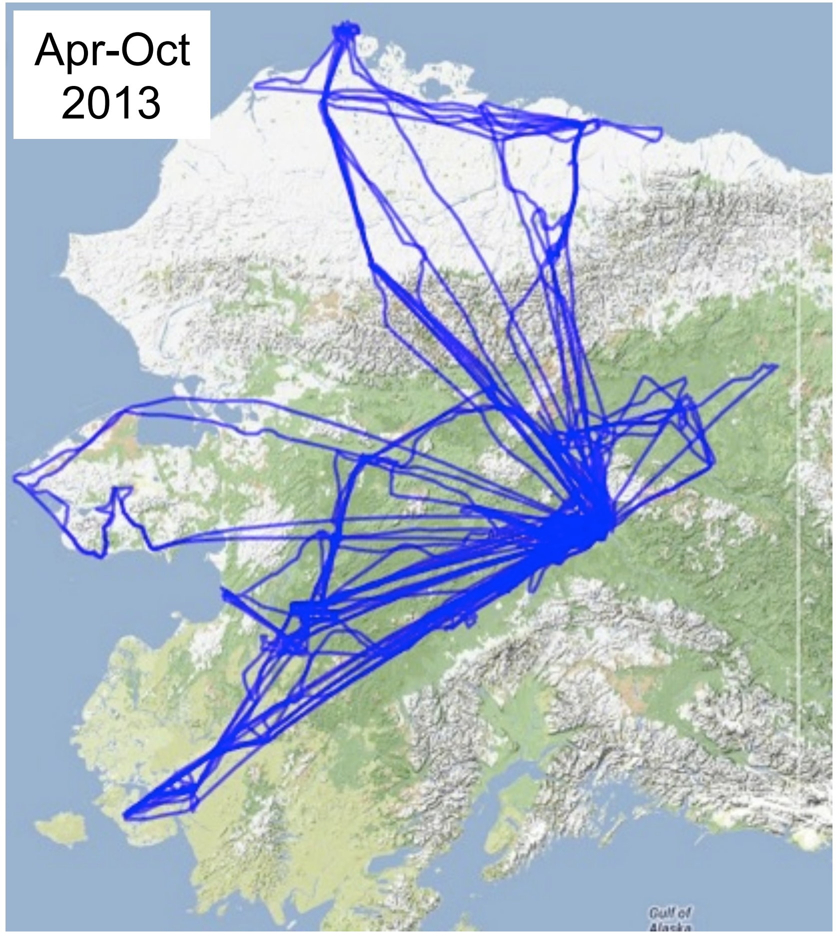
CARVE Operations Strategy: Frequent & Sustained Observations

April – October 2013

45 flights & 262 Science flight hours

2013 Conditions

- Late May thaw in Interior Alaska
- Immediate transition to hot, dry summer
- > 1M acres of wildfires
- Very late re-freeze with unprecedented late October heat wave



CARVE 2013 Flight Tracks

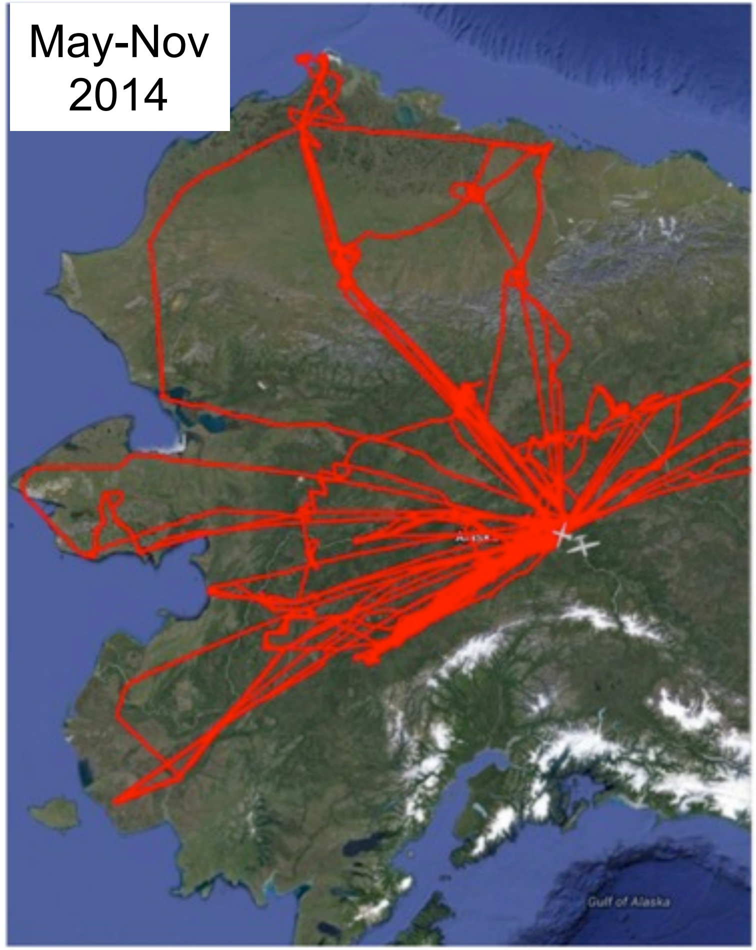
CARVE Operations Strategy: Frequent & Sustained Observations

May – November 2014

47 flights & 266 Science flight hours

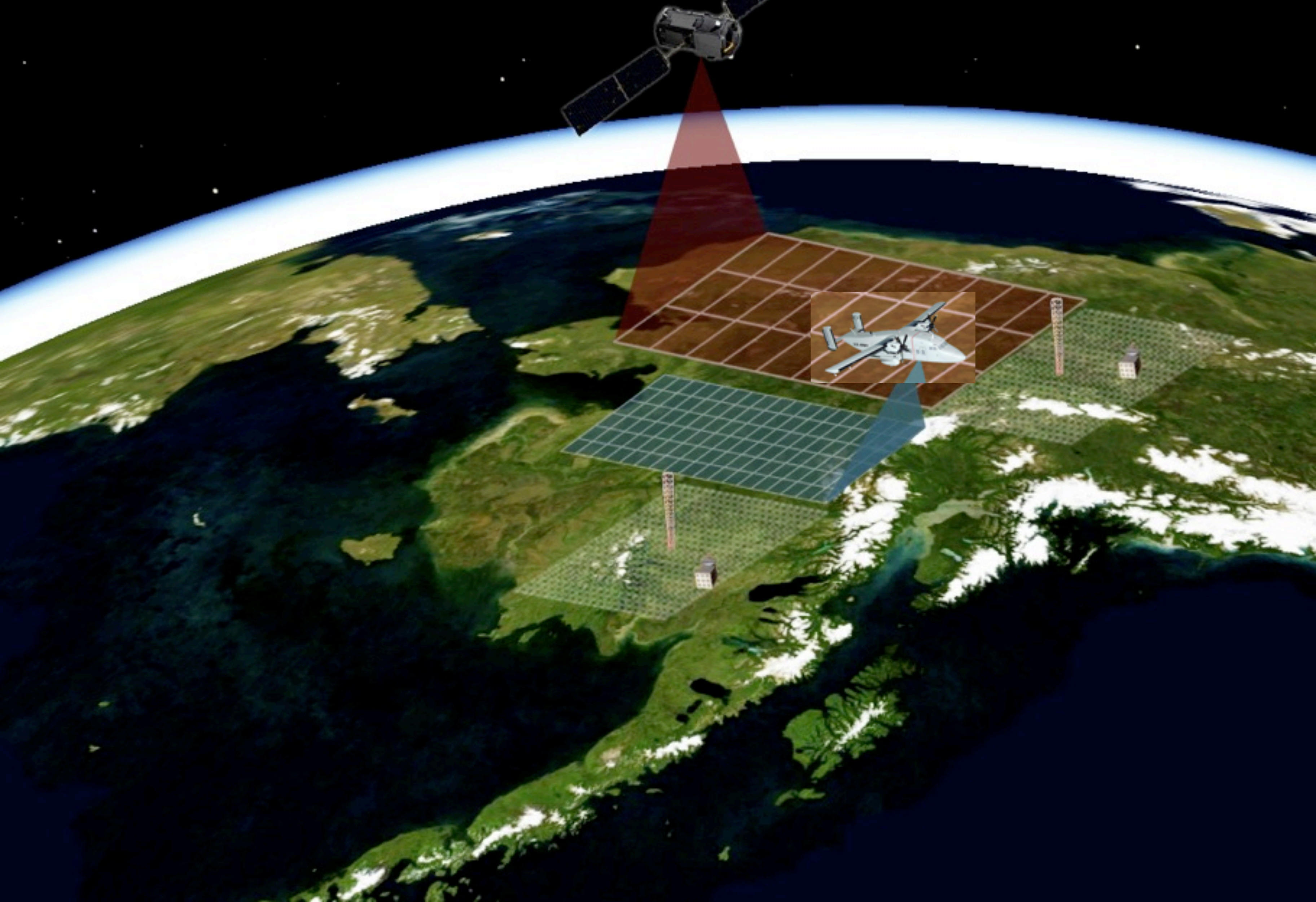
2014 Conditions

- Average thaw dates
- Summer temperatures ~5 C cooler than normal
- Record summer rainfall in Interior Alaska
- >10M acres of wildfires in Canadian NWT
- Sep – Nov snows but late refreeze



CARVE 2014 Flight Tracks

CARVE Science Products

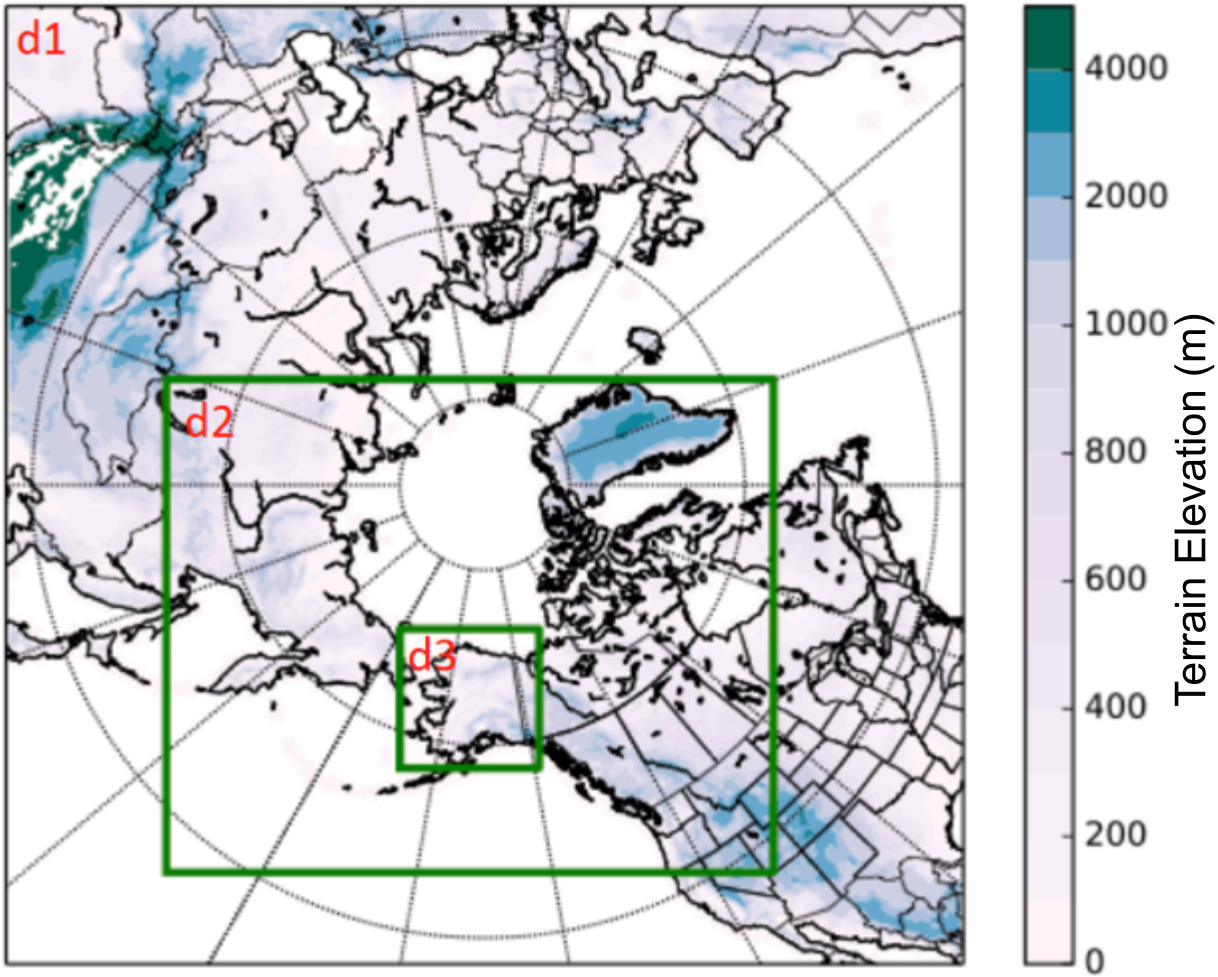


Regional C Fluxes Estimated Using CARVE Polar-WRF/STILT Framework

D1: 30 km
D2: 10 km
D3: 3 km

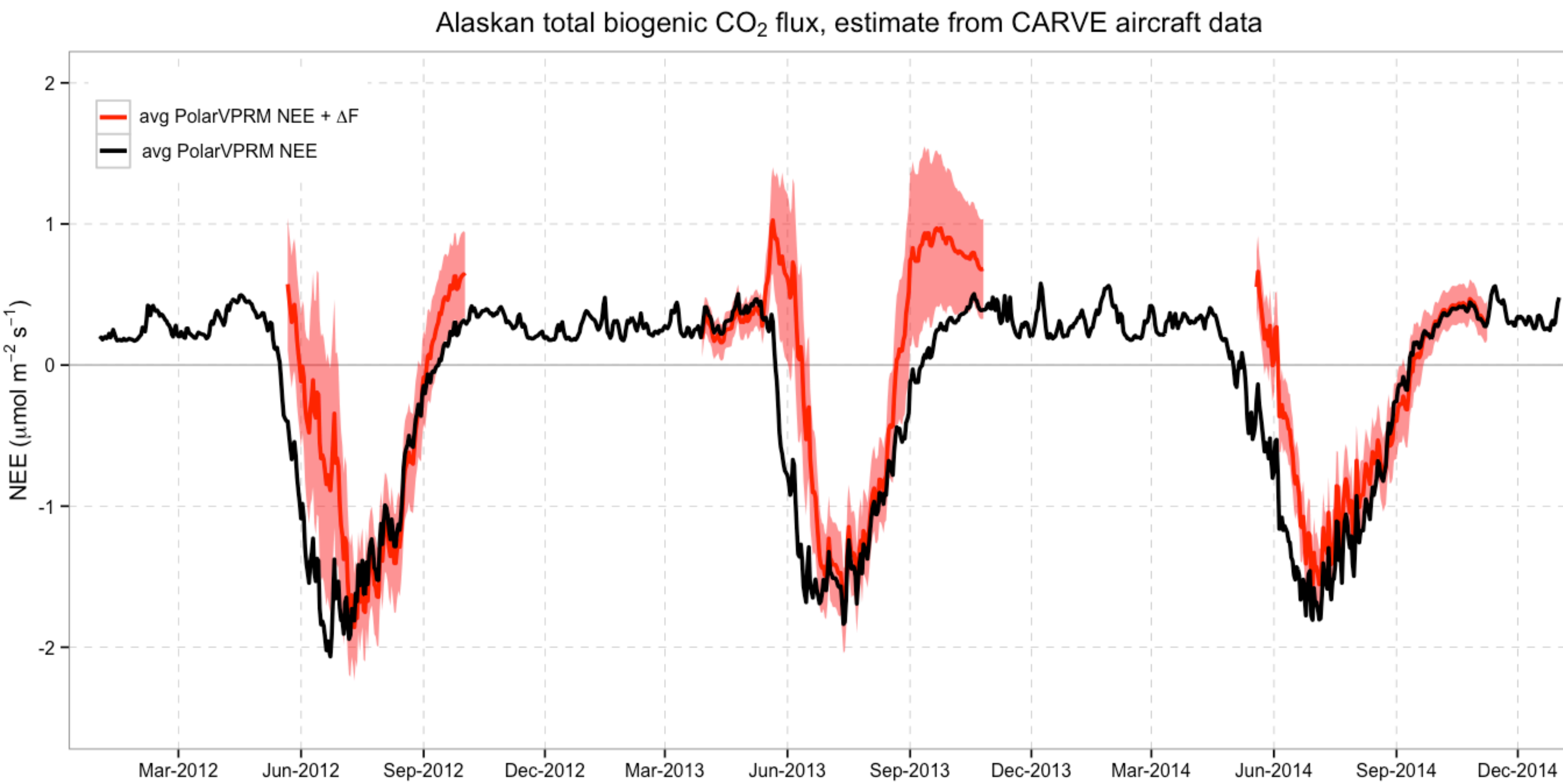
Nested grid maximizes resolution over the CARVE domain

Framework featured at NASA HPC 2014



Henderson et al., Atm Chem Phys Discuss (2014)

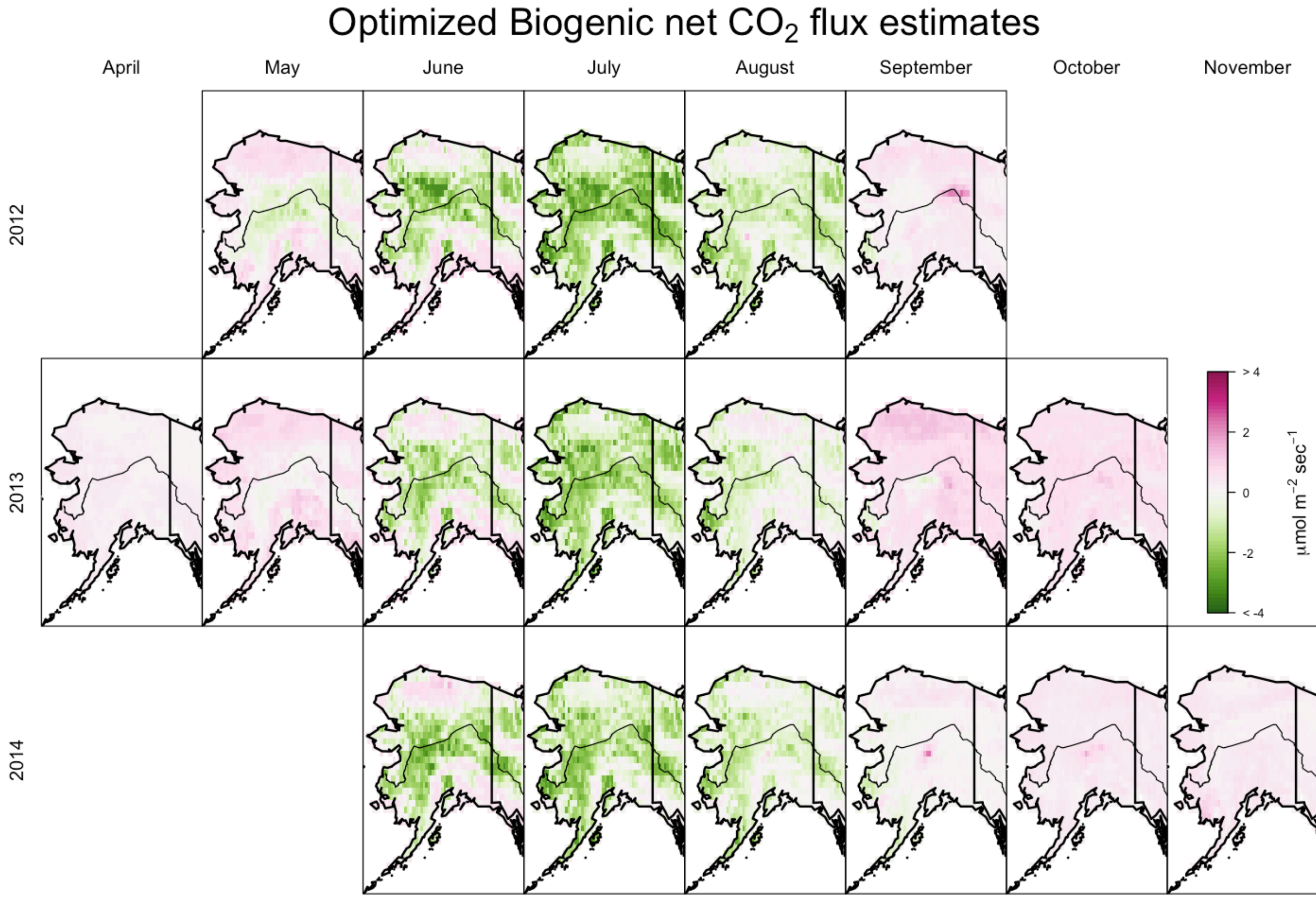
Optimized Biogenic CO2 Flux for AK PVPRM & CARVE



N Luus, R Commane, J Lindaas

- Spring drawdown 2-4 weeks later than PVPRM
- Earlier fall zero crossing and larger emissions signal

Monthly Optimized Biogenic NEE PVPRM & CARVE



N Luus, R Commane, J Lindaas

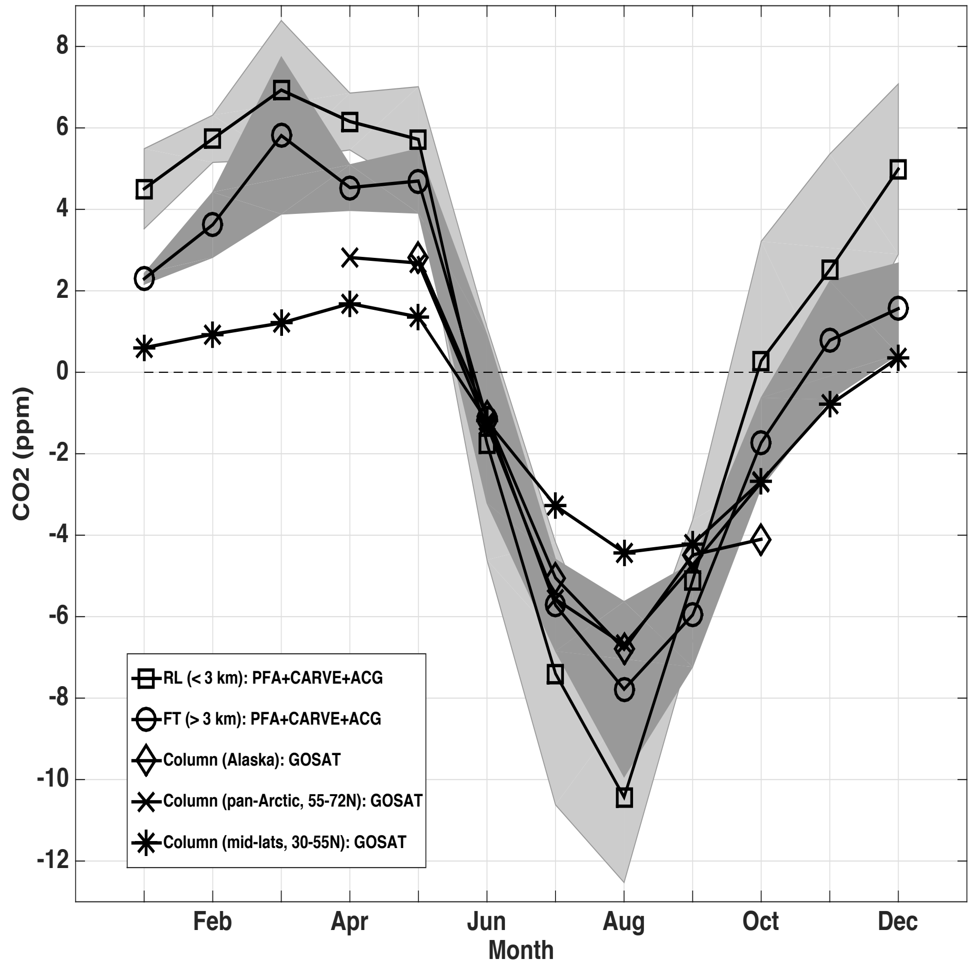
RL, FT and Column CO2 Reveal Different Aspects of Alaska CO2 Seasonal Cycle

CARVE

2009 – 2014 average CO2 seasonal cycle amplitudes for
- Residual Layer (RL)
- Free Troposphere (FT)

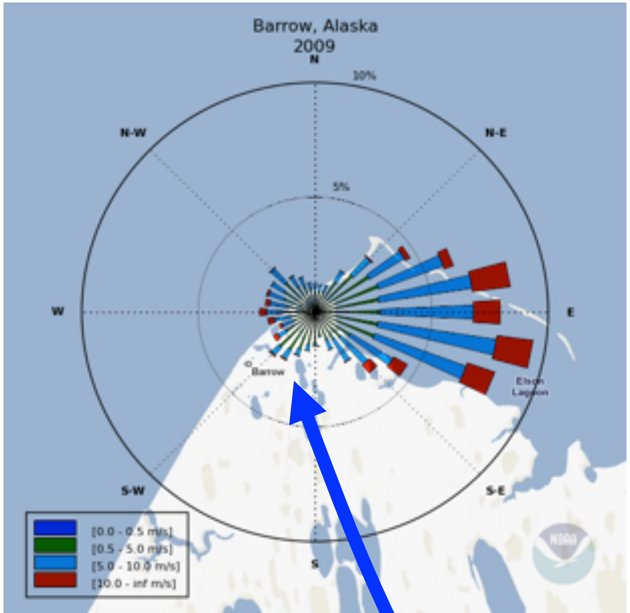
CARVE, ACG, PFA aircraft data profiles

GOSAT column CO2



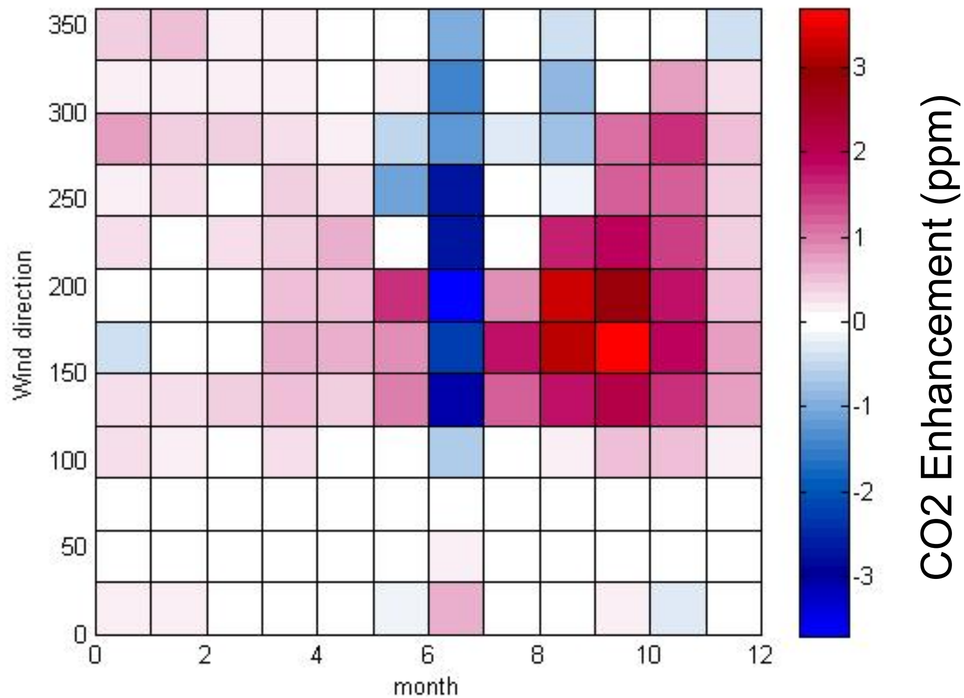
N Parazoo

Re-examining BRW Time Series
CO2 'Land' Sector Analysis



Average BRW Land sector CO_2 anomalies of
- -2 ppm in July
- +2-3 ppm in Aug-Oct

With positive anomalies extending to Dec

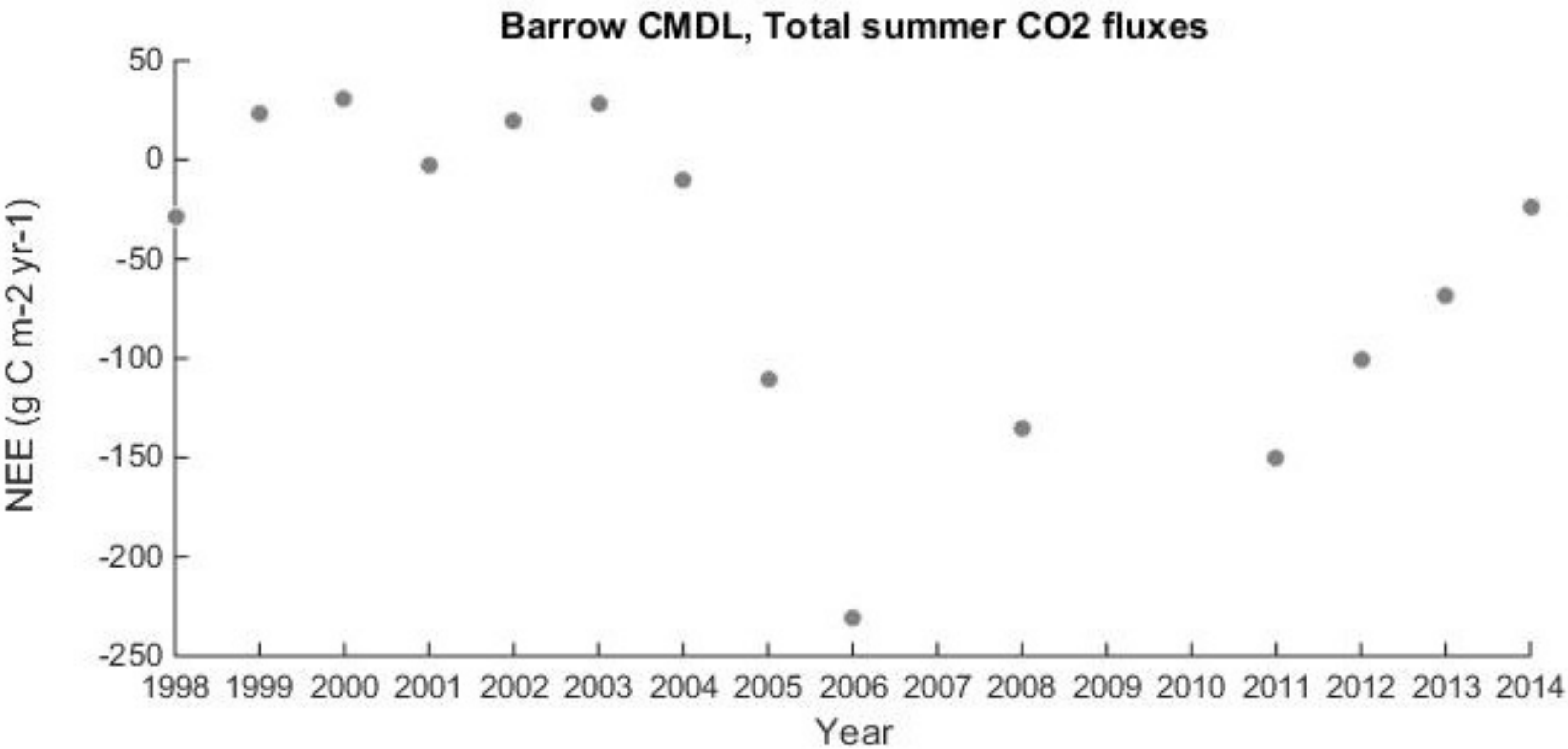


C Sweeney

Barrow Summer CO2 Flux Has Oscillated Over last 20 Years

CARVE

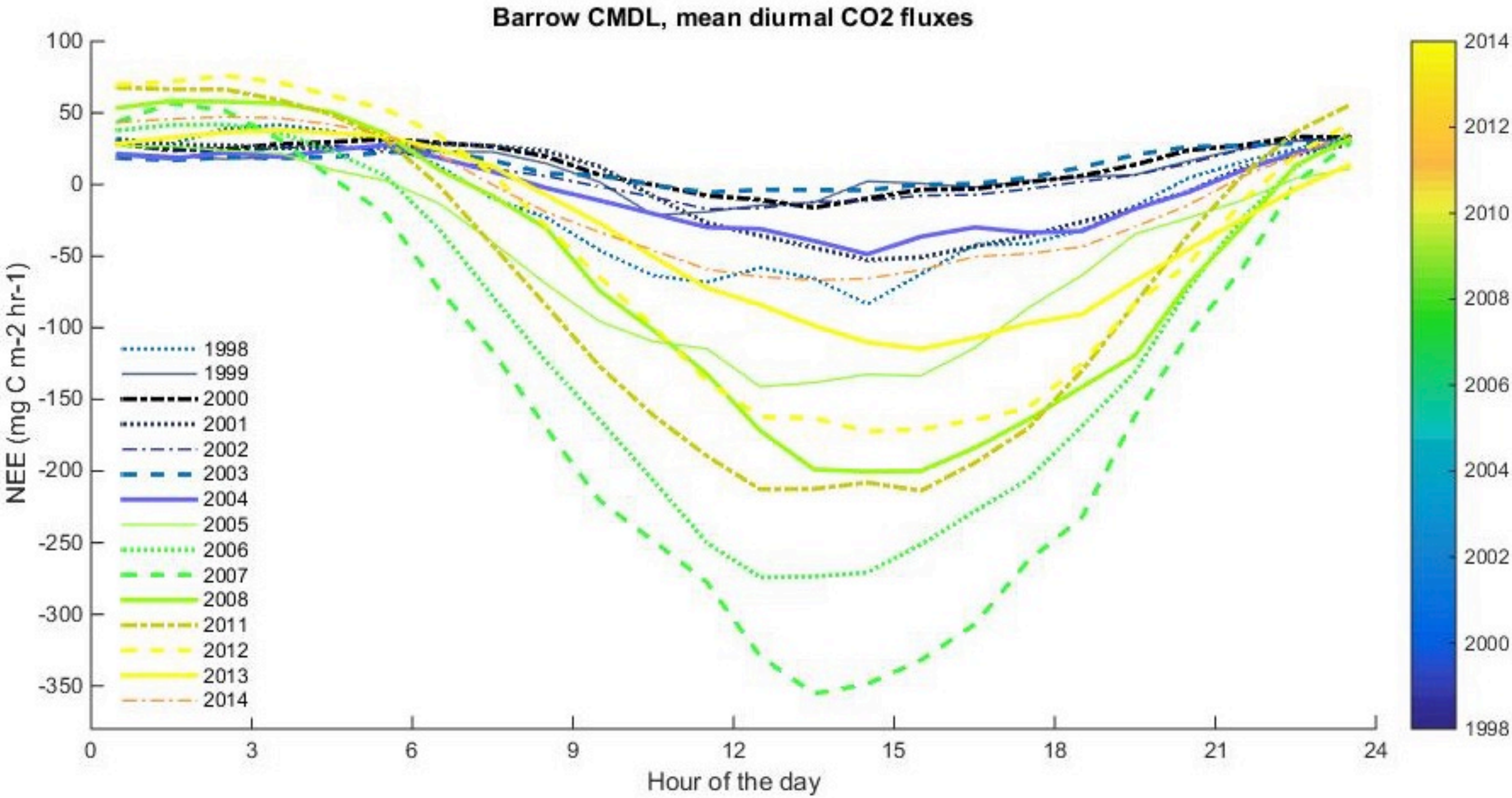
*** Long-term CO2 flux tower data ***



W Oechel

Barrow Diurnal CO_2 Flux Amplitude Has Oscillated Over last 20 Years

*** Long-term CO2 flux tower data ***



W Oechel

Alaska Emitted 2.1 ± 0.5 $TgCH_4$ from May - Sep 2012

PNAS

Methane emissions from Alaska in 2012 from CARVE airborne observations

Rachel Y.-W. Chang[a,1,2], Charles E. Miller[b], Steven J. Dinardo[b], Anna Karion[c,d], Colm Sweeney[c,d], Bruce C. Daube[a], John M. Henderson[e], Marikate E. Mountain[e], Janusz Eluszkiewicz[e], John B. Miller[c,d], Lori M. P. Bruhwiler[c], and Steven C. Wofsy[a]

[a]School of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138; [b]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109; [c]Global Monitoring Division, National Oceanic and Atmospheric Administration Earth System Research Laboratory, Boulder, CO 80305; [d]Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO 80309; and [e]Atmospheric and Environmental Research, Inc., Lexington, MA 02421

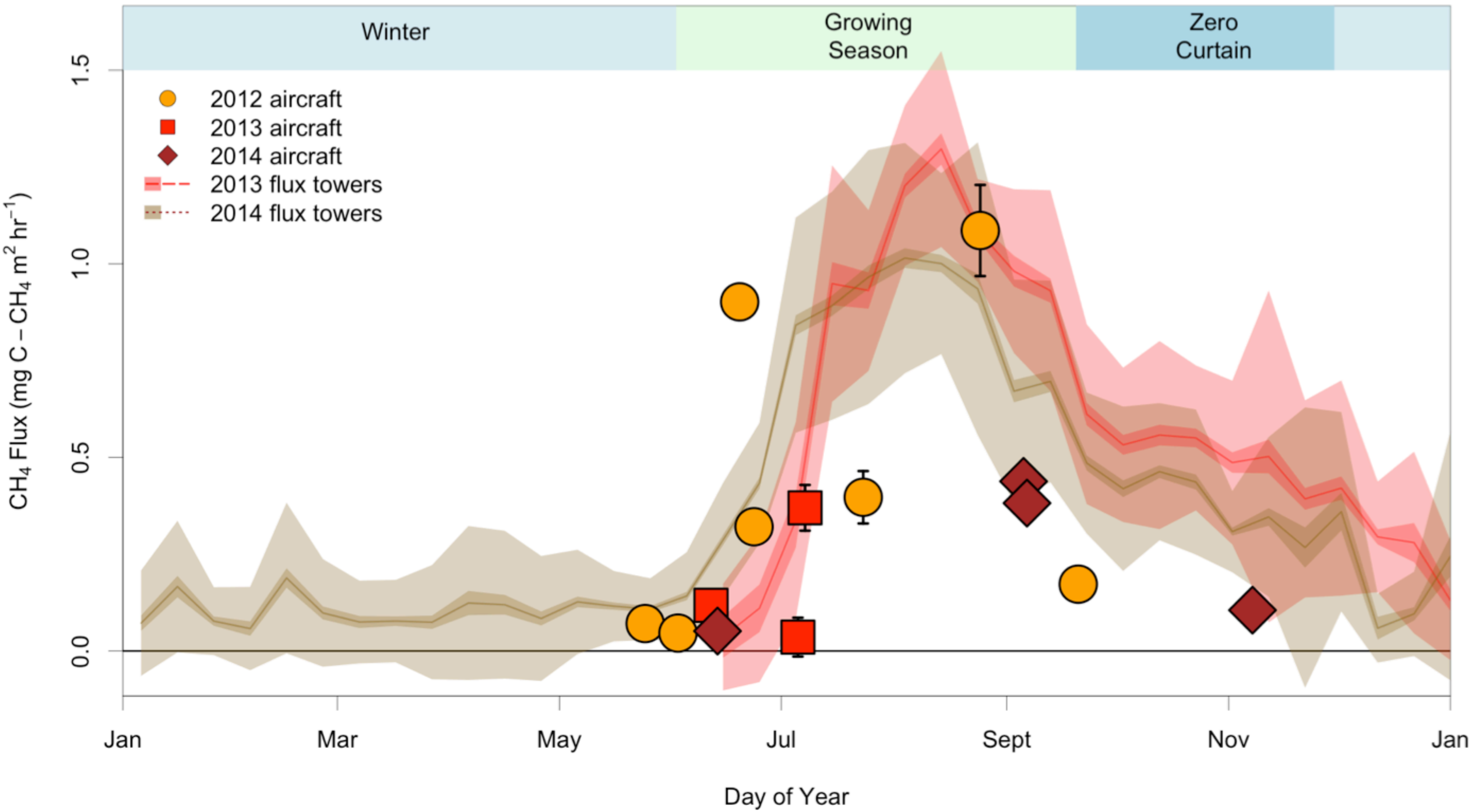
- Alaska 2012 CH_4 emissions are unexceptional despite widespread evidence of permafrost thaw and other climate change
- Boreal forests emit more than North Slope tundra
- First regional airborne study to cover an entire growing season
- Important baseline against which to measure future changes

Chang et al., PNAS 2014

More than 50% of the North Slope CH4 Flux Occurs During the Cold Season

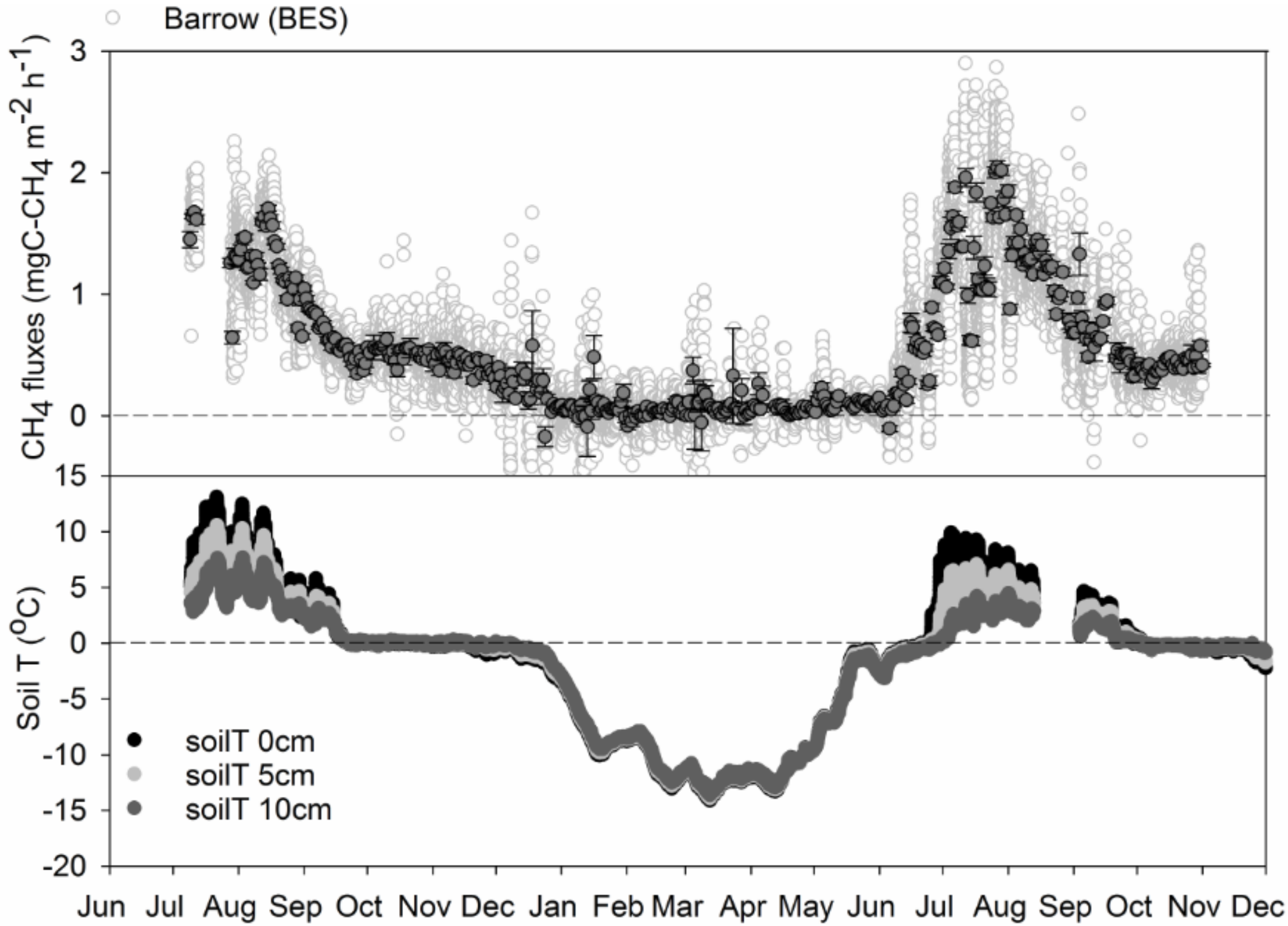
*** Year-round CH4 flux tower data ***

D Zona et al.



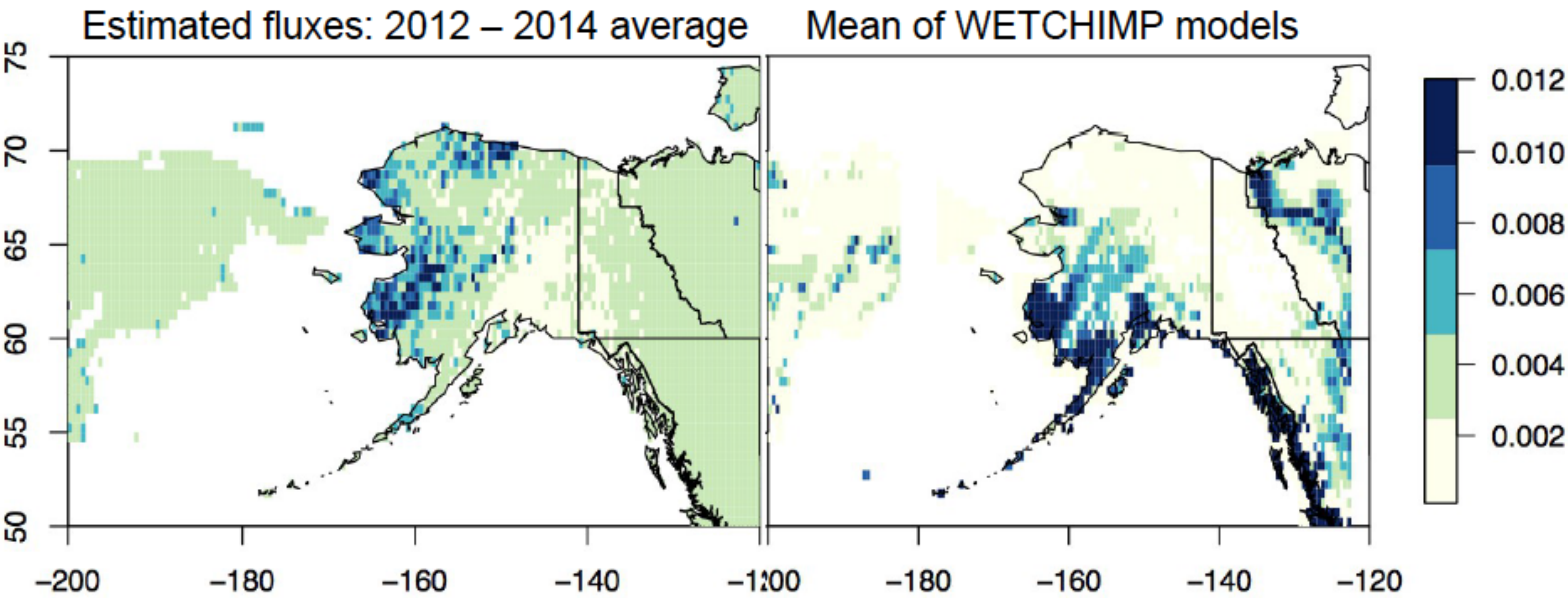
North Slope CH4 Emissions Persist Through the Zero Curtain Period

*** Year-round CH4 flux tower data ***



D Zona et al.

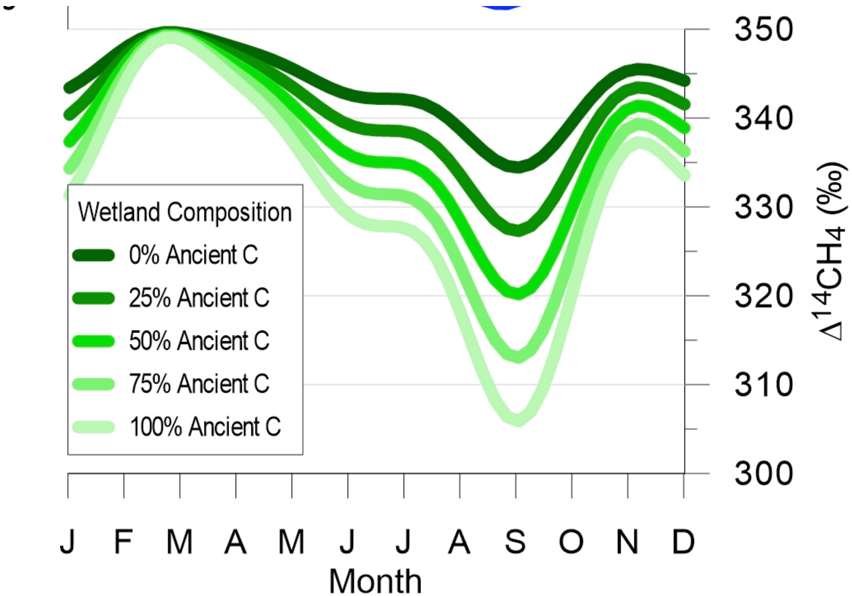
Alaska CH4 Fluxes Estimated from CARVE 2012-2014 Mean



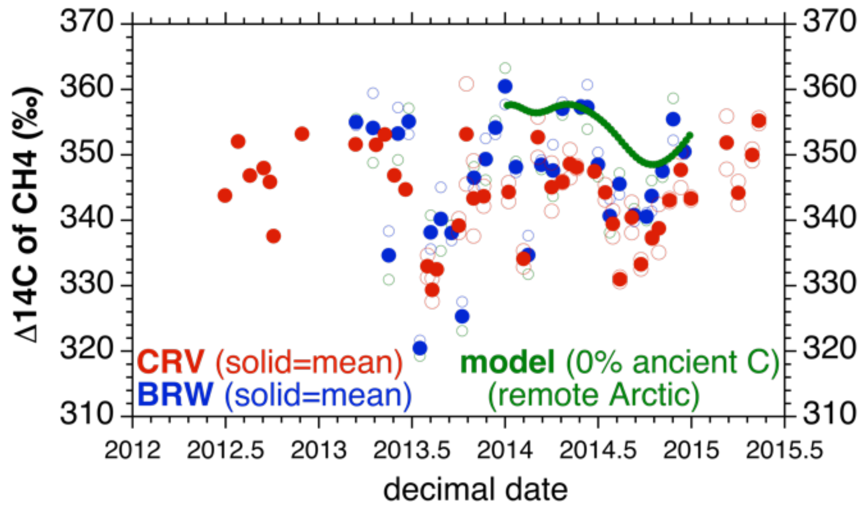
S Miller, A Michalak

$\Delta^{14}CH4$ Measurements at CRV & BRW
Theory vs Experiment

Theory



Experiment



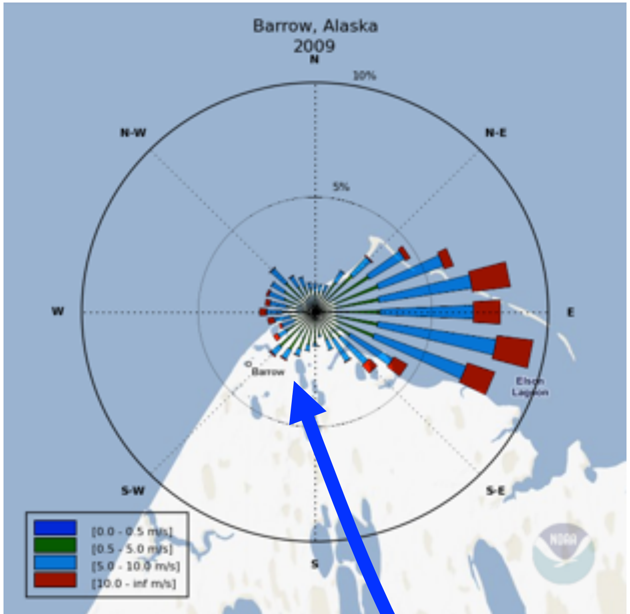
Simple $\Delta^{14}CH4$ model based on observed CH4 and $\delta^{13}CH4$ seasonal cycles

Preliminary Conclusions:

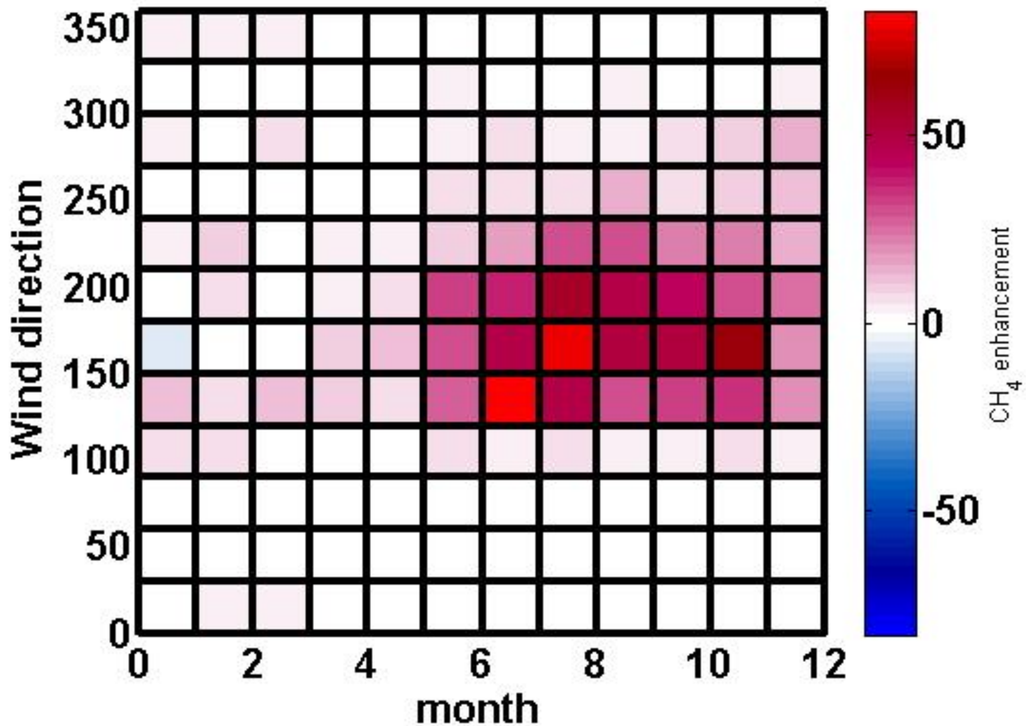
- Some contribution of ancient C (~6000 yrBP) at BRW
- Little ancient C at CRV

L. Mitchell, J Miller, S Lehman

Re-examining BRW Record Shows Persistent CH4 Enhancement from Land



Average enhancements of >70 ppb from southern 'Land' sector July – September (1990 – 2012 averages) consistent with CARVE observations



Background ~ 300 – 60
'Land' ~ 130 - 250

C Sweeney

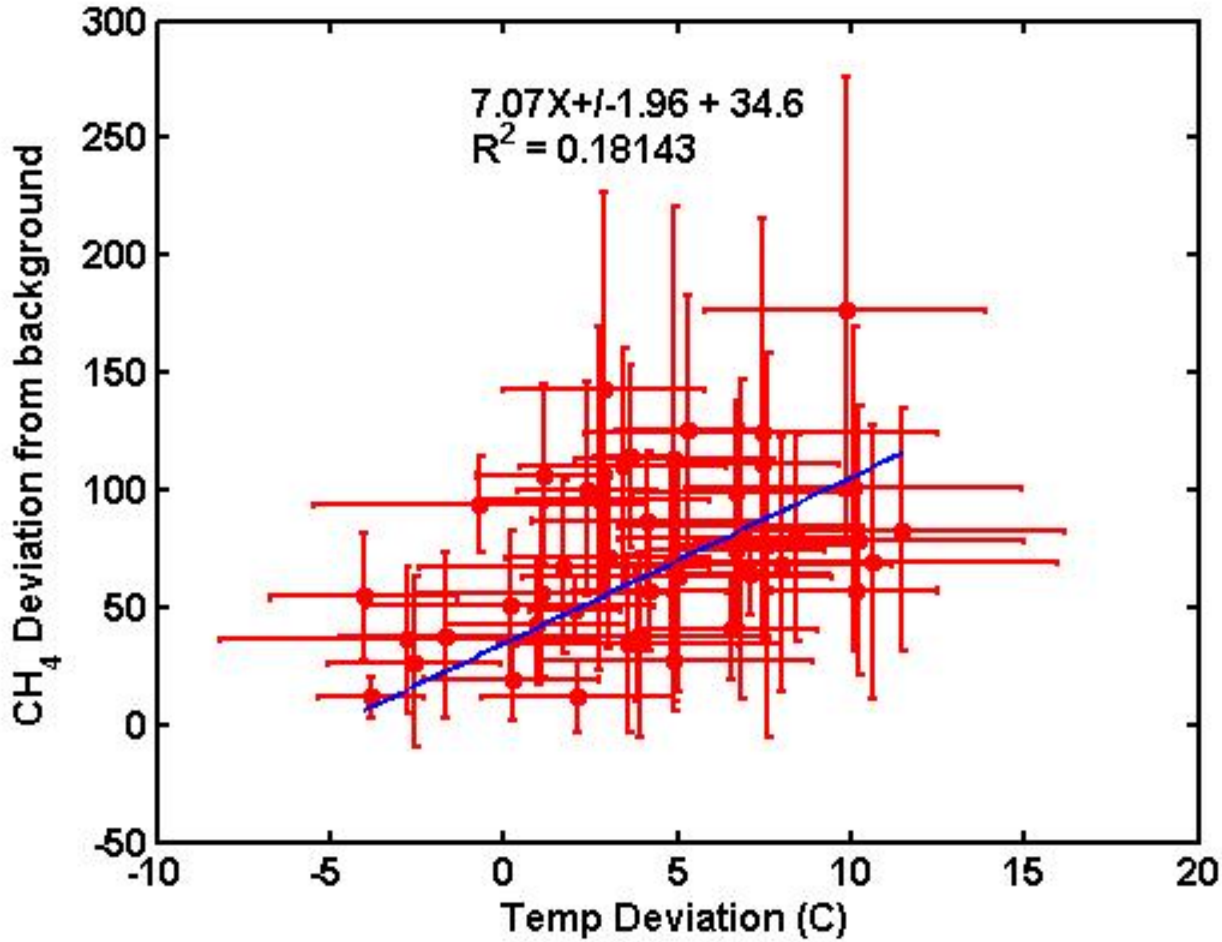
Barrow ‘Land’ Sector ΔCH4 vs T

BRW ‘Land’ sector CH4 anomalies exhibit a 7 ppb/C trend

CH4 increase
7 ppb/C * 0.13 C/yr
= 0.91 ± 0.41 ppb/yr is consistent with BRW CH4 record over the last 2 decades

CONCLUSIONS:
North Slope CH4 emissions increasing slowly despite large ΔT

No evidence of discontinuous change



C Sweeney

CRV Tower (Fox, AK)
Oct 2011 – Present

A Karion, C Sweeney

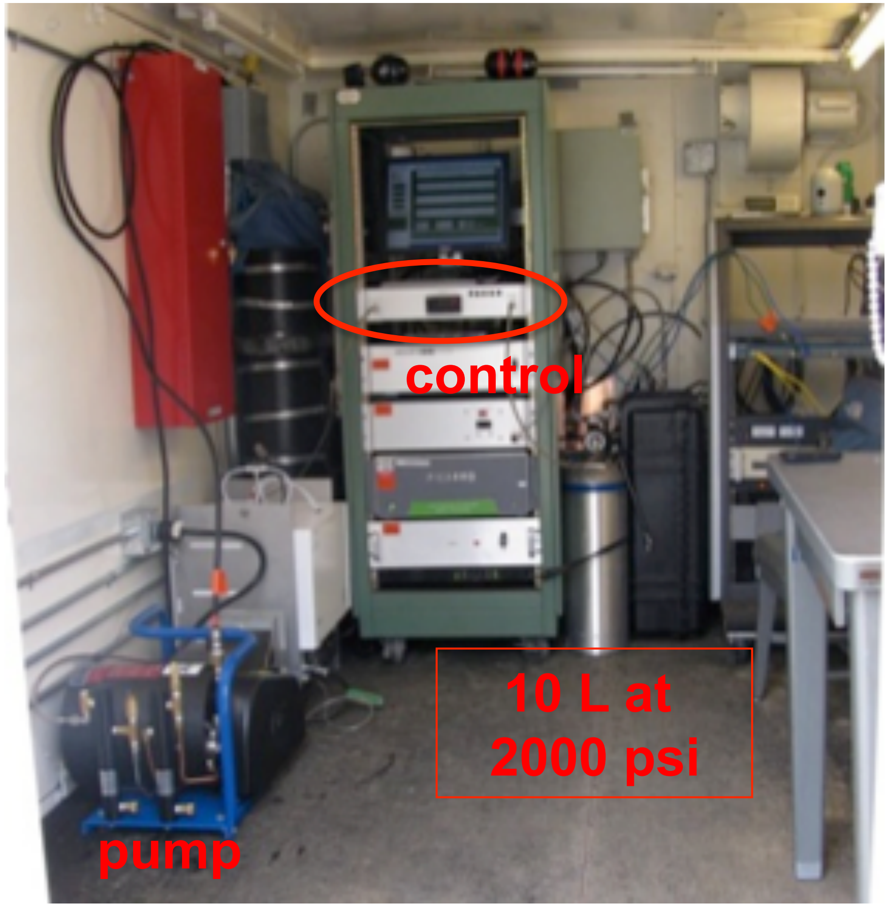
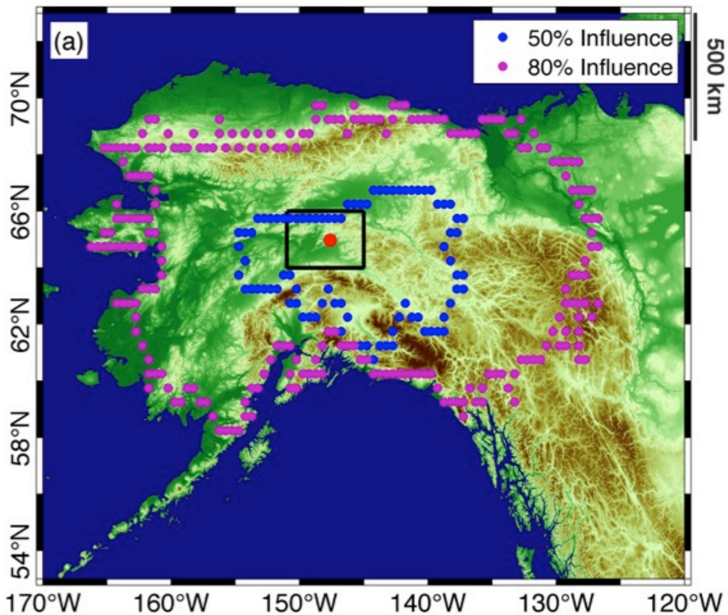


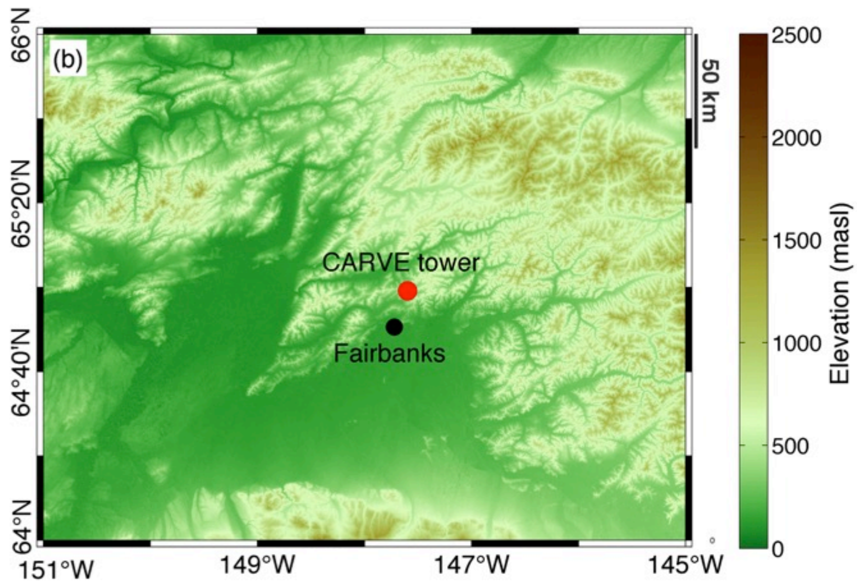
Figure 4.

CRV Tower (Fox, AK)
Oct 2011 – Present

A Karion, C Sweeney

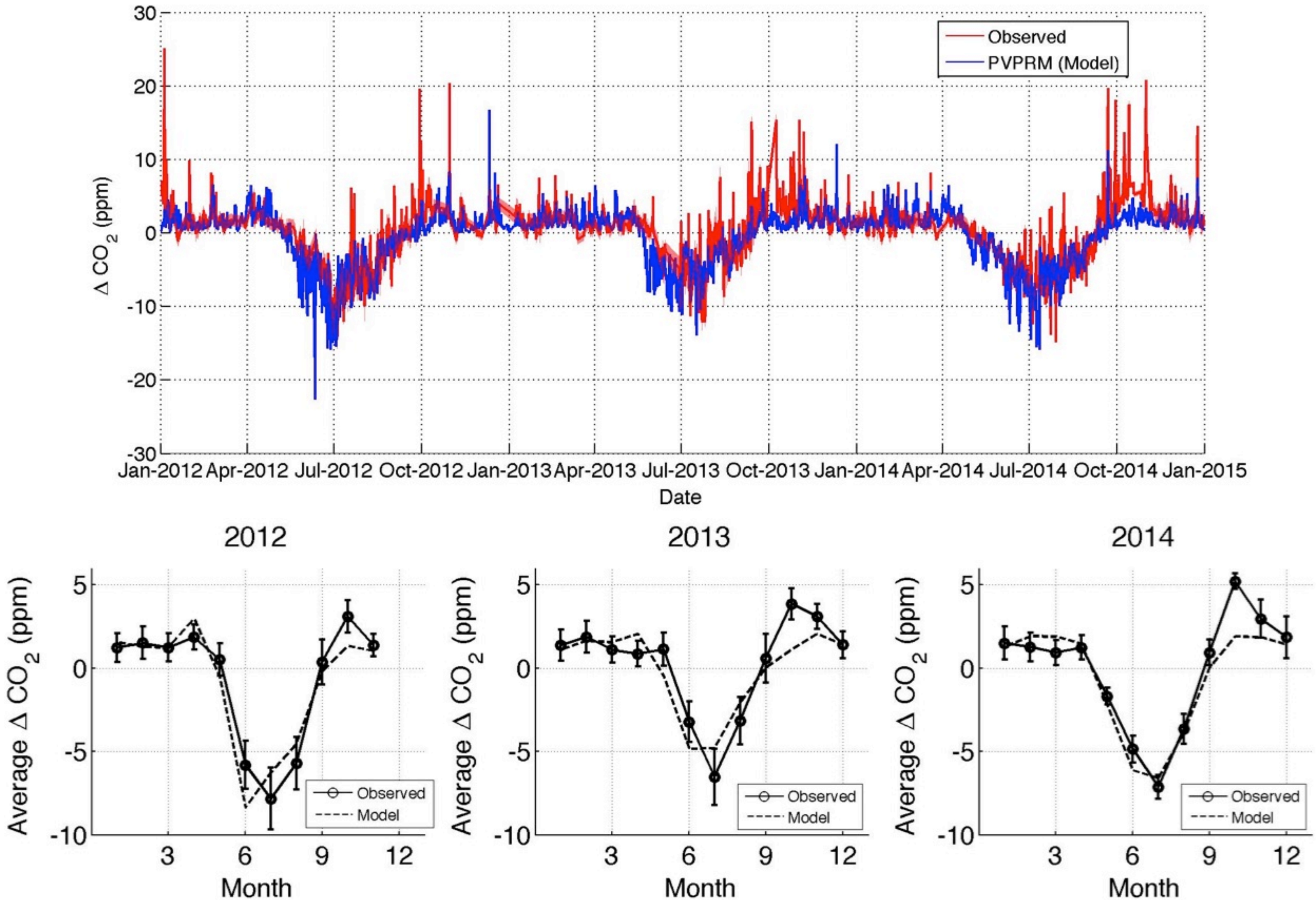


Influence contours for CARVE tower (NOAA site code CRV) for 2012-2014 show broad influence from fluxes in interior Alaska.



The 30-m CRV tower is located on a ridge above Fairbanks.

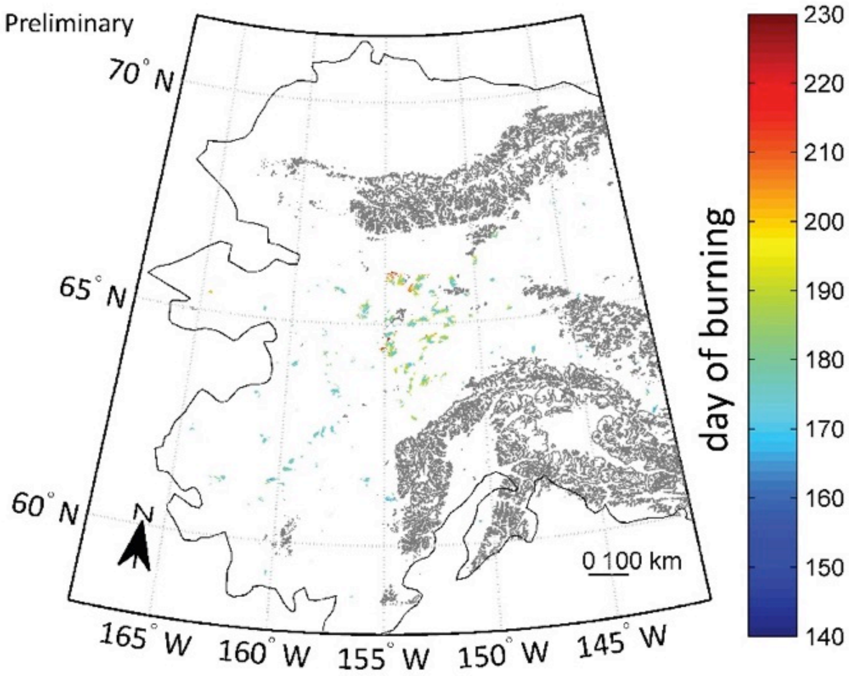
CRV Tower (Fox, AK)
2012-2014 Biogenic CO2

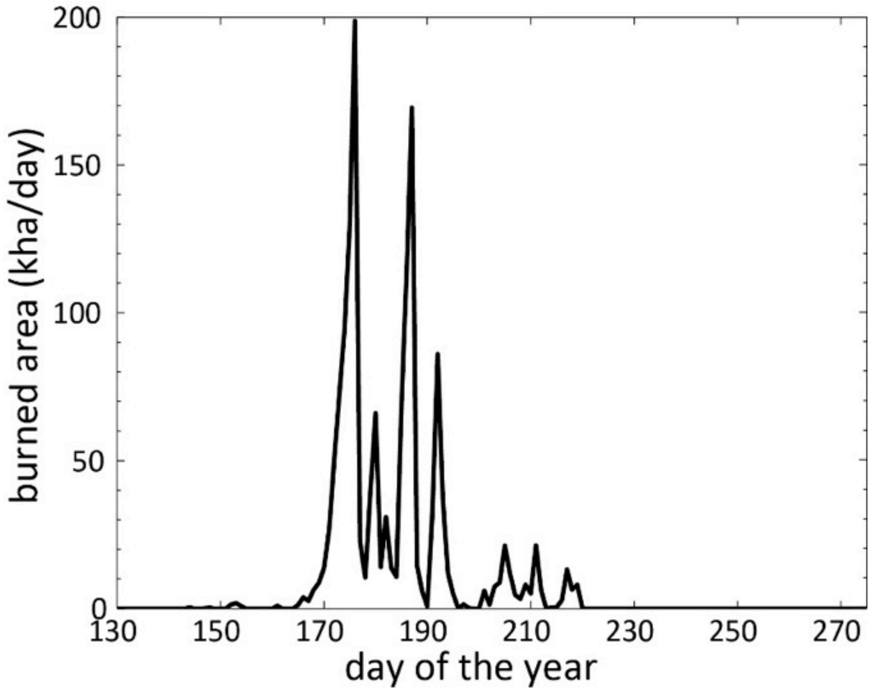


A Karion, C Sweeney

Alaska Fire Emissions Database (AKFED)

S Veraverbeke, B Rogers, J Randerson, Biogeosci. 2015

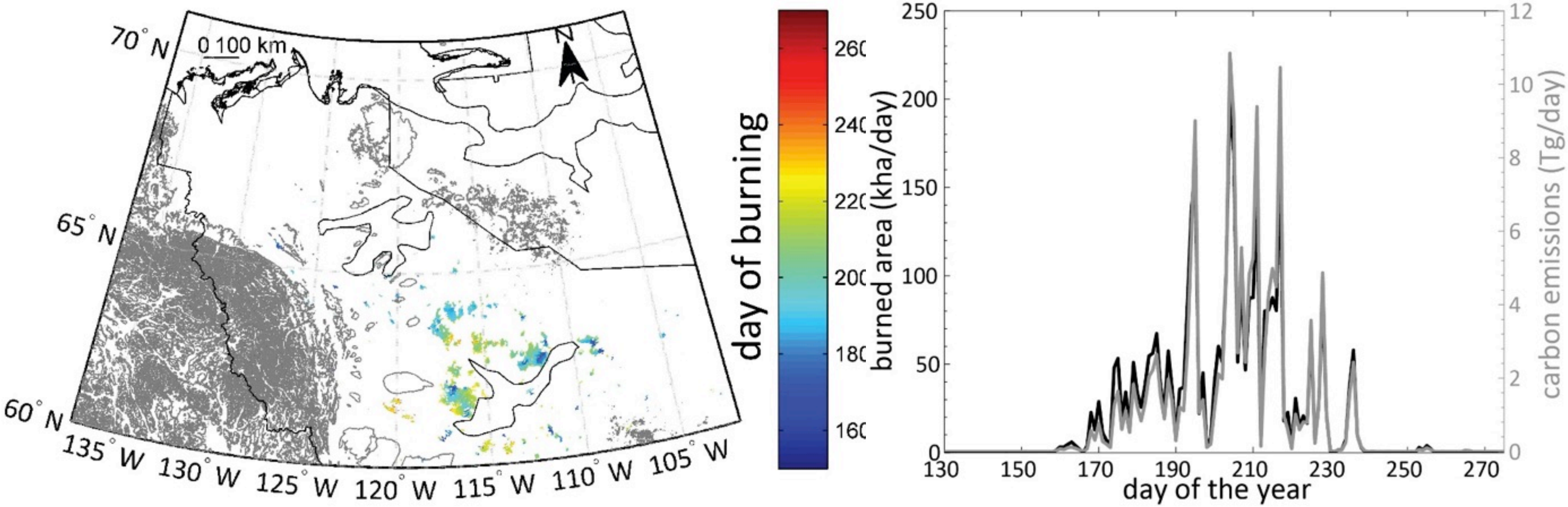




2015 Fire Emissions

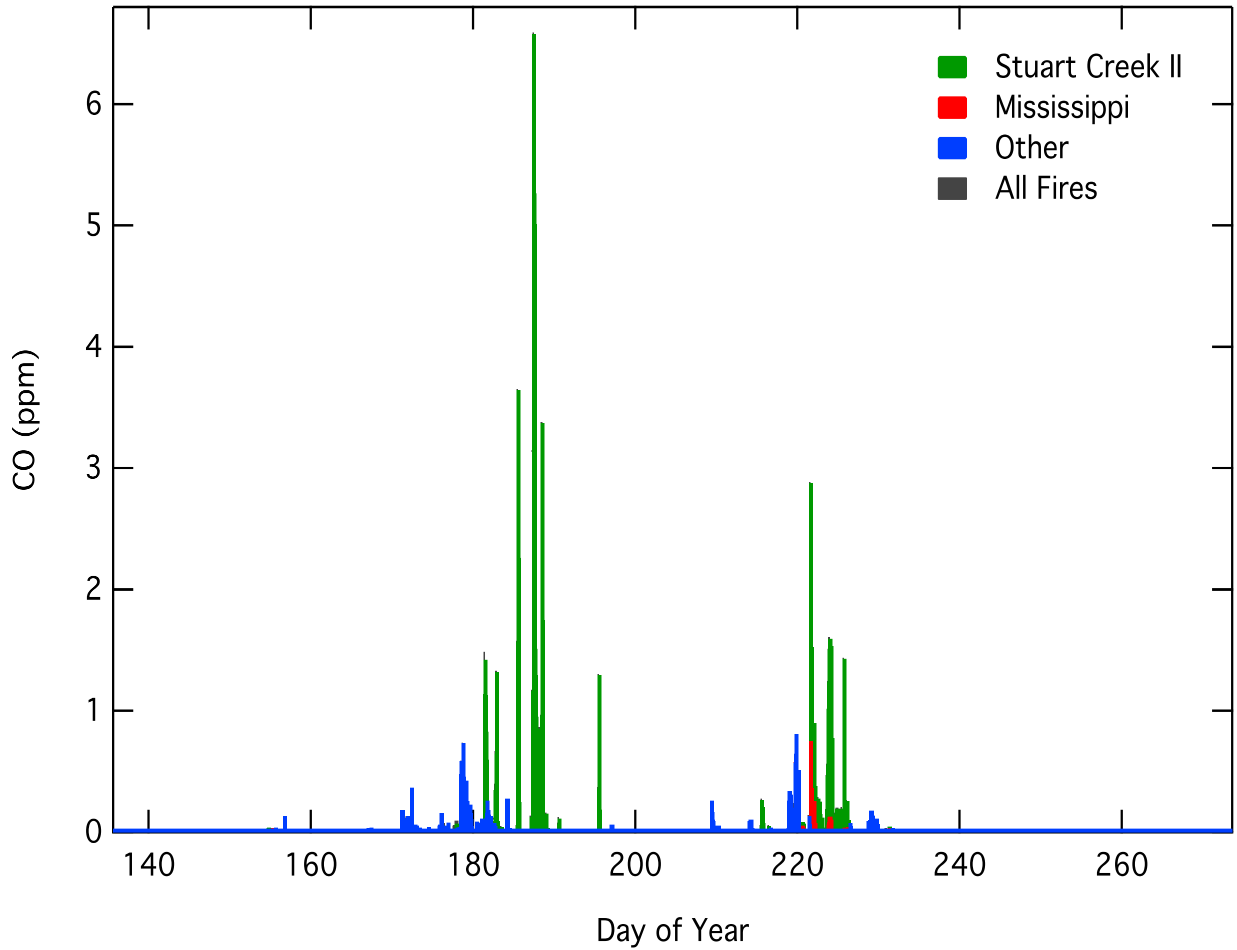
NWT Fire Emissions Database (CANFED)

S Veraverbeke, J Randerson



2014 NWT Fire Emissions

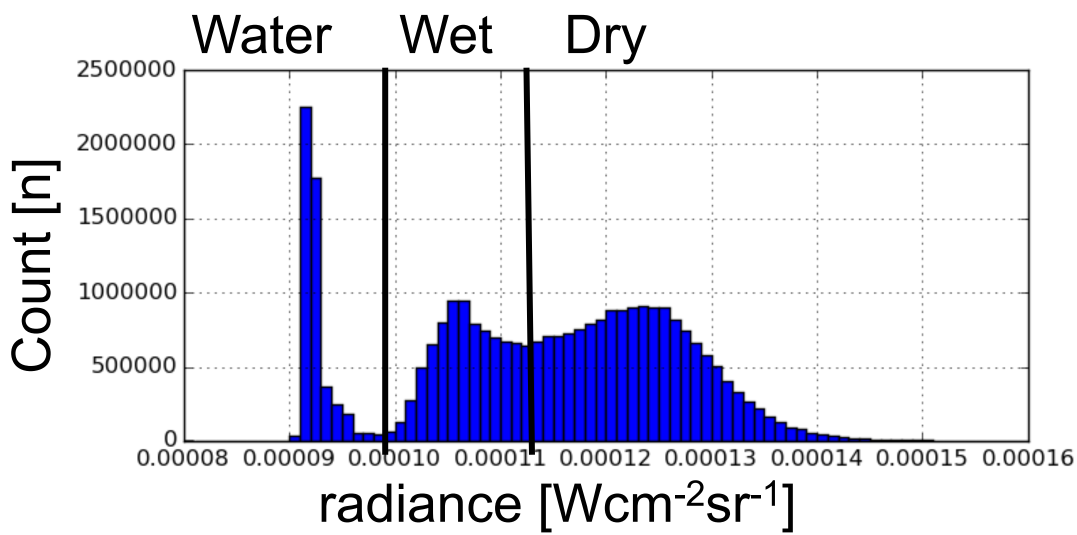
Simulating 2013 Fire Signals at CRV AKFED w/CARVE PWRF-STILT

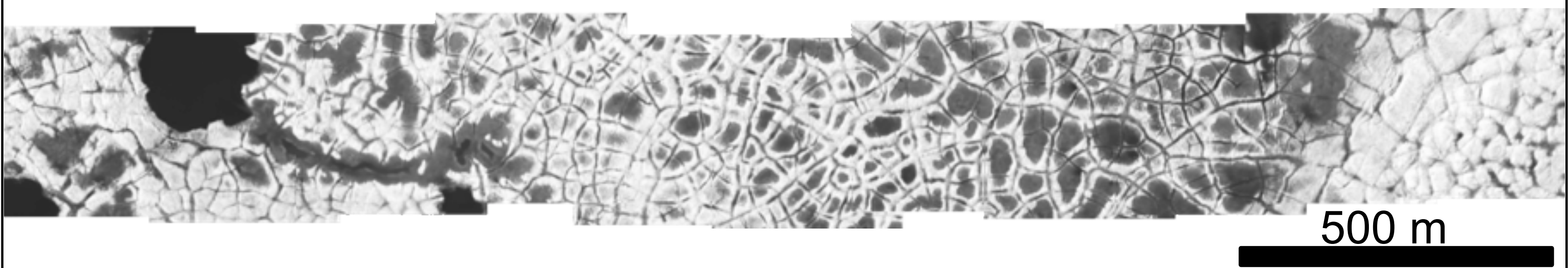


E Wiggins, S Veraverbeke, A Karion, J Henderson

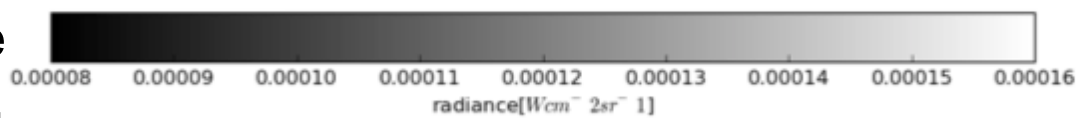
High-resolution IR Imaging of Inundation/Surface Water

- Wetness/surface water important to land/atmosphere carbon flux
- Highly spatially variable
- Surface water fraction may be determined by thresholding FLIR observations
  - ~20 cm resolution
- Useful for upscaling analysis

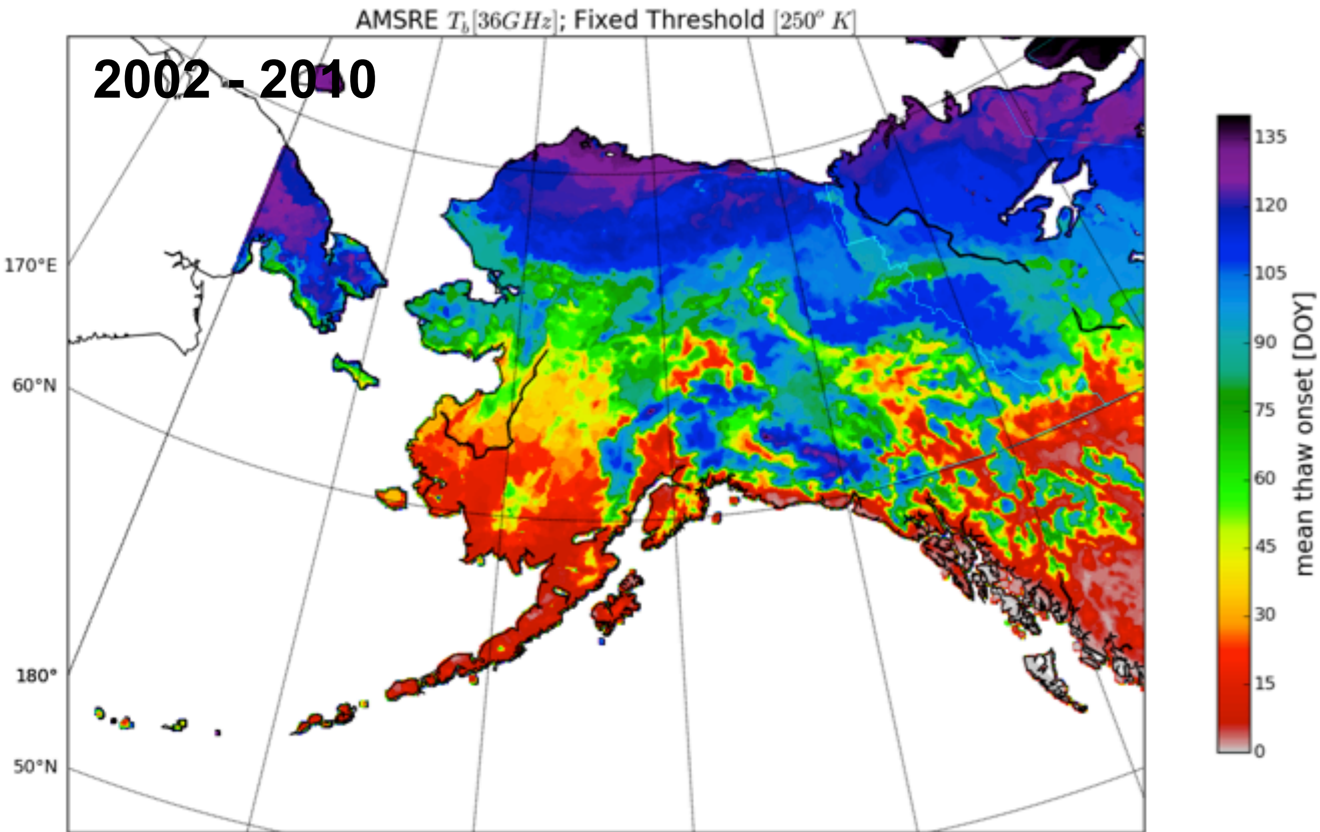




Mid-Infrared Radiance



Latitude-resolved Surface Thaw Onset



N Steiner, K McDonald

- Relate Surface freeze/thaw processes to land/atmosphere carbon exchange at the surface using satellite products
- AMSR-E and SSM/I passive microwave observations will create context for observations made during CARVE experiment (e.g. 4 years for CARVE vs 30 years for SSM/I)

CARVE Lessons Learned → ABoVE

- **Measurements must extend over more than 3 growing seasons to capture average system variability and fast recovery dynamics**
- **Year-round observations desired**
  - Must start before spring thaw and extend past fall refreeze
- **Tiered observing system for Arctic-boreal ecosystem vulnerability**
  - Systematic ^{14}C observing required to monitor ancient C mobilization trends
  - Combine CO2 and CH4 obs with vegetation indexes, SIF, radiation balance, permafrost physical state, active layer depth
  - Separate aircraft for vertical profiling (regional), boundary layer (mesoscale) and flux (local) measurements
  - Establish Arctic 'Ring of Towers' for year-round temporal context
- **Pan-Arctic understanding will require new remote sensing solutions**
  - Passive optical techniques (eg OCO-2) lack year-round coverage

http://CARVE.jpl.nasa.gov Charles.E.Miller@jpl.nasa.gov

Quantifying ABR CO_2 & CH_4 Fluxes

TE14-046

Colm Sweeney (NOAA ESRL)
Anna Michalak, Yuanyuan Fang (Carnegie)
Vineet Yadav (JPL)

Institutional Collaborations (TE14-0046)

- NOAA ESRL
- DOE & NGEE-Arctic
- GFZ Potsdam (Germany)
- Environment Canada

Preliminary

Science Questions & Objectives

CARVE

Tier 2 Science Questions addressed:

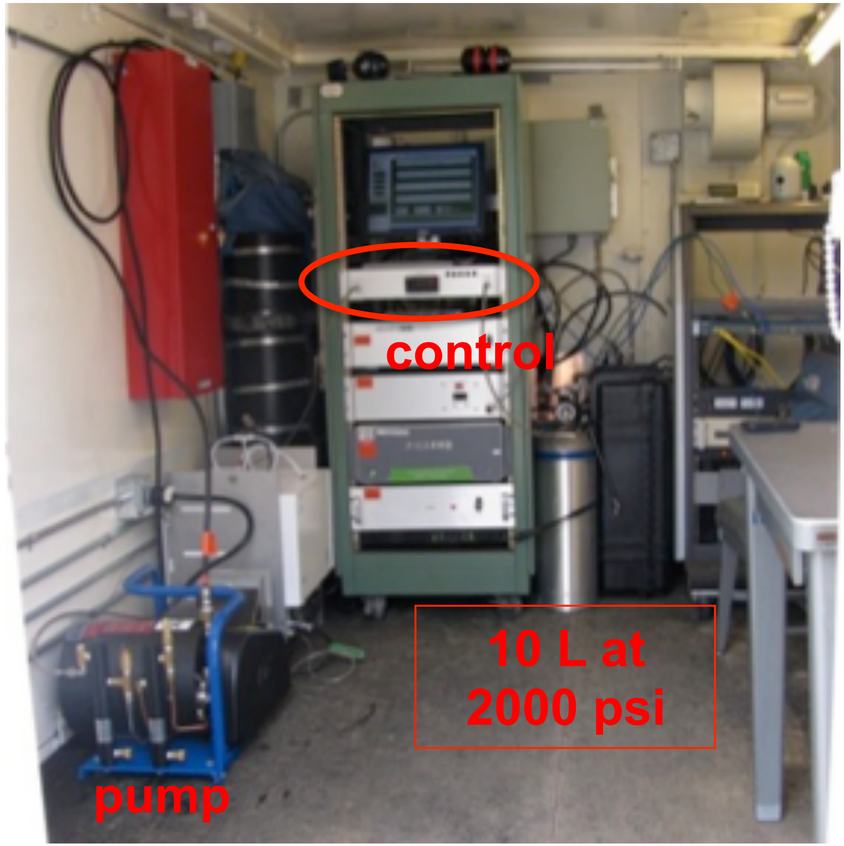
- *How are the magnitudes, fates, and land-atmosphere exchanges of carbon pools responding to environmental change, and what are the biogeochemical mechanisms driving these changes?*

Tier 2 Science Objectives

- **Objective 1**: Acquire, validate and deliver baseline atmospheric CO2, CH4 and CO observations from the CRV tower in Fox, AK.
- **Objective 2**: Use atmospheric CO2 observations in conjunction with a novel geostatistical inverse modeling (GIM) framework to estimate NEE and evaluate the performance of key TBMs (including CASA, TCF and CLM) in simulating the spatiotemporal variability of NEE patterns across the ABoVE domain
- **Objective 3**: Extend the GIM framework to evaluate TBM performance in simulating the spatiotemporal variability of CH4 flux patterns

Field Studies: CRV Tower

64.986°N, 147.598°W, elevation 611 m



Spaceborne Remote Sensing

- GOSAT
- OCO-2

Airborne Remote Sensing

- CARVE
- ACG
- PFA
- AirMETH

Modeling Approaches

- Land Surface Models used to generate CO_2 and CH_4 flux estimates for comparison against CARVE-derived fluxes
  - CASA (C Potter)
  - CLM (C Koven, D Lawrence)
  - PVPRM (N Luus)
  - CARDAMOM (A Bloom)
  - TCF (J Kimball, J Watts)