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DOE/SC-ARM-16-031

ARM-ACME V: ARM Airborne Carbon Measurements V on the North Slope of Alaska Field Campaign Report

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May 2016

ARM CLIMATE RESEARCH FACILITY

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Work supported by the U.S. Department of Energy,
Office of Science, Office of Biological and Environmental Research

Executive Summary

Atmospheric temperatures are warming faster in the Arctic than predicted by climate models. The impact of this warming on permafrost degradation is not well understood, but it is projected to increase carbon decomposition and greenhouse gas production (CO_2 and/or CH_4) by arctic ecosystems. Airborne observations of atmospheric trace gases, aerosols, and cloud properties in North Slopes of Alaska (NSA) are improving our understanding of global climate, with the goal of reducing the uncertainty in global and regional climate simulations and projections.

From June 1 through September 15, 2015, the ARM Aerial Facility (AAF) deployed the G-159 (G-1) research aircraft and flew over the North Slope of Alaska (38 flights, 140 science flight hours), with occasional vertical profiling over Prudhoe Bay, Oliktok Point, Barrow, Atqasuk, Ivotuk, and Toolik Lake. The aircraft payload included Picarro and Los Gatos Research (LGR) analyzers for continuous measurements of CO_2, CH_4, H_2O, and CO and N_2O mixing ratios, and a 12-flask sampler for analysis of carbon cycle gases (CO_2, CO, CH_4, N_2O, $^{13}CO_2$, and trace hydrocarbon species). The aircraft payload also included measurements of aerosol properties (number size distribution, total number concentration, absorption, and scattering), cloud properties (droplet and ice size information), atmospheric thermodynamic state, and solar/infrared radiation.

Acronyms and Abbreviations

AAF	ARM Aerial Facility
ABoVE	Arctic-Boreal Vulnerability Experiment
ARM-ACME	ARM Airborne Carbon Measurements field campaign
ARM	Atmospheric Radiation Measurement Climate Research Facility
ATQ	Atqasuk, Alaska
BRW	Barrow, Alaska
CARVE	Carbon in the Arctic Reservoirs Vulnerability Experiment
CCSP	U.S. Carbon Cycle Science Plan
DOE	U.S. Department of Energy
ESM	earth system model
ESRL	NOAA Earth System Research Laboratory;
FT	free troposphere
GCM	Global Climate Model
GHG	greenhouse gas
IVO	Ivotuk, Alaska
JPL	NASA Jet Propulsion Laboratory
LGR	Los Gatos Research, Inc.
LSM	land surface model
LTER	Long Term Ecological Research Network
m	meter
NACP	North American Carbon Program
NASA	National Aeronautics and Space Administration
NGEE	Next-Generation Ecological Experiment in the Arctic
NOAA	National Oceanic and Atmospheric Administration
NSA	North Slope of Alaska
OLI	Oliktok Point, Alaska
ppb	parts per billion
PBL	planetary boundary layer
ppm	parts per million
TOK	Toolik, Alaska
USCCRP	U.S. Climate Change Research Program
WMGHG	well-mixed greenhouse gases

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Figures

1.0 Background

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University of Colorado/NOAA	Matthew Shupe
DOE Brookhaven National Laboratory	Chongai Kuang

Campaign dates: June 1, 2015, through September 15, 2015

Location: North Slope of Alaska (Figure 1)

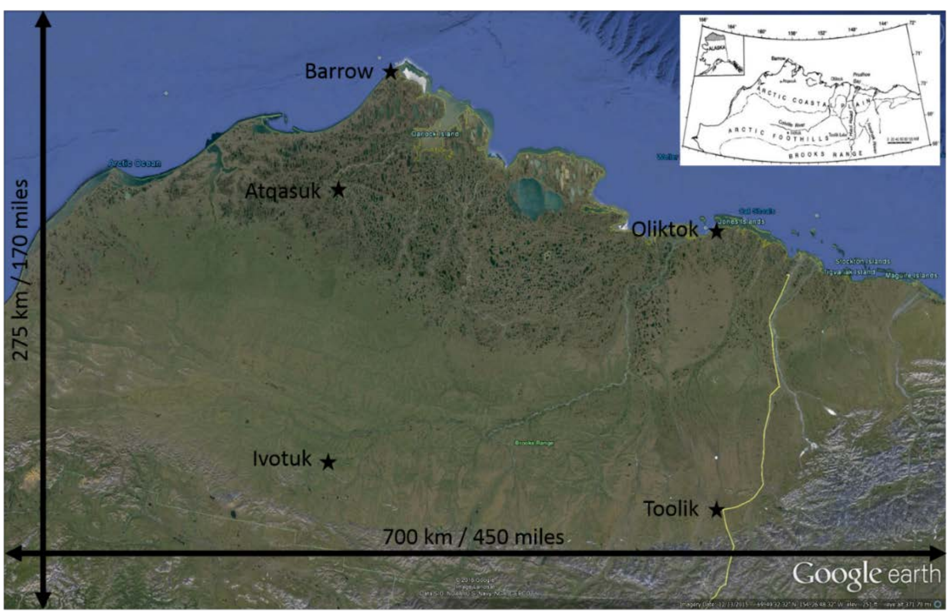

Figure 1. The Alaska North Slope and the location of the existing ARM sites (Barrow and Oliktok), NOAA/ESRL site (Barrow), LTER site (Toolik Lake), and University of San Diego site (Atqasuk and Ivotuk).

The Arctic is a climatically sensitive region on Earth, and high latitudes have experience the greatest regional warming in recent decades (Hansen et al. 2010). This warming trend is projected to increase faster in the Arctic than anywhere else on the globe (Chapman and Walsh 2007; Allison et al. 2009). One of the characteristics of the Arctic region is the existence of permafrost, a layer of permanently frozen subsoil, which stores large amount of carbon (Schuur et al. 2009; Schuur et al. 2015). Observations suggest that permafrost degradation is occurring at a fast pace and linked to increasing air temperature (Jorgenson et al. 2006) and changing surface energy budgets. Permafrost degradation is expected to affect climate forcing (McGuire et al. 2006; Callaghan et al. 2011) through biogeochemical (release of CO_2 and/or CH_4 greenhouse gases) and biophysical feedbacks (inundation, drainage, land cover). The most dramatic changes are expected to occur in the ice-rich permafrost region of the Arctic, such as the Alaska interior and the North Slope. The rate at which permafrost degradation is happening is difficult to quantify and earth system models (ESMs) do not agree on its magnitude (Koven et al. 2013).

The goal of the U.S. Department of Energy (DOE)-funded Next Generation Ecological Experiment in the Arctic (NGEE) is to improve model representations of interactions among vegetation, soils, precipitation, and soil moisture (Koven et al. 2013) that control carbon emissions from Arctic soils. The NGEE-Arctic project and eddy covariance towers deployed in the North Slope of Alaska (NSA), supported by the Atmospheric Radiation Measurement (ARM) Climate Research Facility, the Long Term Ecological Research Network (LTER), and the University of San Diego, provide observations at small spatial scale (1-100 m). Aircraft-based observations of CO_2 and CH_4 mixing ratios, as well as parameters that impact the surface exchange of these, are needed to place these local-scale observations in a larger context. The ongoing National Aeronautics and Space Administration (NASA)-sponsored Carbon in the Arctic Reservoirs Vulnerability Experiment (CARVE), and National Oceanic and Atmospheric Administration (NOAA)-U.S. Coast Guard missions, helped link ground-based observations to regional scales, but focused on Alaska as a whole (Figures 2 and 3). The NASA/Jet Propulsion Laboratory (JPL) Arctic-Boreal Vulnerability Experiment (ABoVE) will start in 2017 and is a large-scale study to better understand "How vulnerable or resilient are ecosystems and society to environmental change in the Arctic and boreal region of western North America", but also targets a vast domain (Figure 4).

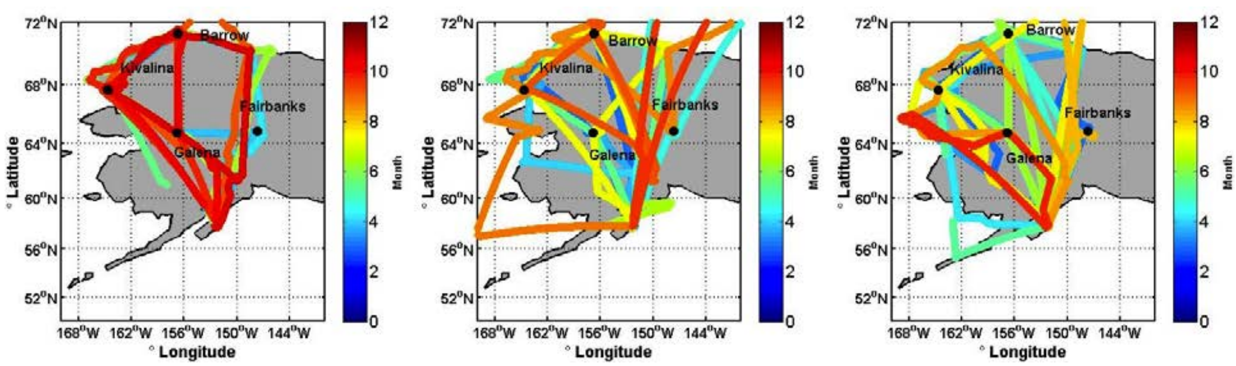

Figure 2. Flight paths of the U.S. Coast Guard aircraft from 2009 (left panel), 2010 (middle panel), and 2011 (right panel). The color of the flight path correspond to the month of the flight (Karion et al., 2013).

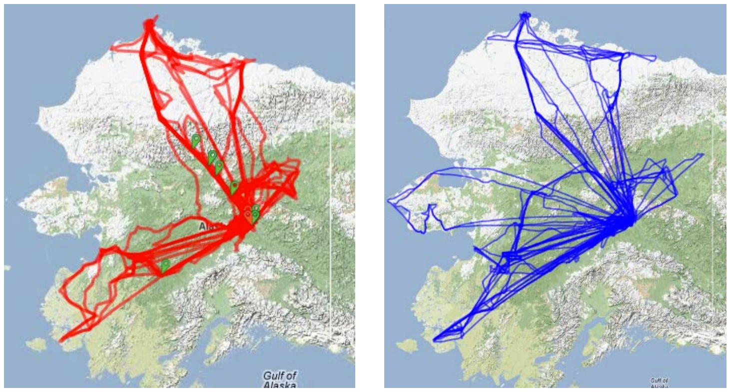

Figure 3. Flight paths of the CARVE missions from May-September 2012 (left panel), and April-October 2013 (right panel).

Figure 4. Domain of study of the ABoVE program. Red and purple lines show the core and extended domain of study, respectively. (http://above.nasa.gov/sites.html).

Recent global inverse models based on these ground and aircraft measurements have found no evidence for increasing CH_4 emissions from Arctic regions in the last 10 years (Bergamaschi et al. 2013; Chang et al. 2014, Zona et al. 2016), despite warming, in contrast to CO_2 emissions (Schaefer et al. 2014). Overall comparison with observations was not as good for CH_4 as for CO_2 (Chang et al. 2014) and showed that the spatial distributions of available model CH_4 emissions are not accurate.

In addition, the ARM Airborne Carbon Measurements V on the North Slope of Alaska field campaign (ARM-ACME V) mission collected measurements of quantities related to aerosols, clouds, and radiation, which both impact and are impacted by surface fluxes of gases. Transfer of energy and gasses between the Earth surface and atmosphere is modulated by clouds and aerosols through their impact on radiative transfer of the atmosphere. The presence, or lack, of clouds directly impacts the amount of solar and infrared radiation reaching the surface of the Earth, thereby impacting surface temperature. In addition, aerosols can also act to regulate radiative transfer through the atmosphere as well as impact the microphysical characteristics of clouds, again changing the amount of radiation received at the surface of the earth. Inversely, clouds can be modulated by turbulent heat fluxes, responsible for acting as a source of heat and moisture for the atmosphere.

The ARM-ACME V mission shed light on processes related to aerosols, clouds, and radiation in the lower Arctic atmosphere, improving our understanding of fundamental processes related to radiative transfer, cloud formation, aerosol-cloud interactions, and the interactions between the surface and lower atmosphere.

2.0 Results

2.1 Results 1: Spatial and Temporal Variability in CO_2 and CH_4

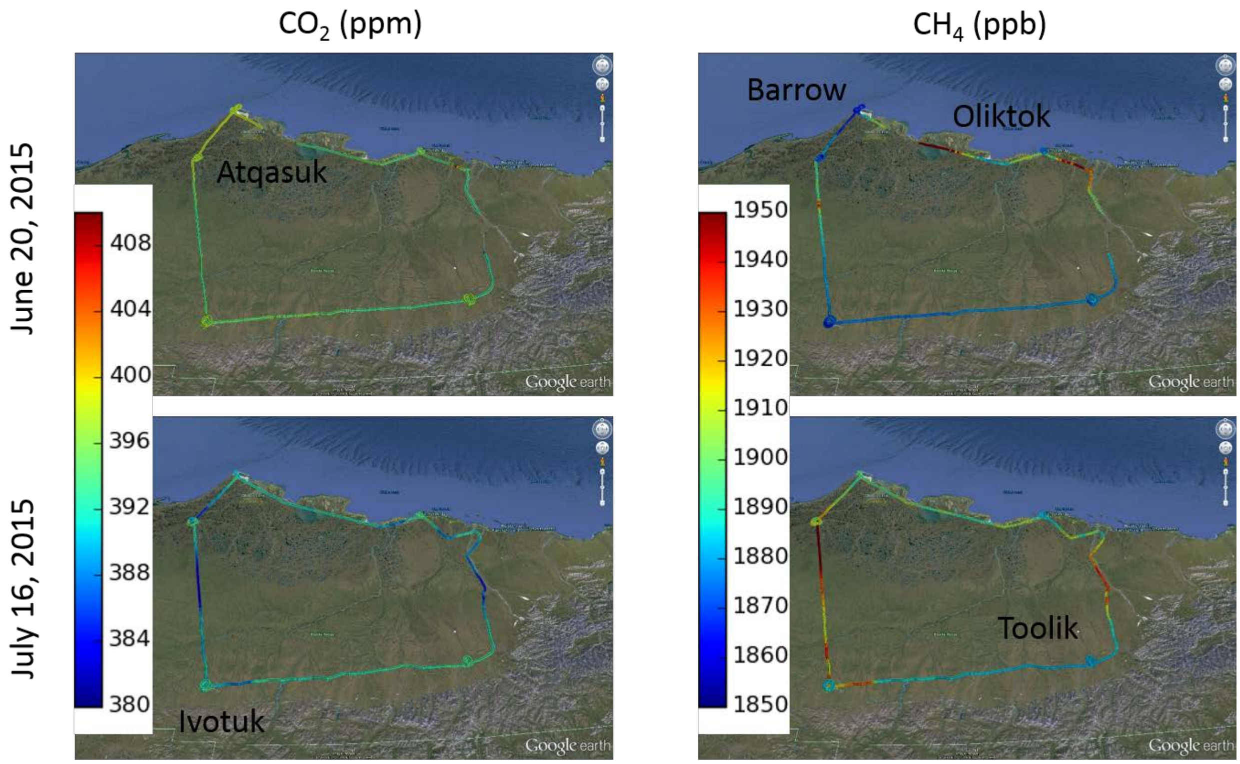

Figure 5. CO_2 (left panels) and CH_4 (right panels) mixing ratios observed during June 20 and July 16, 2015, flights over the NSA.

Spatial variability in CO_2 and CH_4 was documented during the ARM-ACME V mission. An example of spatial and temporal variability is shown in Figure 5.

In June, CO_2 mixing ratios did change across the entire region by more than a couple of parts per million (ppm). As summer unfolded, vegetation became more active and area of lower mixing ratio associated with vegetation uptake started to emerge. The spatial variability across the domain for July was on the order of 10 ppm.

For CH_4, both flights in June and July show large spatial variability, on the order of 100 ppb across the region. The location of large enhancement varies across flights and emphasizes both natural sources and oil- and gas-related sources. For instance, there are large enhancement alongside the trans-Alaska pipeline and in the oilfields along the Arctic Ocean coastline. An interesting feature is associated with CH_4 enhancement between Ivotuk and Atqasuk, which could be associated with natural seeps.

2.2 Results 2: Vertical Profiles of CO_2 and CH_4 over Fixed Sites

The ARM-ACME V mission provided the opportunity to collect much needed statistics on the greenhouse gases vertical profiles over the NSA region.

During each flight, we flew verticals profiles, spiraling up and down from 500 feet all the way to 10,000 feet or higher, over coastal and inland fixed sites: Oliktok, Barrow, Atqasuk, Ivotuk, and Toolik. Figure 6 shows verticals profiles over two sites as whisker plots: on the left side over a coastal site (Oliktok), on the right side over a Brooks Range foothills site (Toolik). There were no flights in September over coastal sites because of the systematic presence of dense fog and low-elevation clouds.

At the coastal site, the lowest elevation shows large mixing-ratio variability for both CO_2 and CH_4 associated with shallow boundary layer and local sources and sinks; this feature is more pronounced for CH_4 than for CO_2. At the foothill site, we did not observe as strong a variability at low elevation, but rather a uniform profile due to a well-mixed, fully developed boundary layer, reaching 10,000 feet on some days.

Variability in the vertical profiles of CO_2 is larger than spatial variability, whereas for CH_4 spatial variability is larger than changes in the vertical.

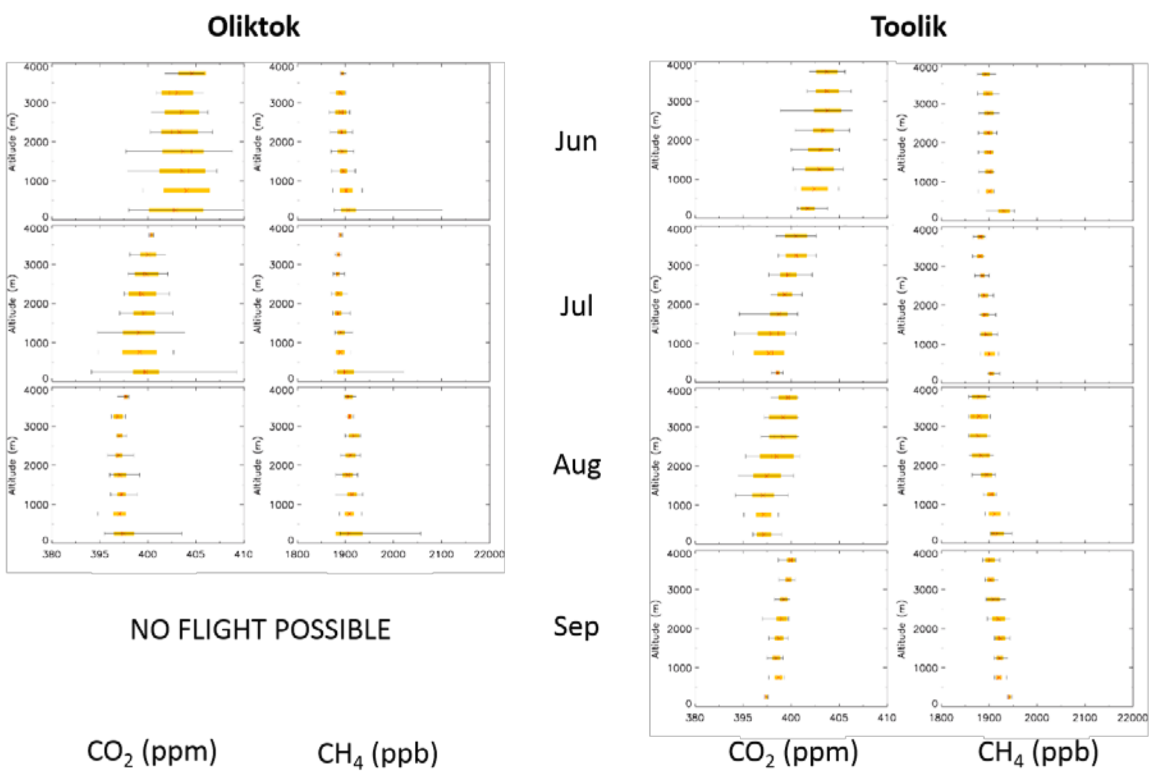

Figure 6. Vertical profile of CO_2 and CH_4 collected over a coastal site (Oliktok) and inland site (Toolik Lake).

3.0 Publications/Presentations

3.1 Journal Articles/Manuscripts

Feldman, DR, WD Collins, SC Biraud, MD Risser, DD Turner, PJ Gero, S Xie, EJ Mlawer, TR Shippert, D Helmig, and MS Torn. "First observation of CH_4 surface radiative forcing reveals local dominance relative to CO_2." Paper submitted to *Nature Geosciences*.

3.2 Meeting Abstracts/Presentations/Poster

FY2016

Biraud, SC, MS Torn, AJ Sedlacek, and S Springston. 2016. "ACME-V mission in the North Slope of Alaska (Airborne Carbon MEasurements)," ARM/ASR PI Meeting, May 2016.

Sedlacek, AJ, Y Feng, S Biraud, and S Springston. 2016. "Vertical and spatial profiling of Arctic black carbon on the North Slope of Alaska 2015: Comparison of model and observation," ARM/ASR PI Meeting, May 2016.

FY2015

Biraud, SC, MS Torn, AJ Sedlacek, S Springston, and C Sweeney. 2015. "Airborne observations of greenhouse gases in the North Slope of Alaska during summer 2015," AGU Fall Meeting, December 2015.

Sedlacek, AJ, Y Feng, S Biraud, and S Springston. 2015. "Vertical and spatial profiling of Arctic black carbon on the North Slope of Alaska 2015: Comparison of model and observation," AGU Fall Meeting, December 2015.

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