Methane and Carbon Dioxide Plume Transit by Scientifically Converted Vehicles in Support of Airborne and Satellite Remote Sensing Source Strength Derivation

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Project Partner Institutions

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ABSTRACT

Two unique scientific platforms have been developed for mobile in situ surface measurements in support of airborne and satellite trace gas remote sensing and emission derivation. Focus is on the greenhouse gases (GHG) methane, CH_4, and carbon dioxide and other trace gases for airmass fingerprinting.

AMOG Surveyor (AutoMObile Greenhouse gas), which is an ordinary commuter car (Nissan Versa) with a trunk science package including an inverter/charger, solar battery, cavity ringdown spectrometer (Fast GHG Sensor, Los Gatos Research (LGR)), high flow scroll vacuum pump, ultrasonic anemometer/weather station, GPS, incident (UV-SWIR) radiation, thermal radiometer, solar spectrometer, continuous video recording (aiding post-processing interpretation), and internal network.

MACLab (Mobile Atmospheric Composition Laboratory) is a 12-ton, 37' diesel RV Toyhauler, with a garage converted for air chemistry analysis, including 4 gas chromatographs (SRI GC) on an independent air suspension rack, ultrapure air and hydrogen generators, 8.5 kw generator, 18-m pneumatic mast, greenhouse gas cavity ringdown spectrometer, high flow vacuum lines. The internal Ethernet network allows access between all computers, instruments, server, and video streams. The habitation module supports a 4-person team, enabling round-the-clock data collection in areas without accommodations, rest stops.

The AMOG Surveyor commuter vehicle operates daily, collecting a large dataset related to offshore platforms, landfills, offshore seepage, numerous pipeline leaks, and urban emissions, while documenting urban diurnal accumulations and orographic methane flushing. AMOG Surveyor also collected surface data at petroleum production sites around Bakersfield and central valley dairies. MACLab collected 18000+ km of GHG data during a transcontinental expedition summer 2013, which surveyed important petroleum production from the Southeast to Midwest and Rockies to California for comparison with satellite methane data.

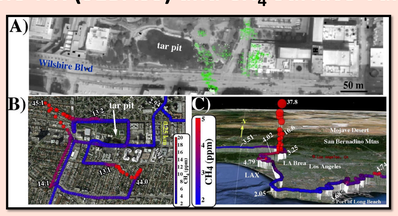
For example, recent AMOG Surveyor SB County landfill data suggests nocturnal accumulations, which surge seaward (crossing US101) with diurnal wind shifts, while outlining the detailed orographic forcing. AMOG Surveyor data documented extreme transiency in FFI, landfill, and feedlot CH_4 emissions, suggesting that unsteady emissions play an important role in overall emissions.

Houston Plume Chasing

Houston GHG data show the dominant CH_4 and CO_2 sources related to the extensive FFI facilities and activities near I-10. The Houston survey first investigated the source and vicinity, while noting wind directions during wind-measurement pauses. Then, cross-wind transects were taken (north-south) for several downwind distances. Given plume dimensions, the transect sequence took ~7 nocturnal hours to complete. Nocturnal measurements provide effective urban mobility (traffic) and decreased (road-biased) vehicular emissions compared to daytime surveys. Estimated boundary layer height was ~75 m based on refinery vapor plume observations.

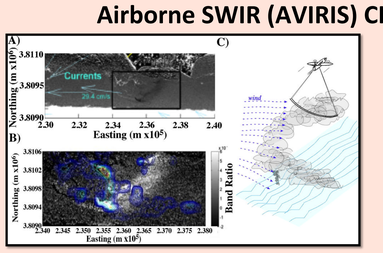
Surveys near and within refineries showed strong transient CH_4 sources clearly related to specific refining structures. Spatial correlation between CH_4 and CO_2 were close but often showed an offset, indicating different, but related origin points. Interestingly, the highest CH_4 concentrations were not in the immediate vicinity of the refineries, but downwind in the vicinity of the city center during a north-south transect, where levels to 10 ppm were observed, higher than observed during 2010 Houston surveys as noted by Farrell et al. (2013). Inversion plume modeling (Leifer et al., 2013) of transect data then can estimate source strength.

Airborne TIR (SEBASS) and CH_4 Surface Validation



La Brea Tar Pit. A) SEBASS TIR image of La Brea Tar Pit area (Wilshire Area) in the Los Angeles Basin showing methane, CH_4, plumes. Data acquired at 2049 UTC, 27 Mar. 2009. (Courtesy, The Aerospace Corporation.) B) CH_4 survey data collected 1100 UTC, 21 Feb. 2012 in the immediate vicinity of the Tar Pit area, height and symbol size proportional to concentration. Color scales are stretched to capture finer CH_4 structure close to ambient; symbol height and size are proportional to CH_4 concentration. C) *In situ* CH_4 survey data of North Los Angeles, La Brea area noted. From *Leifer et al.* (2012).

Airborne SWIR (AVIRIS) CH_4 plume



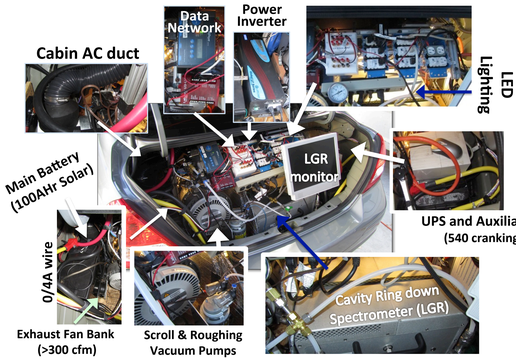
A) AVIRIS band ratio (2058/2288 nm) image for the Coal Oil Point seep field showing CH_4 spectral signatures from a strong methane plume and B) overlain by sonar contours of bubble plumes (source). Adapted from *Bradley et al.* (2011). C) Schematic of "dual plume" from wind shear on a buoyantly rising plume.

Strong CH_4 plumes would provide a good test of the positive synergies from leveraging SWIR and TIR data.

Specifically, because SWIR is independent of thermal profile (i.e., plume altitude) it can map plume dispersion.

Additional, apparent dispersion in TIR data must arise from thermal contrast, allowing deduction of plume vertical profile.

AutoMObile greenhouse Gas Surveyor: *An Evolving Science Package*



Spare tire still in trunk!!

AMOG Surveyor (AutoMObile greenhouse Gas Surveyor) is no ordinary commuter car: Its a Nissan Versa *pimped* for science. Under the hood it sports a 225 amp high performance alternator, and enhanced performance shocks. The trunk spare tire was replaced by a comprehensive science package. Thick, 04/A cables connect 3 batteries to a 1.5kW inverter, powering the system and providing the surge starting power (3.5 kW) for a high performance (30 cfm) scroll vacuum pump. A roughing pump eases startup. A Teflon tube ona CB antennae collects air from 5 m.

A cavity ring down spectrometer (Fast GHG Sensor, Los Gatos Research, LGR), simultaneously measures $CH_4/CO_2/H_2O$ at up to 20Hz, 2D winds are measured by an ultrasonic anemometer at 10 Hz, as are GPS location and weather. A solar incident radiation sensor collects full sky UV-NIR, documenting cloudiness. Immediate improvements for post re-opening of the US Gov't are a thermal radiometer, sun spectrometer, and continuous high definition, 1080P 4-direction video recording.

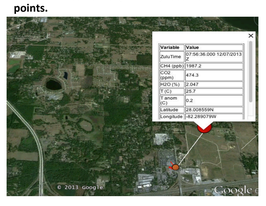
Realtime Multiparameter Data Visualization in the GoogleEarth Environment

✧ Realtime display of up to 5 gases, winds, and temperature simultaneous in Google Earth.
✧ System performance (voltages, current, instrument temperatures), weather, gas concentrations, insolation) are displayed in a monitor window at 0.1 - 5 Hz (depends on parameter).
✧ Streaming of last minute of data allows detailed review of recent history.

Realtime data archiving provides presentation quality, data summary minutes after mission end.

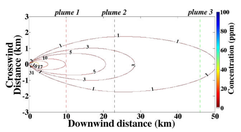
AMOG Surveyor *real-time* winds (red lines), CH_4, and H_2O (symbol size), showing overturning and side to side "sloshing" as interior air rushes seaward through Gaviota Canyon, Santa Barbara County, CA, collected at highway speed. Overall airflow is strongly *onshore*. Real-time visualization is 0.25 Hz, 10 Hz data collection.

Realtime server-push allows remote participants to see in real time (<1 min) last 10 - 100 data points.

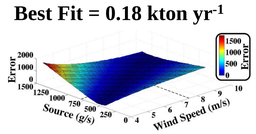


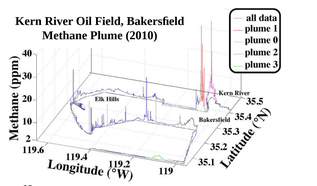
✧ Winds and multiple gases are critical to plume trajectory prediction (see Houston data), to identifying airmass changes, and enabling effective adaptive surveying.
✧ Realtime spatial display reduces: "I wish I had…." Post-processing blues back at the lab.

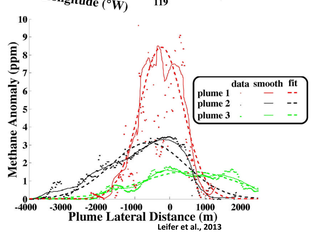
Surface Source Strength Inverse Modeling



Best Fit = 0.18 kton yr^{-1}







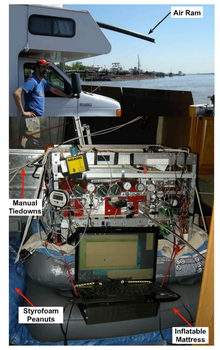
Summary

Realtime data integrated with a mobile surface platform provides an effective approach to plume characterization by allowing adaptive survey route planning for emission source strength estimation, which requires multiple passes through the same plume.

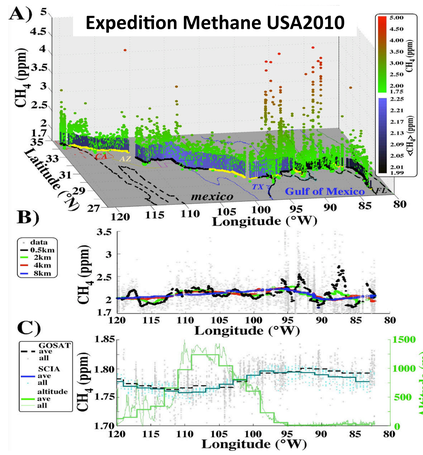
Surface reference plume characterization plays an important role in airborne remote sensing and in situ derivation of source strength by enabling close approach to potential sources, potentially eliminating uncertainty in the case of multiple distinct sources.

Fossil fuel industrial emissions are an important component of the methane budget as demonstrated in satellite data.

MACLab 2010



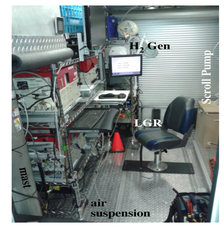
The many improvements evident in MACLab 2013 and in Expedition Methane USA2013 were inspired by direct experience in a rental camper in 2010 and working the data through to publication (2 1/2 yrs. later).



2010 Transcontinental CH_4, unfiltered and spatially filtered (8° median). Survey path day/night track is yellow/black, respectively. B) CH_4 versus along-path longitude and spatial averages from 0.5 to 8°. CH_4 mixing ratios above 3.5 ppm not shown. C) Altitude, and total dry xCH_4 column abundance for SCIAMACHY 2003-2005 and GOSAT values for 2009-2011 within 2° of survey track, and altitude, both all data and longitudinal bin-averaged. From Leifer et al. (2013)

MACLab 2013

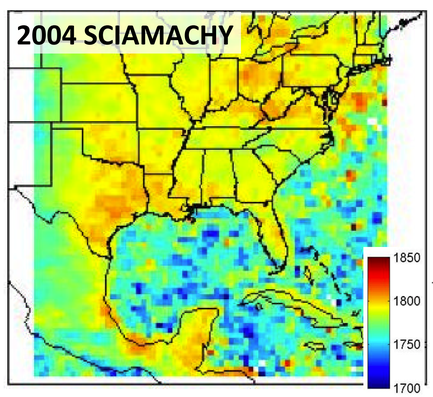
MACLab (Mobile Atmospheric Composition Laboratory) is a 12-ton, 37' diesel RV toyhauler, with a garage converted for air chemistry analysis, including 4 gas chromatographs (SRI GC) on an independent air suspension rack, ultrapure air and hydrogen generators, 8.5 kw generator, 18-m pneumatic mast, greenhouse gas cavity ringdown spectrometer, high flow vacuum lines. An internal Ethernet network allows access between all computers, instruments, server, and video streams. The habitation module supports a 4-person team, enabling round-the-clock data collection in areas without accommodations, rest stops.

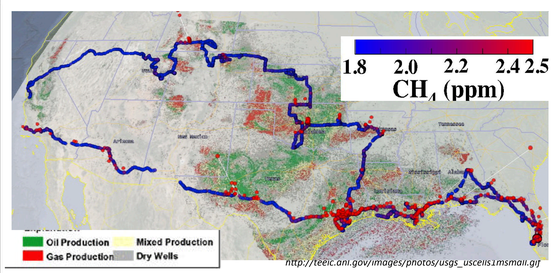


MACLab gas chromatographs currently measure (C_2-C_6+, alkanes, alkenes, alkynes) and BTEX on a ~20 min cycle, NO_x, and other gases. Multiple gases and parameter measurements are used to de-convolve distinct sources. When stationary, the mast is raised to measure winds and to collect air above the near-surface layer, eliminating exhaust contamination. Efforts are underway to resolve issues in MACLab real-time wind data; during a transcontinental, 18,000 km survey, summer 2013, MACLab paused every 1-3 hours to measure winds.

Satellite-scale CH_4 (many pixels)

Expedition Methane USA2013 & Production





http://teeic.anl.gov/images/photos/usgs_usceils1msmall.gif

Beyond further confirming 2010 findings, *Expedition Methane USA2013* collected data in two latitudes bands to explore if central USA satellite CH_4 enhancements were related to Gulf advection or local production. Surface CH_4 related well with local facilities seen during the campaign, which largely avoided large cities. Interesting highly elevated greenhouse gases in Colorado and Wyoming appear related to advanced recovery technologies under use.

Leifer, I., Tratt, D.M., Realmuto, V.J., Gerilowski, K., Burrows, J.P., 2012. Infrared hyperspectral imaging of atmospheric trace gases. EOS (American Geophysical Union Transactions) 93, 525.
Farrell, P., Leifer, I., Culling, D., 2013. Transcontinental methane measurements: Part 1. A mobile surface platform for source investigations. Atmospheric Environment 74, 422-431.
Leifer, I., Culling, D., Schneising, O., Farrell, P., Buchwitz, M., Bovensmann, H., Burrows, J.P., 2013. Transcontinental methane measurements: Part 2. Mobile surface investigation of fossil fuel industrial fugitive emissions Atmospheric Environment 74, 432-441.