DOE/SC-ARM-15-032

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

Science and Implementation Plan

S Biraud

May 2015

DISCLAIMER

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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 at the North Slope of Alaska 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 will deploy the Gulfstream-159 (G-1) research aircraft to fly over the North Slope of Alaska (Figure 1), with occasional vertical profiling to measure trace-gas concentrations between Prudhoe Bay, Oliktok Point, Barrow, Atqasuk, Ivotuk, and Toolik Lake. The aircraft payload includes the Picarro, Inc., (model G) and Los Gatos Research, Inc., (LGR) analyzers for continuous measurements of CO_2, CH_4, H_2O, and CO, and N_2O mixing ratios, and a High Precision Devices, Inc., (HPD) 12-flask sampler for analysis of carbon-cycle gases (CO_2, CO, CH_4, N_2O, $^{13}CO_2$, $^{14}CO_2$, carbonyl sulfide, and trace hydrocarbon species including ethane). The aircraft payload also includes instruments for measuring 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. This research, supported by the U.S. Department of Energy's (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facility and Terrestrial Ecosystem Science programs, build upon the results from the National Aeronautics and Space Administration (NASA) Carbon in Arctic Reservoirs Vulnerability Experiment missions (Miller et al. 2012), and the DOE Next-Generation Ecosystem Experiment Arctic project.

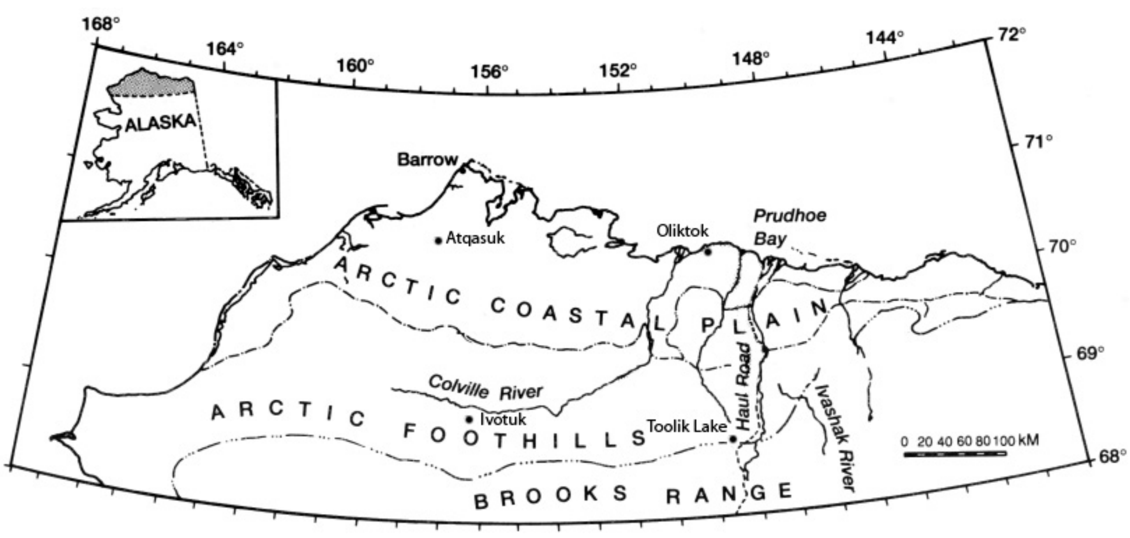

Figure 1. Alaska North Slope and the Location of the Existing ARM Sites (Barrow and Oliktok), National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory (ESRL) Site (Barrow), National Science Foundation (NSF) Long-Term Ecological Research Network Site (Toolik Lake), and San Diego University Site (Atqasuk and Ivotuk). Map adapted from Morrissey and Livingstone (1992).

Acronyms and Abbreviations

ABoVE	Arctic-Boreal Vulnerability Experiment
AMF3	third ARM Mobile Facility
ARM	Atmospheric Radiation Measurement (program)
ARM Facility	ARM Climate Research Facility
ARM-ACME	ARM Airborne Carbon Measurements Project
BC	black carbon
CARVE	NASA Carbon in Arctic Reservoirs Vulnerability Experiment
CCSP	U.S. Carbon Cycle Science Plan
DOE	Department Of Energy
ESRL	NOAA Earth System Research Laboratory
IRGA	infrared gas analyzer
NACP	North American Carbon Program
NASA	National Aeronautics and Space Administration
NASA JPL	NASA Jet Propulsion Laboratory
NGEE	Next-Generation Ecosystem Experiment
NOAA	National Oceanic and Atmospheric Administration
PGS	Precision Gas System
USGCRP	U.S. Global Change Research Program

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1.0 Background

The Arctic is a climatically sensitive region on Earth, and high latitudes are experiencing 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 that stores a large amount of carbon (Schuur et al. 2009; Schuur et al. 2015). Observations suggest that permafrost degradation is happening rapidly and is 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 (e.g., release of CO_2 and/or CH_4, which are greenhouse gases) and biophysical feedbacks (e.g., inundation, drainage, land cover, etc.). 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 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-Artic) 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 (supported by ARM, the Long-Term Ecological Research network, and the University of San Diego) provide observations at small spatial scale (1 to 100 m). Aircraft-based observations of CO_2 and CH_4 mixing ratios, as well as parameters that impact the surface exchange of these gases are needed to place these local-scale observations in a larger context. The ongoing NASA sponsored Carbon in the Arctic Reservoirs Vulnerability Experiment (CARVE), and NOAA U.S. Coast Guard missions helped link ground-based observations to regional scales, but focused on Alaska as a whole (Figure 2 and Figure 3). The National Aeronautic and Space Administration/Jet Propulsion Laboratory (NASA JPL) Arctic-Boreal Vulnerability Experiment (ABoVE), scheduled to start in 2017, be a large-scale study that will target a vast domain (see Figure 4) with a focus on developing a better understanding of the vulnerability or resiliency of ecosystems and society to environmental changes in the Arctic and boreal region of western North America.

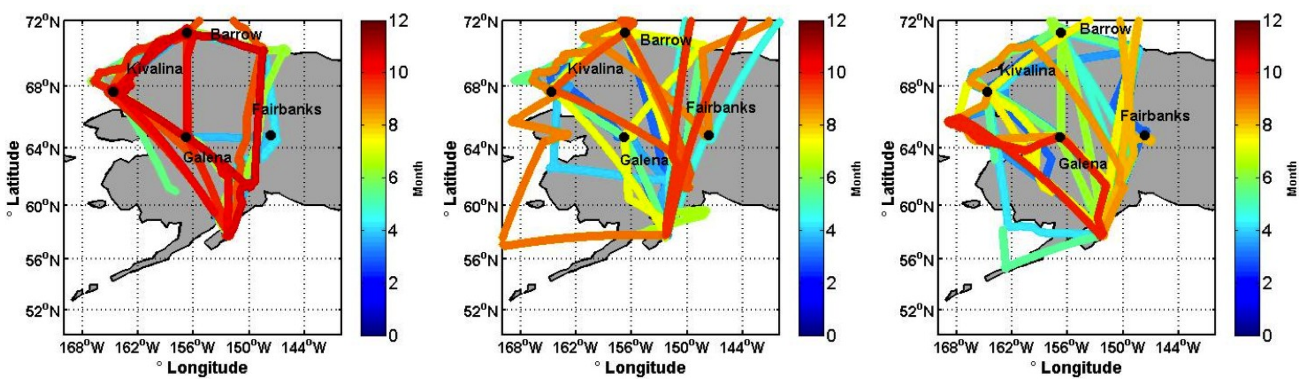

Figure 2. Flight Paths of the U.S. Coast Guard Aircraft from 2009 (left panel), 2010 (middle panel), and 2011 (right panel). The color of a flight path corresponds to the month of the flight (Karion et al. 2013).

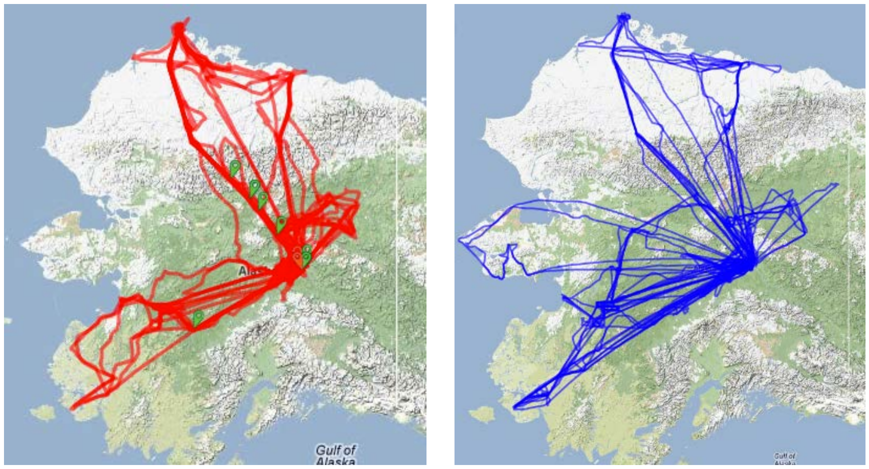

Figure 3. Flight Paths of the CARVE Missions from May–September 2012 (left panel), and April-October 2013 (right panel)

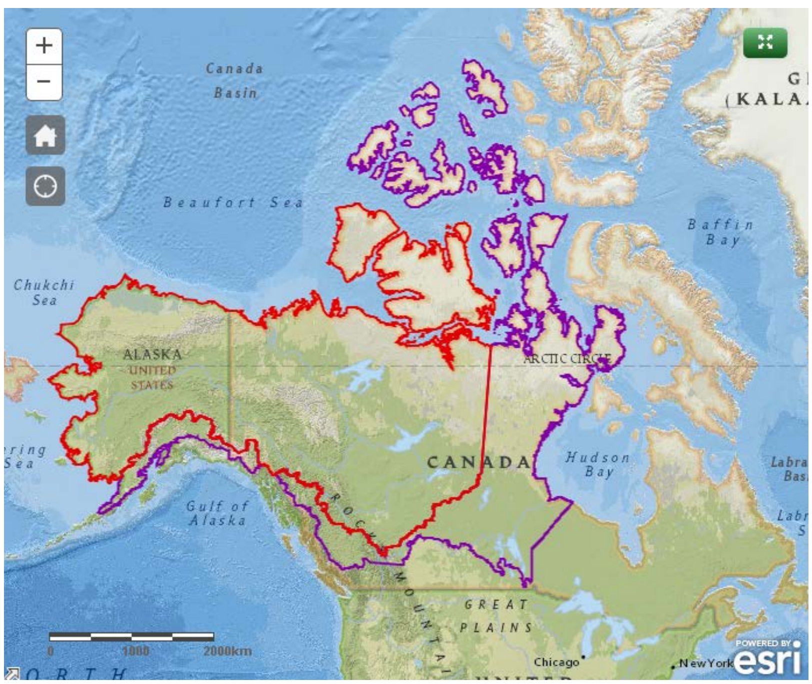

Figure 4. Domains of the ABoVE Program. Red and purple lines show the core and extended domain of study respectively (http://above.nasa.gov/sites.html).

Despite warming, recent global inverse models based on these ground and aircraft measurements have found no evidence of increasing CH_4 emissions from Arctic regions in the last 10 years (Bergamaschi et al. 2013; Chang et al. 2014). This finding is in contrast to CO_2 emissions (Schaefer et al. 2014). Overall comparison with findings from 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. Observations collected during the ARM Airborne Carbon Measurements V Project (ARM-ACME V) are needed and will help address this discrepancy.

In addition, the ARM ACME-V mission will obtain measurements of quantities related to aerosols, clouds, and radiation, which both impact and are impacted by surface fluxes of gases. Transfers of energy and gases between the earth surface and atmosphere are modulated by clouds and aerosols through their impact on radiative transfer of the atmosphere. The presence, or lack, of clouds will directly impact the amount of solar and infrared radiation reaching the surface of the Earth, thereby impacting surface temperature. Aerosols also can act to regulate radiative transfer through the atmosphere and to 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 also will shed light on processes related to aerosols, clouds, and radiation in the lower arctic atmosphere, thus improving our understanding of fundamental processes related to radiative transfer, cloud formation, aerosol-cloud interactions, and interactions between the surface and lower atmosphere.

2.0 Campaign Abstract

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. If the Arctic becomes warmer and drier, most of the carbon will be released as CO_2; if the Arctic becomes warmer and wetter, most of the carbon will be released as CH_4. Processes that control the surface energy and moisture budgets responsible for permafrost changes are not well understood, but are known to be strongly influenced by the atmospheric structure and radiative effects of clouds and aerosols. The deployment of a new, third ARM Facility (AMF3) at Oliktok, Alaska, provides a rare opportunity to couple ground-based and airborne observations of greenhouse gas concentrations in the Arctic and to study their relevant surface exchange processes.

In the summer of 2015, the ARM Aerial Facility will deploy the G-1 research aircraft to fly over the North Slope of Alaska, with occasional vertical profiling to measure background concentrations between Prudhoe Bay, Oliktok Point, Barrow, Atqasuk, Ivotuk, and Toolik Lake. The aircraft payload includes existing Picarro and LGR analyzers for continuous measurements of CO_2, CH_4, H_2O, and CO and N_2O mixing ratios, and a 12-flask HDI sampler for analysis of carbon-cycle gases (CO_2, CO, CH_4, N_2O, $^{13}CO_2$, $^{14}CO_2$, carbonyl sulfide, and trace hydrocarbon species including ethane). To characterize important atmospheric parameters that influence the surface energy budget, the aircraft payload also will include measurements of atmospheric state, aerosol, cloud, and radiation properties. Aerosol measurements will include number size distribution, total number concentration, absorption, and scattering. Cloud measurements include size distributions across the range of sizes that includes both liquid and ice hydrometeors and allows for derivation of bulk parameters. Radiation measurements include upwelling and downwelling broadband longwave and shortwave radiation in addition to radiation in specific narrow radiative bands. This research (supported by the DOE Atmospheric Radiation Measurement (ARM) and Terrestrial Ecosystem Science programs) will build upon the results from the NASA CARVE missions (Miller et al. 2012), and the DOE NGEE-Arctic project.

3.0 Campaign Summary and Scientific Objectives

ARM-ACME V campaign flights are designed to collect a unique data set of trace-gas mixing ratios and atmospheric properties over the North Slope of Alaska in and out of the planetary boundary layer to address multiple science objectives:

- Characterize atmospheric mixing ratios across the North Slope of Alaska region
- Characterize the spatial (horizontal/vertical) distribution of aerosol and cloud size and number concentration, and their relationships, across the region
- Characterize spatial variability of upwelling and downwelling radiation budgets related to cloud, aerosol, and surface properties
- Evaluate interactions between aerosols and clouds and the impact of these interactions on cloud radiative forcing
- Evaluate representativeness of ground sites at regional scales
- Relate spatial and seasonal differences in greenhouse gas sources (e.g., proximity to fossil sources), land-surface properties (e.g., thaw or inundation), and atmospheric transport to variations in CO_2 and CH_4 mixing ratios.

To fully address these questions would require several years of observations along with coordinated analyses, led by Lawrence Berkeley National Laboratory, of remote sensing and ground-based observations that are currently supported by ARM and NGEE-Arctic projects, and NASA CARVE missions. Nevertheless, we believe our project will contribute to addressing our science objectives and further collaborations between federal agencies (NOAA, NASA, and DOE).

4.0 Project Description

4.1 Motivation

4.1.1 Trace Gas Observations

Eddy covariance measurements (using an infrared gas analyzer and sonic anemometer) provide information on net ecosystem exchange at small scales in response to climate trends and inter-annual variability. Currently, all measurement sites across the North Slope of Alaska show that ecosystems are a net source of CO_2, but the magnitude of this source is not uniform, thus posing a challenge to earth system models. Fewer sites, with trace-gas mixing ratio observations, are available for use in inversion studies to infer large-scale carbon fluxes. A recent re-examination of CO_2 observations collected at Barrow by NOAA ESRL since the early 1970s has shown an increase in ocean/land CO_2 differences, indicating that warming in the Arctic has already increased emissions from arctic ecosystems.[1]

[1] Personal communication, Professor S. Wofsy, Harvard University.

The ARM-ACME V project will collect observations of CO^2, CH^4, CO, and other trace gases to improve estimates of biogenic emissions of CO^2 and CH^4 in the North Slope of Alaska. Carbon monoxide, ethane, and soot spectroscopy observations will be used to distinguish between biogenic and thermogenic (biomass burning, and oil and gas production) contributions (Fisher et al. 2011). These observations will (1) put ground-based observations into a regional perspective, (2) provide a better definition of the boundary conditions for air masses entering the North Slope of Alaska region, (3) document the locations of key transitions in the vertical profile (heights of the planetary boundary layer and residual layer), and (4) give more accurate observations of atmospheric concentrations within each zone. By combining data from flask samples and continuous observations, we will assess the representativeness of tower-based observations and contribute to improving inverse modeling studies.

It is worth noting that some estimates show that 40% of arctic CH_4 emissions occur in the shoulder seasons (Tagesson et al. 2012, Sturtevant et al. 2012) when ground observations are very rare. The challenging climatic conditions and complex logistics of working in the Arctic make it more expensive and difficult to collect data outside of the growing season, and the episodic nature of these CH_4 “bursts” (Mastepanov et al. 2008) means that many ground-based observations—and luck—would be needed to capture them. Thus, it is important to fly as early and as late as possible in the shoulder seasons (especially April/May and October/November) to constrain estimates of regional greenhouse gas fluxes during the spring thaw and fall freeze.

4.1.2 Aerosol Property Observations

One of the major issues confronting aerosol climate simulations of the Arctic and Antarctic cryospheres is the lack of detailed data on the vertical and spatial distribution of aerosols with which to test these models. This lack of data is due, in part, to the inherent difficulty of conducting such measurements in extreme environments. However, given the pronounced sensitivity of the Polar Regions to radiative balance perturbations, it is incumbent upon our community to better understand and quantify these perturbations, and their unique feedbacks so that robust model predictions of this region can be realized. One class of under measured radiative forcing agents in the Polar Region is the absorbing aerosol—black carbon (BC) and brown carbon. A second important issue regards the influence of aerosols on clouds and their radiative properties.

Black carbon (also referred to as light absorbing carbon, refractory black carbon [rBC], and soot) is second only to CO^2 as a positive forcing agent. Approximately 60% of BC emissions can be attributed to anthropogenic sources (fossil fuel combustion and open pit cooking) with the remaining fraction resulting from biomass burning. Brown carbon, a major component of biomass burning, collectively refers to non-BC carbonaceous aerosols that typically possess minimal light absorption at visible wavelengths but exhibit pronounced light absorption in the near ultraviolet region. Both species can be sourced locally or be remotely transported to the Arctic region and are expected to perturb the radiative balance.

The proposed work will address one of the more glaring deficiencies currently limiting improved quantification of the impact of BC radiative forcing in the cryosphere; that is, the paucity of data on the vertical and spatial distributions of BC. To acquire the BC vertical and spatial data, the G-1 payload includes the Single Particle Soot Photometer (SP2) made by Droplet Measurement Technologies. Because the SP2 is a particle-resolved measurement, the resulting data set will provide rBC mass loadings, size and mass distributions, and rBC-containing particle mixing state, all of which are expected to readily find value in the modeling community.

This campaign also will contribute substantially to understanding the baseline state of the regional aerosol population for which our current knowledge is limited. This baseline characterization is needed for source attribution and to investigate the relative impacts of aerosol from long-range transport versus regional sources. Such a characterization also will provide the basis for studying aerosol properties and processes such as aerosol formation and growth, which can impact radiative forcing directly from scattering, and indirectly by serving as potential cloud condensation nuclei. Related to aerosol-cloud interactions, important questions exist concerning the vertical distribution of aerosol relative to cloud layers and the stratified arctic atmosphere. While most aerosol measurements are made near the surface, the linkage between near-surface aerosol and the clouds aloft is not clear but could have important implications for cloud persistence and radiative properties.

4.1.3 Cloud Property Observations

Arctic clouds are known to exert a significant influence on atmospheric radiation, vertical atmospheric structure, surface energy budget, and precipitation. These processes in turn can affect surface and subsurface processes related to permafrost, surface gas exchange, moisture exchange, and more. While the background, clear-sky atmospheric radiation is reasonably well understood as a result of relatively well-constrained processes related to sun angles and large-scale temperature advection, the variability of all-sky radiation related to clouds is a major area of uncertainty. Arctic clouds pose specific challenges in part because they frequently exist as mixed phases, containing both ice and liquid water, sometimes at super-cooled temperatures. The complex vapor-liquid-ice system in these clouds is difficult to represent in models, yet it has profound implications for surface energy budgets and other processes. It is known that cloud liquid water has a much stronger influence on surface radiation than cloud ice, primarily because of aerosol and microphysical processes that influence liquid and ice particle size distributions. Thus, the main issues concerning arctic clouds pertain to phase partitioning and maintenance of cloud liquid water in the face of dissipative tendencies. To resolve these issues and their implications requires longer-term measurements of cloud microphysical properties along with atmospheric thermodynamic state, atmospheric radiation, aerosol concentrations, surface properties, and other environmental conditions.

The ARM-ACME V campaign will help to address multiple arctic cloud research objectives. First, observations are designed to characterize the particle size distributions over ranges that represent both populations of liquid droplets and ice crystals, allowing detailed microphysical characterization of observed cloud layers. Along with coordinated aerosol concentration and radiation measurements, these data will offer the ability to examine aerosol–cloud interactions, the vertical interplay of aerosols and clouds with the stratified arctic atmosphere, spatial heterogeneity of cloud radiative properties, vertical radiative heating rate profiles, and other processes.

Routine and repeated observations over specific flight paths will be important for building statistical data sets to study key processes. For example, multi-month data sets will be needed to examine the radiative and microphysical cloud properties in a wide range of aerosol conditions ranging from heavily polluted to relatively clean air masses. Aircraft profiling above ARM ground-based facilities at Barrow and Oliktok Point will contribute critical data sets for comparing with cloud property retrievals from remote sensors operated at the surface. This verification data will support more robust ground-based cloud retrievals that can be applied to operational, long-term measurements. Finally, aircraft profiling allows for cloud vertical structures to be examined in more detail, specifically near cloud base and top that serve as key interfaces with the surface layer and free troposphere. Radiation measurements below clouds will help to characterize the linkages between cloud-level radiation and surface energy fluxes.

4.1.4 Solar and Infrared Radiation Observations

Spectral albedo calculated from the up-looking and down-looking multifilter radiometer onboard the G-1 will be used to correlate land-surface properties to exchanges of carbon between the land surface and the atmosphere. The broadband net radiation (both for shortwave and longwave radiation) then will help quantify the radiation budgets associated with these land-surface properties (Figure 5), which is in turn associated with the permafrost degradation process. These flight-level radiation measurements also will help to link atmosphere, cloud, and aerosol property measurements to radiative influences on the surface.

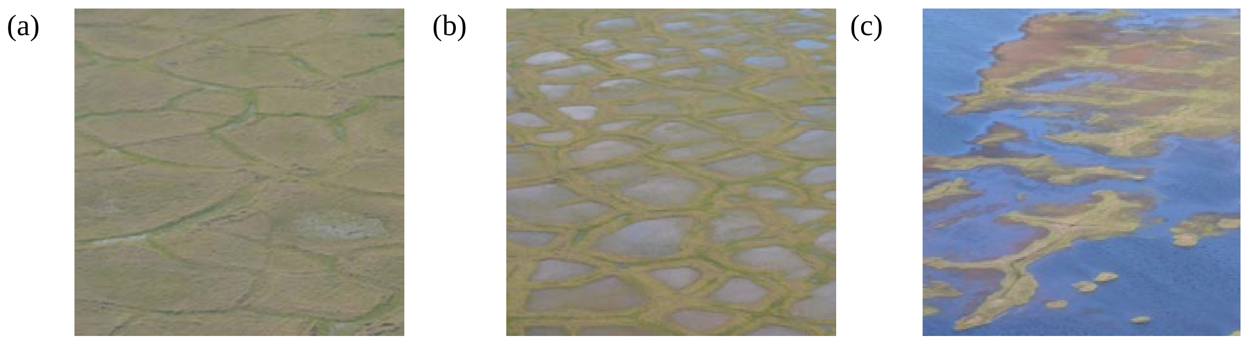

Figure 5. (a) Dry, (b) Partially Inundated, and (c) Inundated Polygonal Tundra. Differences in land-surface properties are expected to have different CO^2 and CH^4 signatures. Photographs courtesy of Chip Miller (NASA JPL).

4.2 Instrumentation

The standard atmospheric state G-1 payload will be included (temperature, static pressure, dew-point temperature, absolute humidity), as well as the downward and forward video imaging systems, the full set of broadband and spectral radiometers, and aircraft attitude diagnostic variables (true airspeed, angle-of-attack, geographic coordinates).

4.2.1 Aircraft Observations

- *Continuous $CO_2/CH_4/H_2O$ Analyzer*. One cavity ring down spectroscopy continuous $CO_2/CH_4/H_2O$ analyzer built by Picarro for aircraft-based mixing ratio measurements. This system, currently in use on the G-1, was recently refurbished (spring 2015) and tested to assess its field precision and accuracy (early May 2015).
- *Continuous $CO/N_2O/H_2O$ Analyzer*. One continuous $CO/N_2O/H_2O$ analyzer built by LGR for mixing ratio measurements. This system has previously operated on the G-1 (GoAmazon campaign).

- *Twelve-Flask Package*. The 12-flask sampler is built by HPD and was installed on the G-1 at the beginning of May 2015. Samples are collected from the community inlet for as many as 12 elevations. The operator triggers sampling when location and latitude have been reached. Each flask (0.75 L) is sampled for about 2 minutes and pressurized to 40 psi. The sampler has two components: (1) a rack mounted programmable compressor package and (2) a programmable flask package. Prior to each flight, the pilot connects a new programmable flask package to the programmable compressor package. An automatic test is then performed to check for leaks. After each flight the programmable flask package is sent back to the laboratory for trace-gas analysis.

4.2.2 Surface Observations

Ground-based measured for trace gases are available in and around the North Slope of Alaska:

- Continuous measurements of CO_2 and CH_4 mixing ratios will start at Oliktok Point in May 2015. This site will offer boundary values for northerly flow conditions and will be essential for inversion studies.
- Continuous CO_2 and CH_4 observations from NOAA ESRL are available for Barrow, and flask samples are available from Cold Bay. Resulting information will provide boundary conditions for westerly flow conditions (collaborator: C. Sweeney).
- Continuous data are available from Arctic and Boreal Canada (Collaborator: D. Worthy). Sites include Alert, Nunavut; Fraserdale, Ontario; East Trout Lake and Candle Lake, Saskatchewan; Egbert, Ontario; Chibougamau, Quebec; Lac Labiche, Alberta; Sable Island, Nova Scotia; and Estevan Point, British Columbia.

4.2.3 Aerosol Property Observations

Instruments making up the aerosol properties payload for the G-1 aircraft are listed in Table 1.

Table 1. Aerosol Properties Payload

Manufacturer	Instrument	Measurements
Droplet Measurement Technologies	Single Particle Soot Photometer (SP2)	rBC (refractory black carbon) concentration
Trust Science Innovation Inc.	Ultrafine Condensation Particle Counter (UCPC), Model 3025A	Total particle concentration (>3 nm)
Trust Science Innovation Inc.	Condensation Particle Counter (CPC), Model 3010	Total particle concentration (>10 nm)
Droplet Measurement Technologies	Ultra High Sensitivity Aerosol Spectrometer - Airborne (UHSAS-A)	Aerosol size distribution (60–1000 nm)
Droplet Measurement Technologies	Passive Cavity Aerosol Spectrometer (PCASP-100X)	Aerosol size distribution (100–3000 nm)
Radiance Research	Particle/Soot Absorption Photometer (PSAP)	Aerosol absorption, three wavelengths
Trust Science Innovation Inc.	3-Wavelength Integrating Nephelometer, Model 3563	Aerosol scattering, three wavelengths

Ground-based, continuous aerosol measurements for absorption, scattering, and the total aerosol number concentration larger than 10 nm are available at Barrow from NOAA ESRL (collaborator: A. Jefferson).

4.2.4 Cloud Property Observations

Instruments making up the cloud microphysics payload for the G-1 aircraft are listed in Table 2.

Table 2. Cloud Microphysics Payload

Manufacturer	Instrument	Measurements
Science Engineering Associates, Inc.	SEA WCM-2000	Cloud liquid water content, total water content, and ice water content derived
Stratton Park Engineering Company	High Volume Precipitation Spectrometer Version 3 (HVPS-3)	Cloud particles size distribution (150–19,600 mm)
Stratton Park Engineering Company	Two-Dimensional Stereo Probe (2D-S)	Cloud particles size distribution (10–3,000 mm)
Stratton Park Engineering Company	Fast-Cloud Droplet Probe (F-CDP)	Cloud particles size distribution (2–50 mm)
Droplet Measurement Technologies	Cloud Droplet Probe, Version 2 (CDP-2)	Cloud droplet size distribution (2–50 mm)

Solar and Infrared Radiation Measurements

Instruments making up the solar and infrared radiation payload for the G-1 aircraft are listed in Table 3.

Table 3. Solar and Infrared Radiation Payload

Manufacturer	Instrument	Measurements
Delta-T Devices	Sunshine Pyranometer (SPN-1) shaded	Downwelling shortwave radiation global, broadband
Delta-T Devices	Sunshine Pyranometer (SPN-1) unshaded	downwelling shortwave radiation total broadband
Delta-T Devices	Sunshine Pyranometer (SPN-1) unshaded	Upwelling shortwave radiation global, broadband
Yankee/PNNL modified	Multifilter radiometer	Downwelling shortwave radiation global, 415, 500, 615, 673, 870, 940, 1625 nm spectral channels
Yankee/PNNL modified	Multifilter radiometer	Upwelling shortwave radiation global, 415, 500, 615, 673, 870, 940, 1625 nm spectral channels
Kipp & Zonen	Pyrgeometer CGR-4	Downwelling infrared radiation, hemispheric
Kipp & Zonen	Pyrgeometer CGR-4	Upwelling infrared radiation, hemispheric

4.3 Flight Paths

The flight paths over land consist of low horizontal transects (~500 feet above ground), starting near Prudhoe Bay, and flying over Oliktok, Barrow, Atqasuk, Ivotuk, and Toolik Lake fixed sites (see Figure 6. When the plane is passing over established ground sites, it will fly a spiral pattern through the planetary boundary layer to reach the free troposphere. The maximum altitude of the spiral is flight path dependent (10,000 feet or 20,000 feet) because of the amount of fuel necessary to complete each mission and the fact there are very few alternate airports available in the North Slope of Alaska.

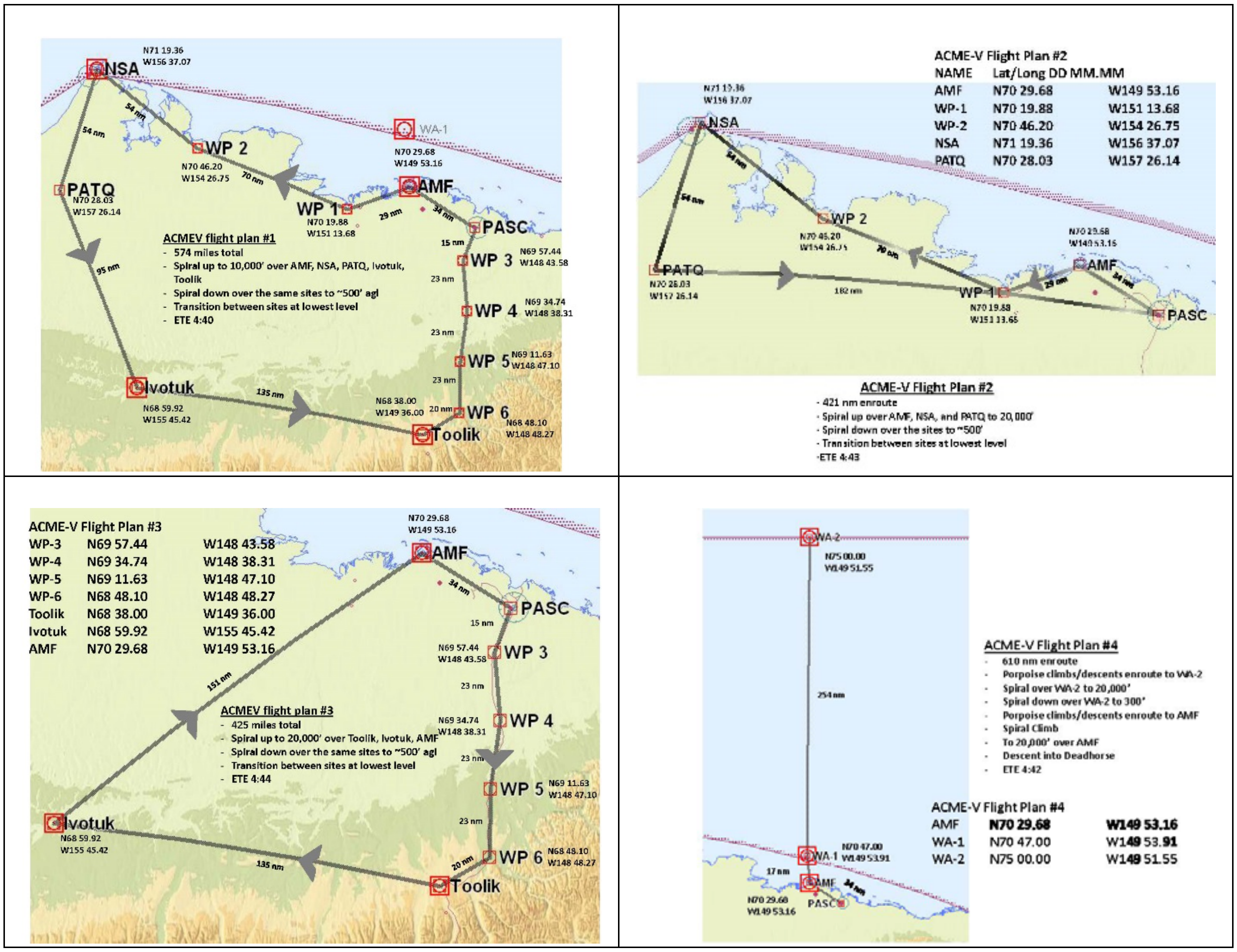

Figure 6. Maps Showing Possible Flight Paths for the ARM-ACME V Campaign

The flight pattern of the Arctic Ocean is a horizontal transect between Prudhoe Bay and Oliktok point, continuing north to the 75°N parallel. During the ocean transect, the plane will ascend and descend between 300 and 3000 feet multiple times (porpoise-like), before ascending in a spiral up to 20,000 feet and back down to 300 feet over the 75°N parallel and reversing course. Note that 300 feet represents the lowest altitude the plane could fly over the ocean.

5.0 Relevancy to Long-Term Goals of the U.S. Department of Energy Office of Biological and Environmental Research

The Department of Energy is an active member of the U.S. Global Change Research Program (USGCRP, globalchange.gov) and its carbon cycle interagency working group, which sponsors the U.S. Carbon Cycle Science Plan (CCSP). Our research is guided by one of the implementation plans of the CCSP, the North American Carbon Program (Denning et al. 2005; Wofsy et al. 2002), which calls for observational campaigns over the continental United States for diagnosis, attribution, and scaling of CO_2 sources and sinks. The ARM-ACME V project supports CCSP goals for in situ measurements of CO_2 and tracers of carbon-cycle processes. The ARM-ACME V project is a significant contributor to USGCRP carbon-cycle goals and helps the ARM Facility meet DOE's Climate and Environmental Sciences Division strategic objective as a valuable resource "… to NOAA and NASA."

The proposed work will enhance the ARM Climate Research Facility as a user facility for the study of global change by generating high visibility, coupled-system datastreams for the carbon cycle. The ARM carbon datastreams we produce are among the most frequently downloaded and used data in the ARM archives. In terms of earth system components listed in the ARM mission statement, these data will be used to advance our understanding of the interaction of physical (i.e., climatic), chemical (i.e., atmospheric), and biological (i.e., land-surface) processes that regulate atmospheric greenhouse gas concentrations and land productivity. In addition, the proposed work will contribute to monitoring and predicting radiative forcing related to clouds and aerosols.

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