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Investigating Alaskan methane and carbon dioxide fluxes using measurements from the CARVE tower

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1. Abstract

The Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE) was designed to use a variety of measurements, including in-situ greenhouse gas measurements, from aircraft and a ground station to understand and quantify emissions and changes in emissions of carbon to the atmosphere from Arctic and boreal Alaska over several years. Arctic and boreal carbon sources and sinks are expected to be sensitive to the rapidly warming climate in these regions in the coming decades. The measurements described here are an example of the monitoring that will be required to detect the impact of climate change on biosphere-atmosphere gas exchange in this sensitive region. Here we describe the in-situ greenhouse gas measurement record started in October 2011 at the NOAA tower in Fox, AK (64.986 N, 147.598 W, elevation 611 masl; NOAA site code CRV) to support CARVE. We present analysis of in-situ continuous carbon dioxide (CO_2), methane (CH_4) and carbon monoxide (CO) measurements as they compare with background air coming into Alaska from the west. We also present the region of influence for the tower measurements during 2012-2014, calculated using high-resolution meteorological fields generated for the CARVE project for Alaska from 2012-2014 coupled with a Lagrangian particle dispersion model. We use the modeled influence functions (footprints) to constrain average land-based CH_4 fluxes for the time period. In addition, we find that CO_2 enhancements at the site can be reproduced remarkably well using the modeled footprints convolved with the Polar Vegetation Photosynthesis and Respiration Model (VPRM; Luus and Lin, 2015).

2. Measurements

We have deployed a trace-gas measurement system with continuous measurements of CO_2, CH_4, and CO using a CRDS system, in addition to flask sample collection for additional trace gas analysis. The observations come from a NOAA tower located on a ridge in central Alaska; this high elevation (611 magl) allows the site to simulate a tall tower with regional sensitivity even though it is only 32 magl.

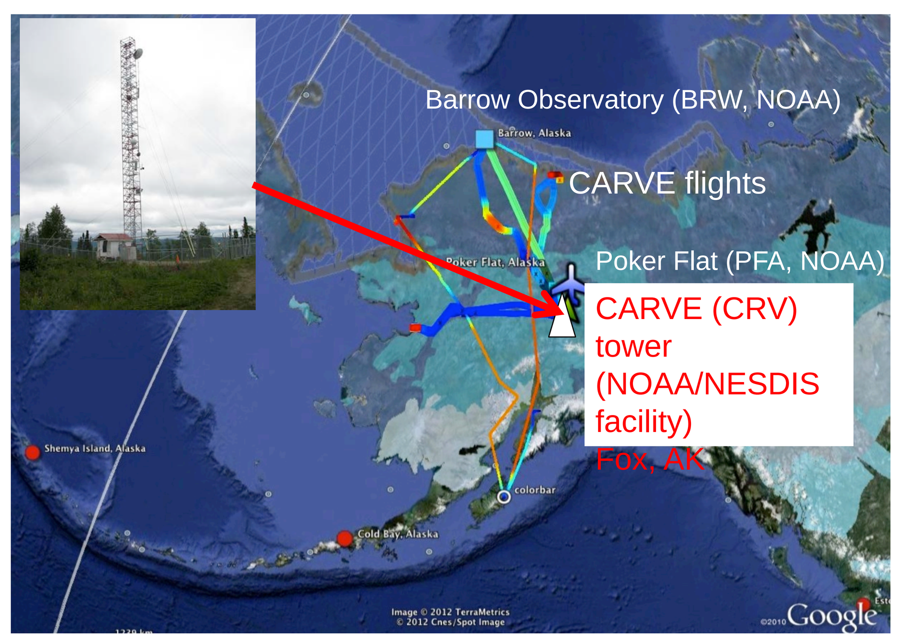


Figure 1. The CARVE tower is a valuable addition to the CARVE aircraft flights, the NOAA ACG flights (flight tracks), and other NOAA global network sites.

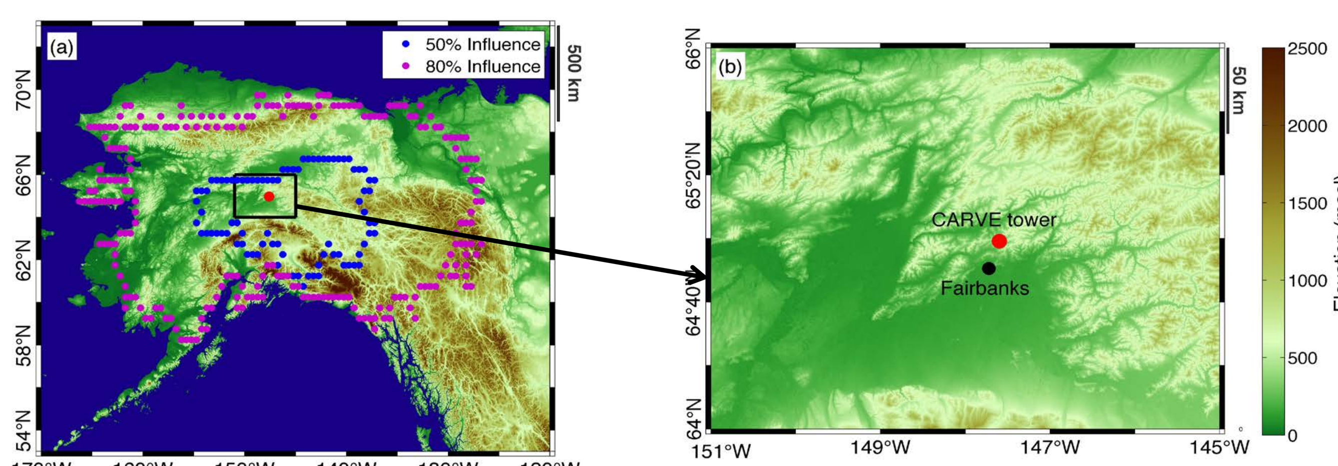
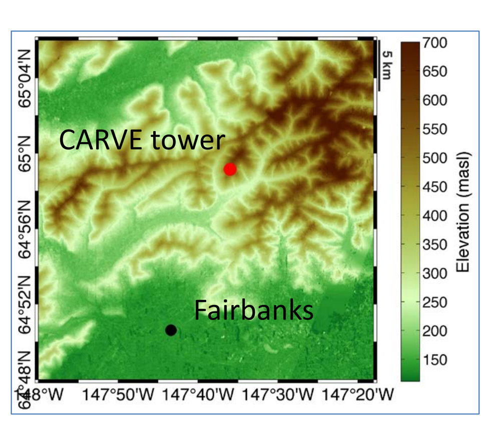


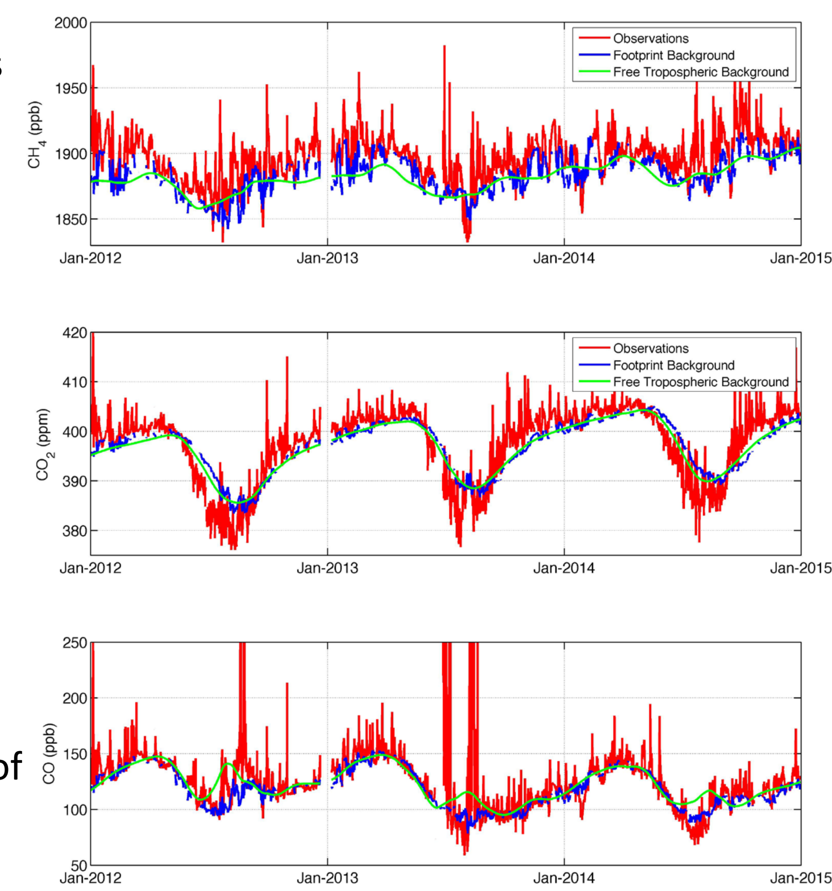
Figure 2. Location of the CARVE tower (red circle, both panels) shown on an elevation map. (a) The average 50% (blue) and 80% (purple) surface influence contours for the average PWRF/Stilt influence functions (footprints) over all three years (daily mid-afternoon averages used only). The contours show that 80% of the influence on the tower is from the region in purple; there is hardly any influence at all from the North Slope. Elevation data is from NOAA's NGDC. High-resolution elevation data is from ASTER GDEM, a product of METI and NASA. Right: even higher zoom view of elevation, with different color scale, showing the high elevation of this tower.



Higher zoom of the above elevation maps.

3. Annual Cycle and Background

Figure 3. Time series for three full years of measurements at the CARVE tower outside Fairbanks (red, mid-afternoon hourly averages only). Incidents of high CO (>1000ppb) occurred during fires in the summers of 2012 and 2013. The background determined from Polar WRF/STILT modeling and an empirical boundary curtain (blue) follows variability in the observations much more faithfully than a simple free-tropospheric background (green). The CH_4 signal over background is quite small (top), but larger for CO_2 (middle), making the background a large source of uncertainty in CH_4 enhancements.



4. CH_4 Analysis

Polar WRF/STILT footprints (Henderson et al., ACP, 2015) were used to estimate the CH_4 average flux from the entire region of Alaska influencing mid-afternoon daily average tower measurements, filtered for biomass burning, times with good vertical mixing (judged by the observed CH_4 gradient between different tower levels), and low variability. Average CH_4 fluxes were estimated by scaling two different flux maps to match monthly average CH_4 enhancements at the tower. The first flux map is a uniform land-based flux (with zero flux assumed from all ocean regions) similar to that used in Chang et al. (PNAS, 2014) to estimate CH_4 fluxes using aircraft observations from the 2012 CARVE campaign. The second flux map pattern was based on elevation data from NOAA's NGDC (Figure 2(a)). The elevation map was coarsened to the same resolution as the footprints (0.5x0.5 degrees) and adjusted so that water regions and elevations higher than 1000 masl were assumed to have zero CH_4 flux. Elevations between 0 and 1000 masl were scaled linearly from 1 to 0, with areas of zero elevation assigned 1 and >= 1000 masl assigned 0. Fluxes were assumed to be diurnally constant.

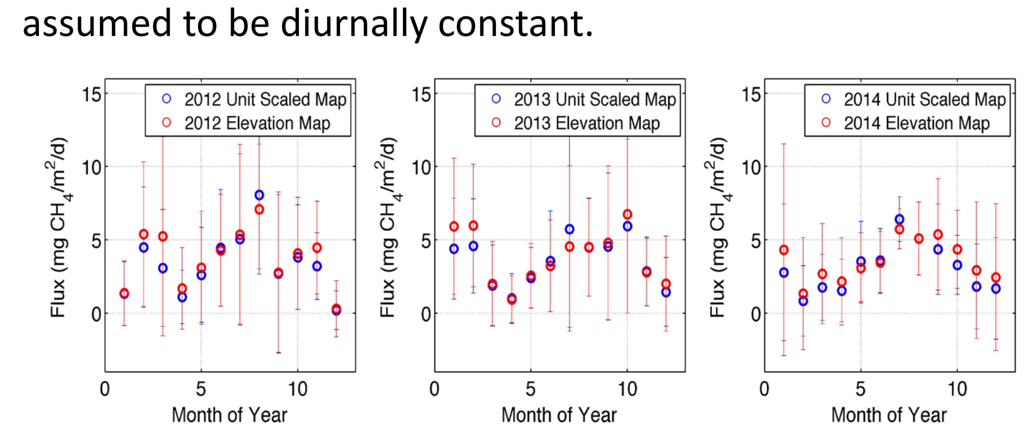


Figure 4: Average monthly fluxes over the Alaskan influence region of the tower for the three study years using the uniform flux map (blue) and the elevation-based map (red). Error bars are the uncertainty propagated from the background estimation alone and represent 1-sigma. Transport and other errors are not included.

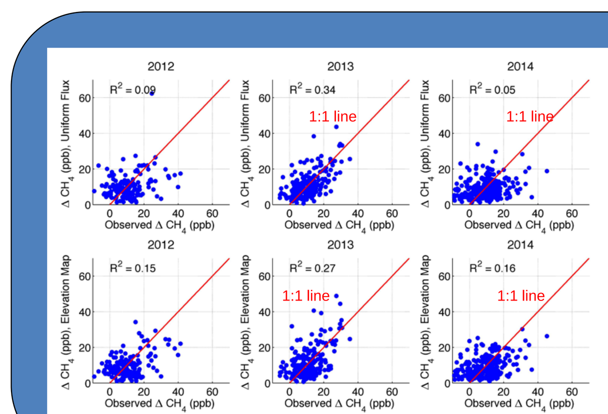


Figure 5: Observed daily mid-afternoon CH_4 enhancements shown against modeled enhancements using a uniform flux map (top row) and an elevation-based flux map (bottom row).

5. CO_2 Analysis & Polar VPRM

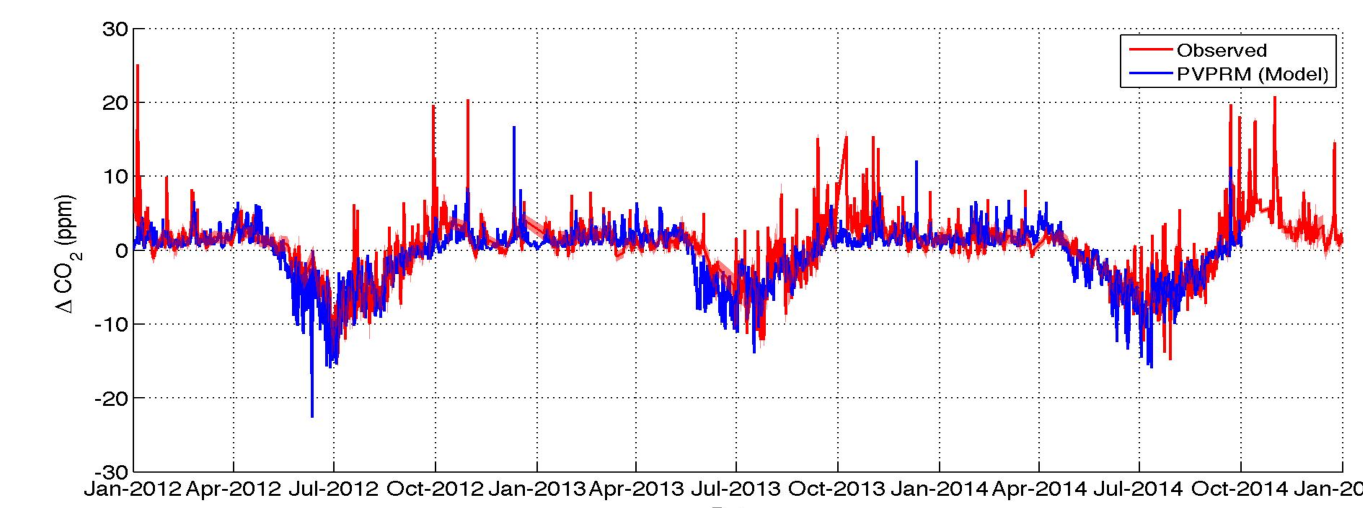


Figure 6. CO_2 fluxes from PVPRM (Luus, 2015) were convolved with PWRF/STILT footprints for the mid-afternoon hours each day for the period from January 2012 through December 2014. The resulting ΔCO_2 mole are compared to the hourly averaged CO_2 enhancements (relative to the blue background shown in Figure 3) at the tower during the mid-afternoon. The time series data in Figure 6 has not been filtered.

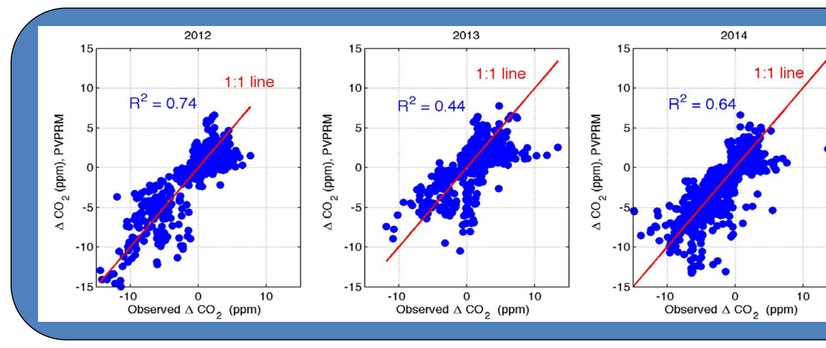


Figure 7. Hourly mid-afternoon enhancements of CO2 over each study year plotted against PVPRM/PWRF/STILT enhancements. Hourly data was filtered for biomass burning, poor vertical mixing, and high variability.

6. Conclusions

The CARVE tower site provides a continuous observation platform that will contribute to future efforts to investigate the high-latitude carbon cycle and its response to warming. As a long-term measurement site with large regional coverage it will provide understanding of changing emissions in interior Alaska. Our analysis of the years 2012-2014 indicates no change in CH_4 emissions influencing this site over this period, and that average CH_4 emissions are small (Figure 4), even though other work has shown that CH_4 emissions at small scales may be large. The tower observations provide the capability to detect changes in CH_4 emissions in the future. In addition, we find that the Polar VPRM model (Luus, 2015) coupled with our PWRF/STILT footprints reproduces tower CO_2 observations remarkably well. However, the influence region of the CARVE tower prohibits any quantification or observation of processes on the North Slope (Figure 2), indicating that additional long-term observation sites with large regional coverage are required north of the Brooks Range of Alaska to detect changes in emissions in the far northern latitudes. Future efforts will combine the observations from the CARVE tower with other aircraft and ground-based observations in a formal inversion framework to solve for spatially and temporally resolved CH_4 and CO_2 fluxes in the Arctic.

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