Operations on BAO Tower during FRAPPÉ / DISCOVER

Steve Brown, NOAA Earth System Research Laboratory

Profiling Instrument Shelter with Amenities "PISA Hut"

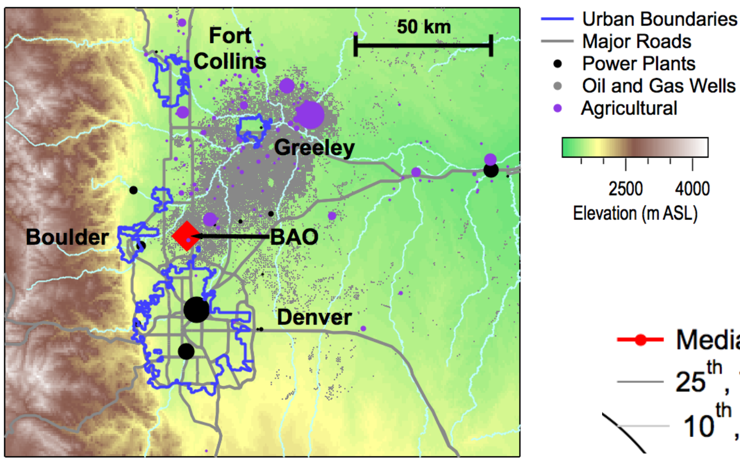
- 300 m tower
- Ascent / descent rate 0.6 m s^{-1}, One vertical profile = 9 min
- Usable payload of approximately 1 ton
- Temperature-controlled enclosure, 5-15 kW available power, real time communication with ground

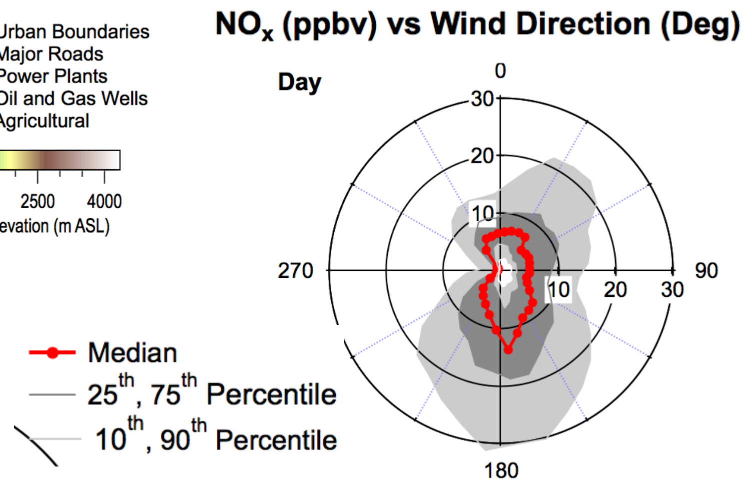
Measurements planned for summer 2014

NO, NO_2, NO_y, O_3 (instrument also has NO_3, N_2O_5)	CRDS	Brown
Organic / Inorganic Acids	CIMS	Farmer
NH_3	TLDS	Murphy
Open Path Aerosol Extinction	CRDS	Gordon

(Some) Scientific Goals

1. Investigate relationships between NO_x, NO_y and O_3 as a function of wind direction and height to differentiate between various sources (e.g., urban, oil and gas) in local O_3 production





NO_x wind rose from the NACHTT study at BAO, winter 2011

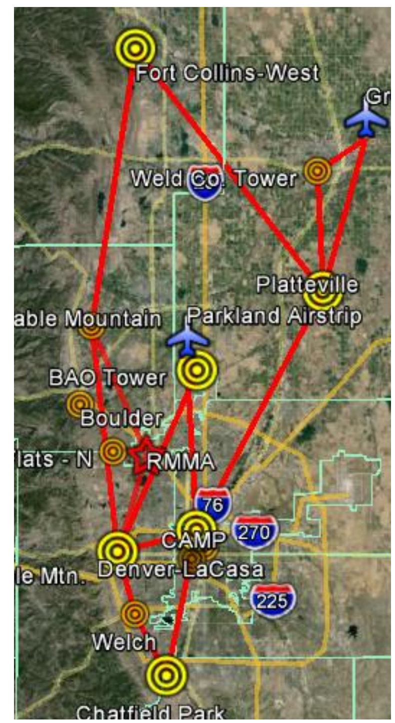
Urban (from south) and “other” (from northeast) NO_x sources appear spatially distinct

2. Augment aircraft measurements of NO_x, O_3 and other species through vertical profiling in the lowest 300 m of the boundary layer

• Currently expect to run continuous vertical profiles during periods when either the P-3 or C 130 is flying

• May run vertical profiles during other periods, depending on investigator interest in these data

• Open to suggestions re: instrument payload or tower operation. Contact: steven.s.brown@noaa.gov



Observational constraints on the impact of oil and gas exploration on O_3 production in the Northern Colorado Front Range Metro Area as part of FRAPPÉ

Delphine K. Farmer and **Emily V. Fischer,** Colorado State University

Measurements Proposed for BAO Tower Ground site:

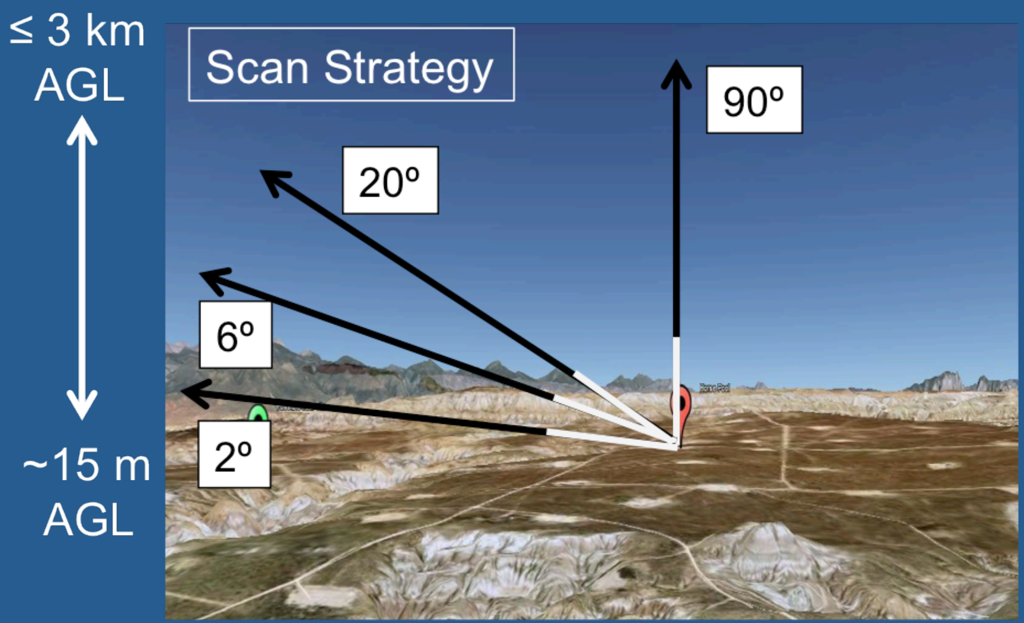
Measurement	Instrument/Technique	Frequency	Expected Uncertainty (u), Precision (p), LOD
$J(NO_2)$	Filter Radiometer	1 min avg	<2% (p)
CO, CO_2, CH_4	Picarro G4201	5 min avg	CO: (p) 2 ppbv (when CO > 100ppbv); CO_2: (p) 50 ppbv CH_4: (p) 0.7 ppbv
OH reactivity	Comparative Reactivity	40 min pt	(u) 25% above 8 s^{-1}
SO_2	Thermo Sci Model 43i	1 min	(u) 1 ppbv or 1%
O_3	2B Technology	1 min	(u) 1 %
Hydrocarbons (C_2-C_8)	GC-FID; Rt®-Alumina BOND/Na_2SO_4 (Restek)	20 min avg	(u) 10% at mixing ratios >> detection limit
PAN	NCAR GC-ECD	5 min pt	(u) 10% at mixing ratios >> LOD
Aerosol size distributions (60nm – 1µm)	DMT Ultra High Sensitivity Aerosol Spectrometer (UHSAS)	1 s pt, avg to 5 min	Detection efficiency ~100% for particles between 100-1000 nm

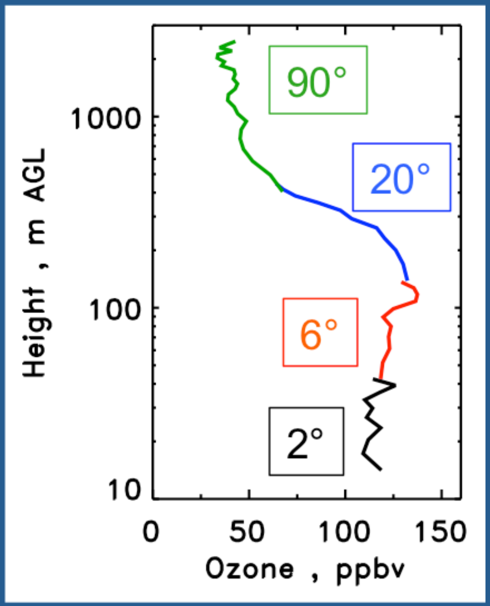
Measurements on BAO Tower (PISA, vertical profiling):

Measurement	Instrument/Technique	PI / Institution
NO, NO_2, O_3 , NO_y,N_2O_5	Diode laser cavity ring down spectroscopy	Steve Brown, NOAA
Oxidized VOCs (carboxylic acid, organic nitrates), HONO (?)	I^- / Acetate CIMS	Delphine Farmer, CSU
$NH_{3\,(g)}$		Jennifer Murphy, UofToronto

NOAA TOPAZ Ozone Lidar (1)

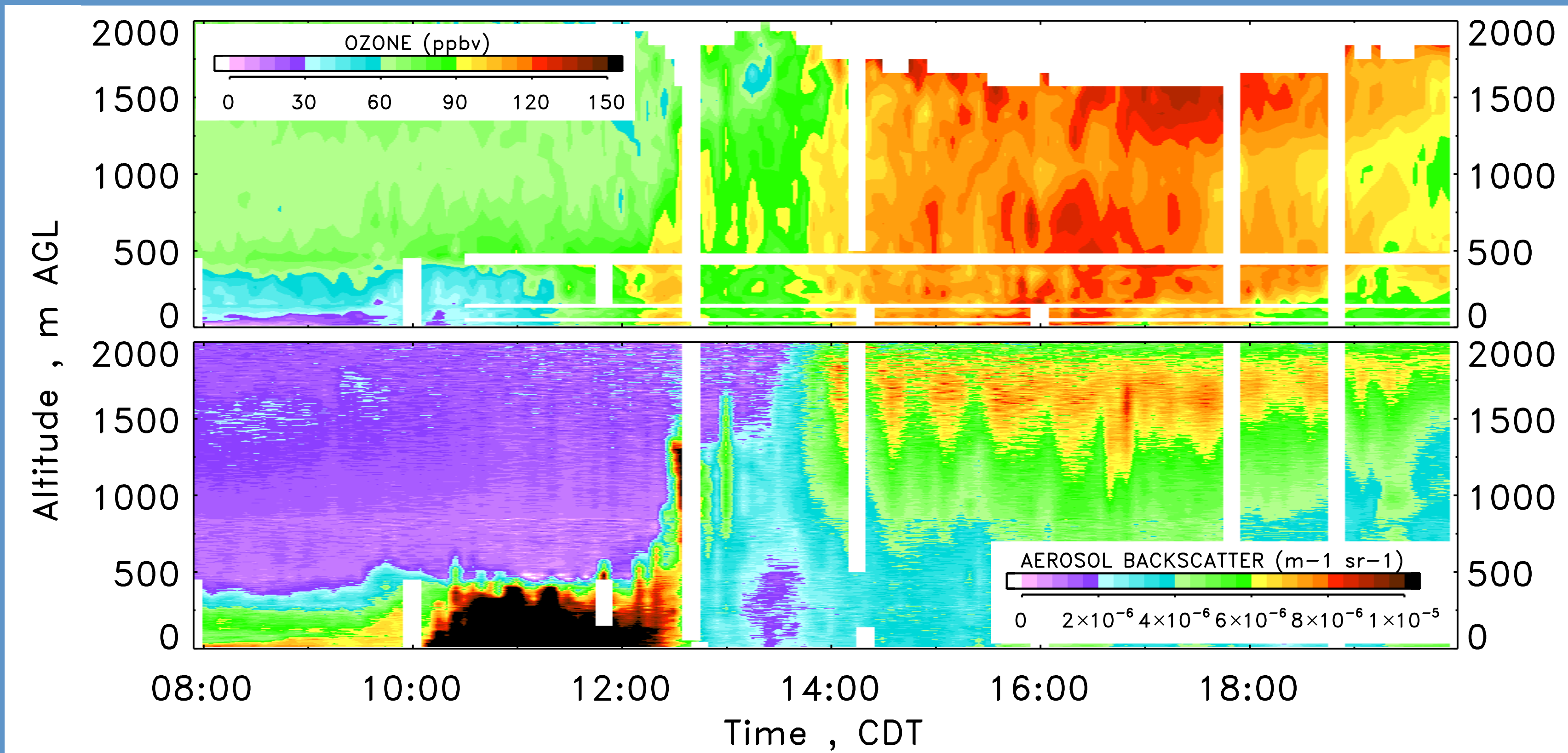
- Tunable UV ozone differential absorption lidar (DIAL)
- Truck-based, scanning instrument
- Ozone and aerosol backscatter profiles from ~15 m up to 3 km AGL





Composite vertical profiles every 5 min

NOAA TOPAZ Ozone Lidar (2)



12-hour time-height cross sections of ozone (top) and aerosol backscatter (bottom) observed with TOPAZ on 25 September 2013 at La Porte, TX during DiscoverAQ Houston. Light winds and sunny skies combined with high levels of O_3 precursors advected from the Houston Ship Channel led to very high afternoon O_3 concentrations.

Ozone Chemistry and Dynamics in the Colorado Front Range

D. Helmig (P.I.), Institute of Arctic and Alpine Research, University of Colorado

G. Pfister (Co-P.I.), Atmospheric Chemistry Division , NCAR

Figure 1 One of the proposed flight patterns for FRAPPÉ, investigating the mountain-plains air circulation patterns. The extension of the surface sites network proposed in this study is indicated by the red area. (Figure adapted from the NCAR FRAPPÉ LAOF white paper).

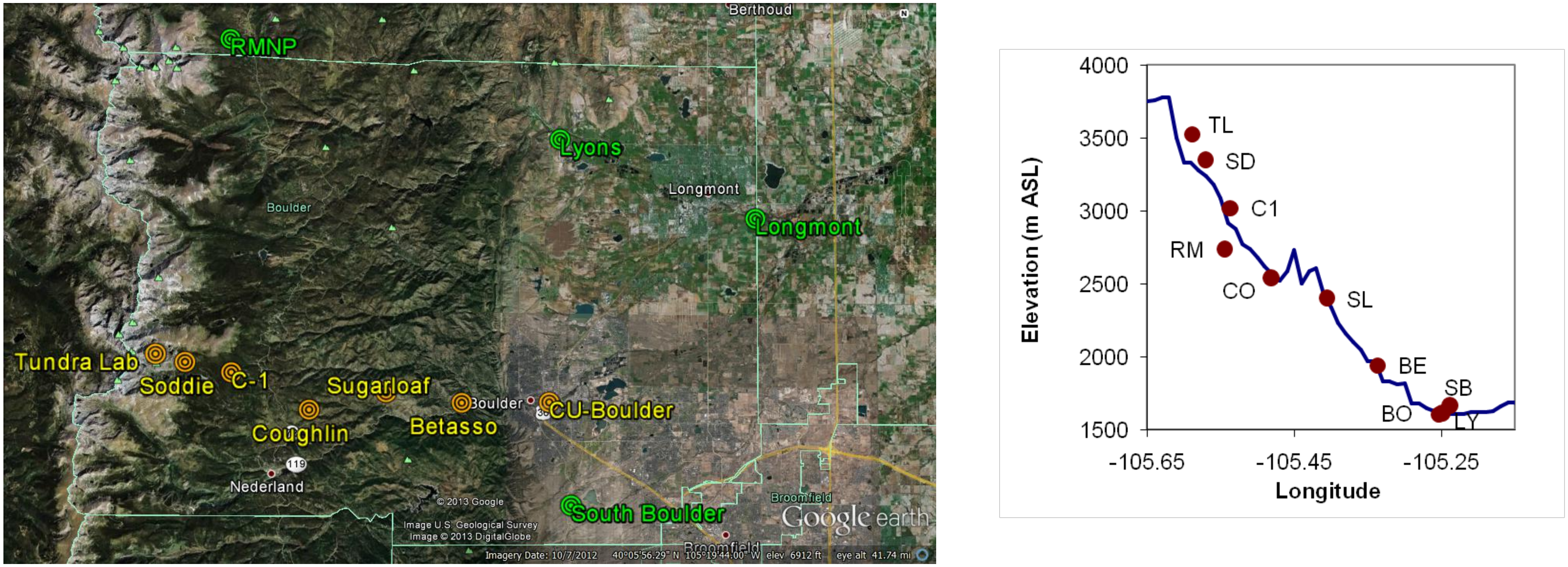


Figure 2 a) Map of the study area showing the seven sites on an east-west transect from which data will be collected. b) Graphical representation of the elevation cross-section. Abbreviations used stand for Tundra Lab (TL), Soddie (SD), C1 (Mountain Research Station), Coughlin (CO), Sugarloaf (SL), Betasso (BE), and Boulder (BO). Also included for reference are the sites that were included within the framework of the Boulder County Air Toxics Study, i.e. Lyons, South Boulder, Longmont, and Rocky Mountain National Park.

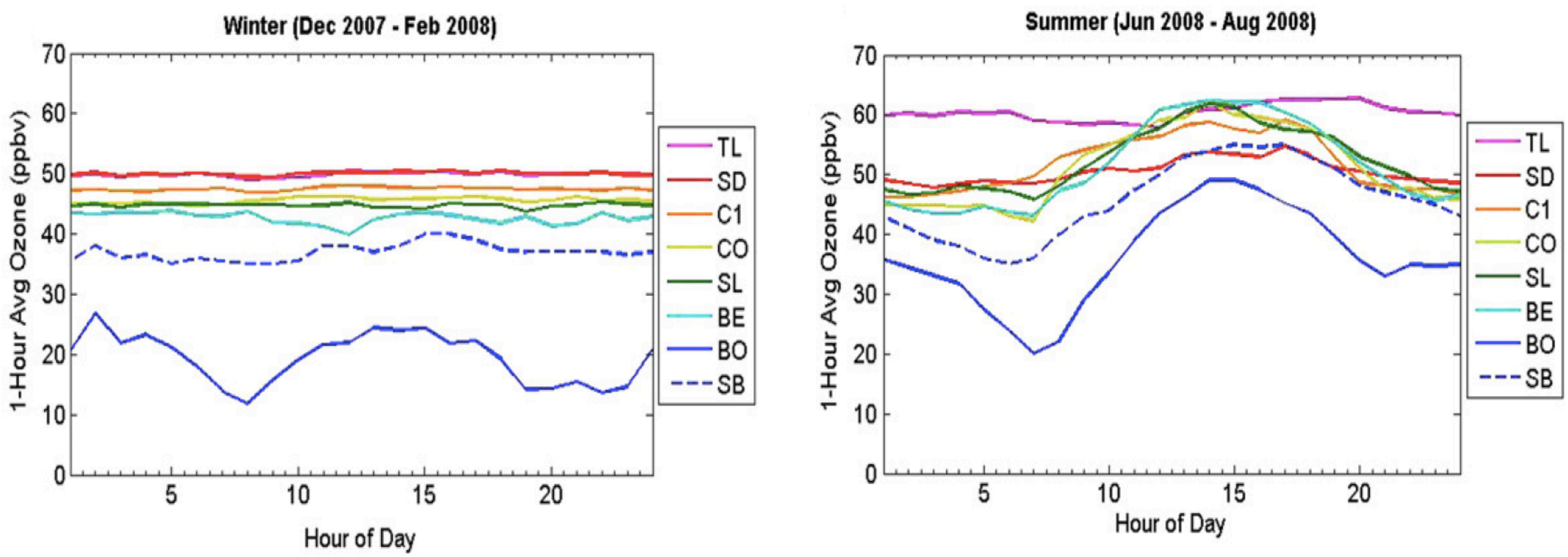


Figure 3 Average diurnal ozone profiles at each site for winter and summer seasons in the 2007-2008 study.

Frappe Experimental Plan:

1. Continuous Monitoring of Ozone
    - eight elevation gradient sites
    - May – August
    - one hour time resolution

2. Methane and Volatile Organic Compounds on FRAPPE and DISCOVER-AQ flight days
    - five elevation gradient sites
    - 72 in-situ samples in Boulder
    - 72 flask/canister samples

3. WRF – Chem Transport and Chemical Modeling

UW-Madison Space Science and Engineering Center (SSEC) High Spectral Resolution Lidar (HSRL)

- Ground based measurements of aerosol backscatter cross section, depoloarization, and extinction at 532nm
- Backscatter cross section measurements are robust more then one order of magnitude below molecular backscatter

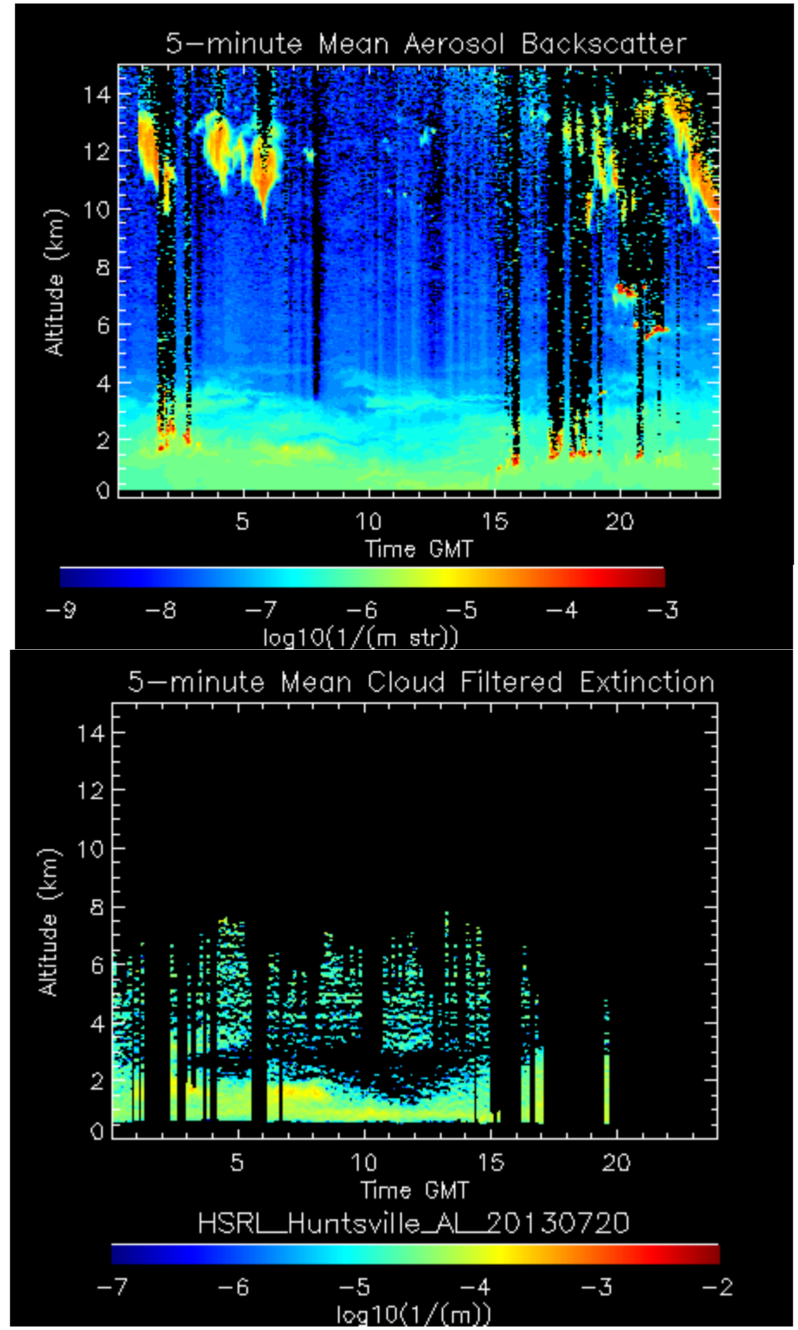
Recent deployments:
Norman, OK (2012, DC3),
Huntsville, AL (2013, SEAC4RS)

HSRL aerosol extinction near the surface is historically difficult due to narrow field of view of the system and need for large overlap corrections at altitudes below 4km asl.

Instrument now has improved temperature stability and additional molecular wide field channel that allows direct measurement of overlap correction.

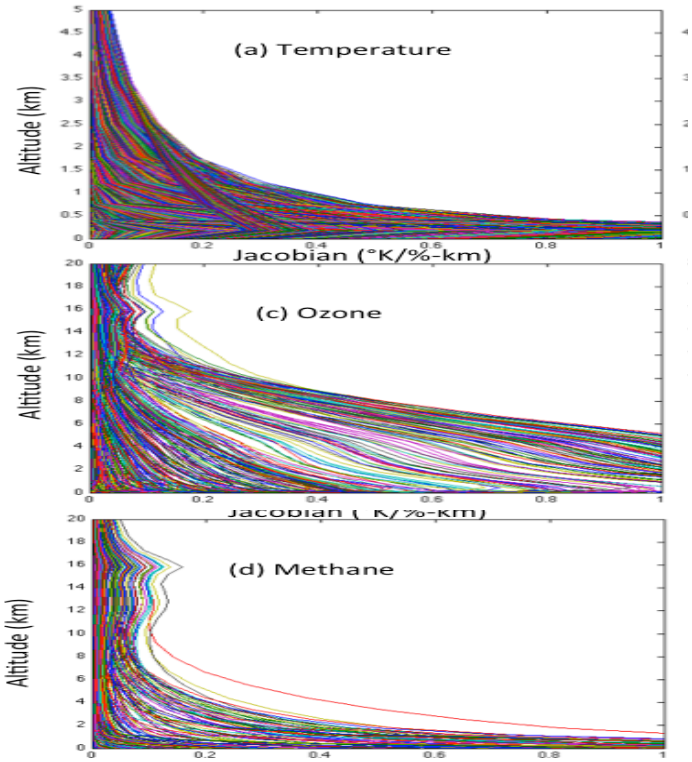
Wide field of view overlap correction is applied down to ~400m and then the lidar ratio measured above 400m (but within BL) is used to extend the overlap correction to ~100m (lowest measurement altitude)

Contact: Edwin Eloranta (eloranta@ssec.wisc.edu)



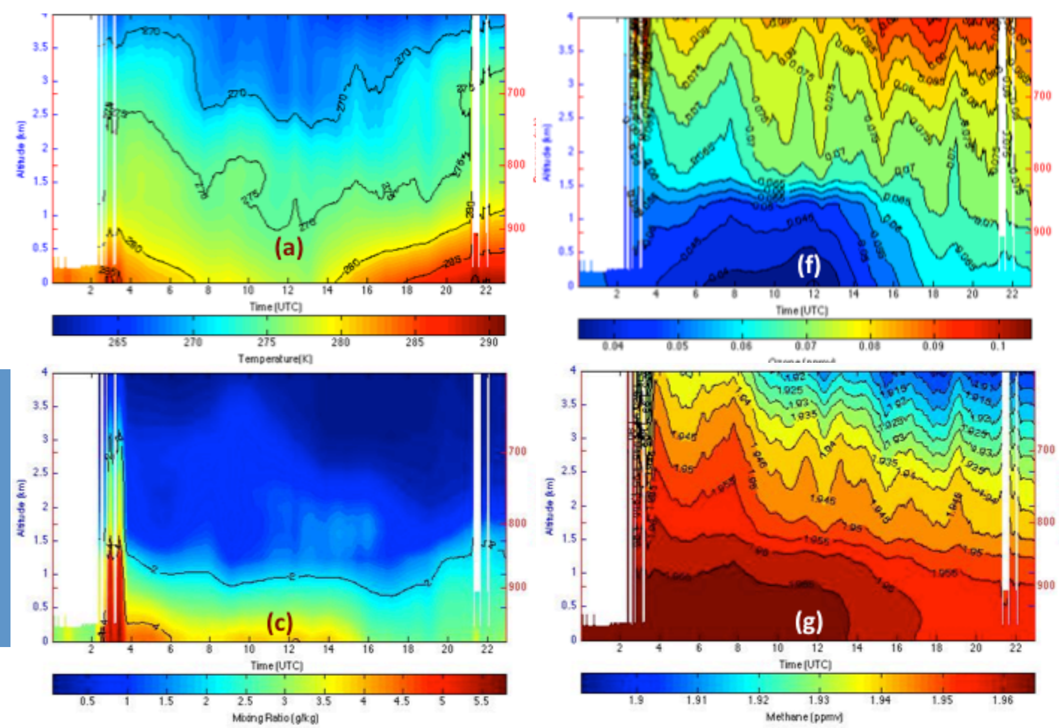
HSRL cross-sections for August 20, 2013 over Huntsville, AL

UW-Madison Space Science and Engineering Center (SSEC)
Atmospheric Emitted Radiance Interferometer (AERI)



Temperature, ozone, and methane Jacobians

- Ground-based measurements of downwelling atmospheric radiance from 3.3 to 18.2 µm (550–3000 cm^{-1}) with a spectral resolution of 0.5 cm^{-1} and an absolute calibration accuracy <1% of the ambient radiance
- Vertical profile retrievals of temperature (T), humidity (Q), carbon monoxide (CO), ozone (O3), methane (CH4), and nitrous oxide (N2O).
- AERI accuracy of 1K and 10% for T and Q, respectively, most accurate in the boundary layer.



Retrieval cross-sections for April 19, 2013 over Moody Texas.

ARM Facility Instrument:
Deployed at North Slope, Southern Great Plains, Tropical Western Pacific, and ARM Mobile Facility ARM sites. Trace gas retrieval developed by Bill Smith (HU/

Contact:
Jonathan Gero jonathan.gero@ssec.wisc.edu

NOAA Tethered Ozone and Met Profiles in FRAPPE

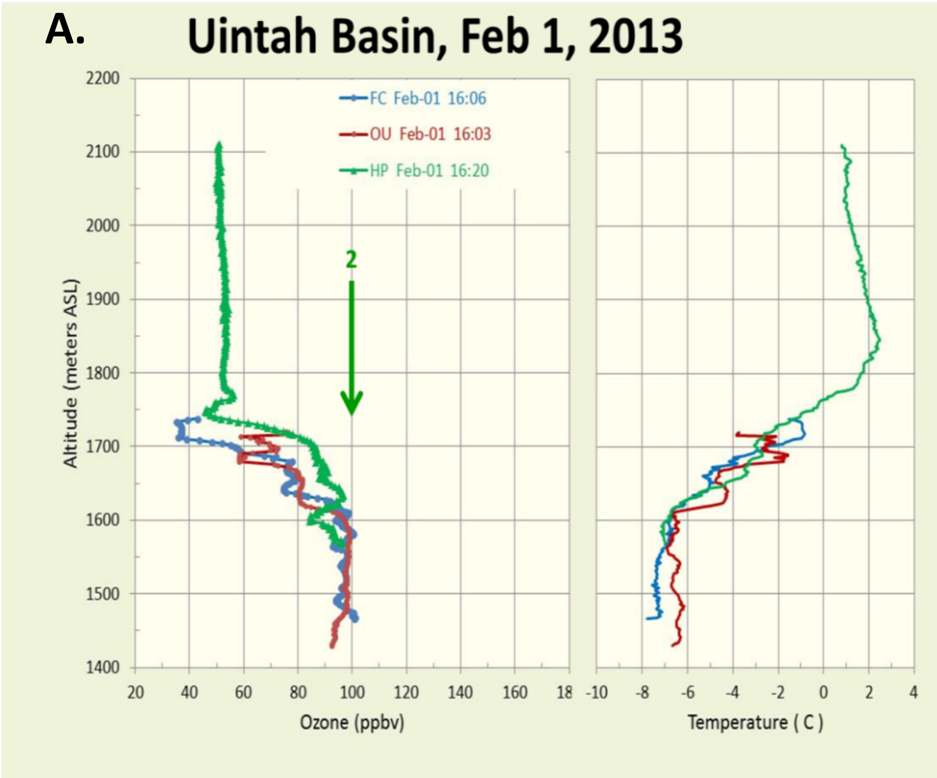
Russ Schnell for NOAA Tethersonde Group

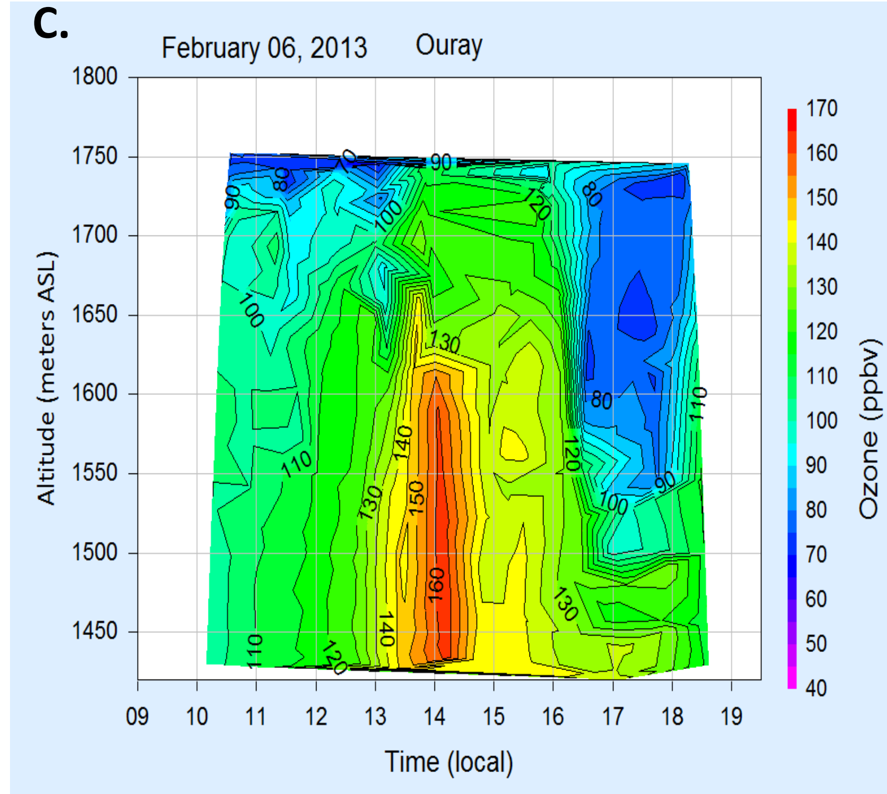
russell.c.schnell@noaa.gov

- NOAA will operate a profiling ozone/met tethersonde at one site.
- Profiles from the surface to 1,000/2,000 ft. depending on FAA clearance and wind speed.
- A profile can be completed every 30 minutes.
- Ozone and met available in real time.
- Surface ozone will be measured continuously at the tethersonde site and at Niwot Ridge.
- The tethersonde will operate on 10 selected days, 16 profiles/day.

Tethersonde specifications:

Ozone Absolute accuracy:	± 2ppbv
Temperature accuracy:	± 0.2 C
Humidity accuracy	± 3%
Pressure accuracy	± 0.5 mb
GPS Altitude	± 5 m
Data Frequency:	± 1 hz





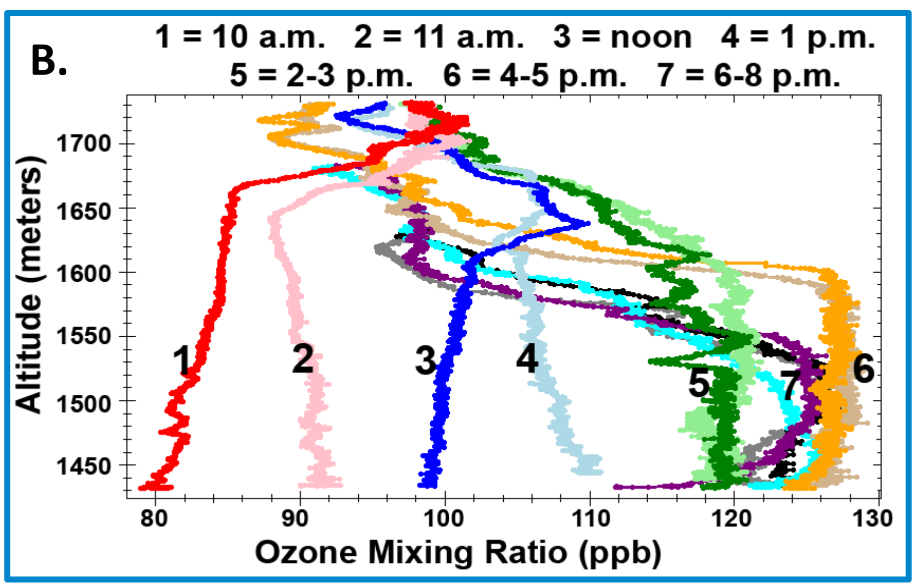


Figure Legends for Tethersonde Data: **A.** Individual ozone and temperature profiles, three different locations, Utah. **B.** Ozone profiles, winter day, Uintah Basin, Utah. **C.** Ozone contours showing rapid, low altitude ozone production in mid-day (red) and ozone removal later in the day (blue).

INSTAAR, University of Colorado Stable Isotope Lab

Supporting Regional Assessments of CH_4 Emissions with Ground-Based Isotopic Measurements and FLIR (Forward Looking InfraRed) Imaging

Bruce H. Vaughn & Owen Sherwood, Andrea Sack

Contact: Bruce.Vaughn@colorado.edu

Combining Real-Time Mobile CH_4 Measurements with Infrared Imaging Leak Verification and Isotopic Fingerprinting

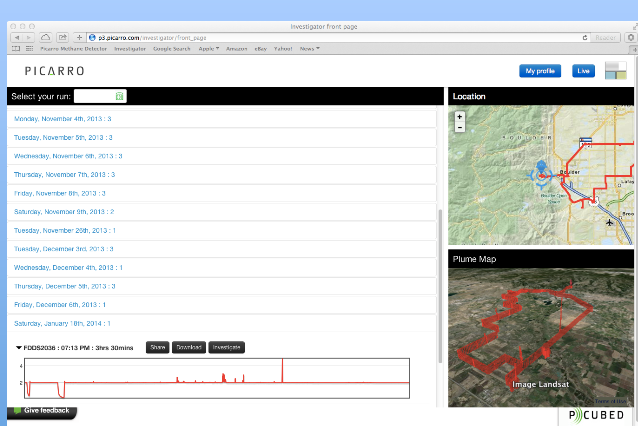
Mobile Picarro Isotopic CH_4 Analyzer

- 4-wheel drive platform
- GPS
- Sonic Anemometer
- Wireless package
- Cloud Computing
- Real-time air and Mega-Core measurements

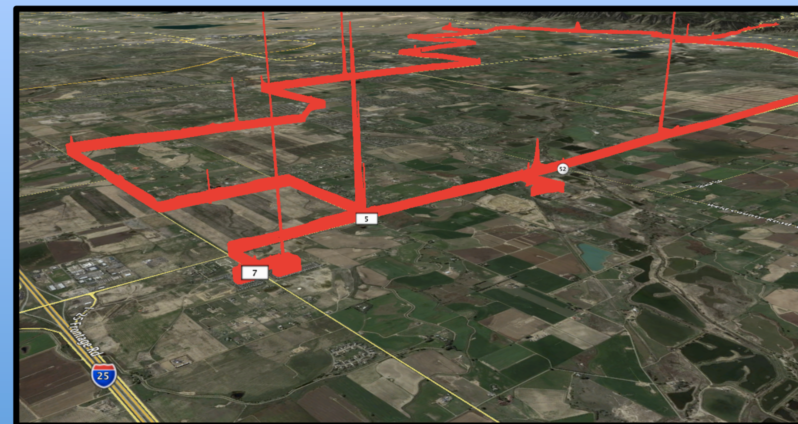
FLIR Camera

Thermal Infrared gas leak detection using the Regional Air Quality Council Optical Gas Imaging (OGI) Camera Loan Program (as available)

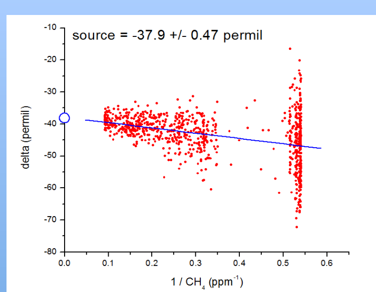
Examples of Outputs



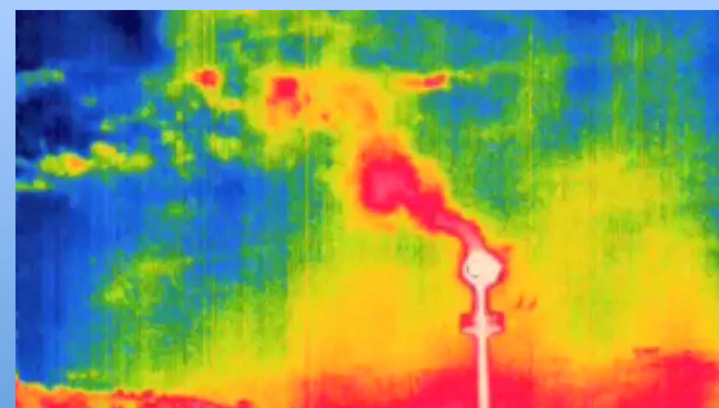
Real-Time analysis of ambient air and collection of ‘Mega-Core’, samples of transects that can be analyzed in detail for $\delta^{13}C$ of CH_4 in post processing.



Generate maps with measured CH_4 concentration over study area along accessible roads. All data are archived and KML files aid visualization.



Use ‘Keeling-plot’ identification of isotopic source signatures to distinguish methane from natural gas and oil from landfills, feedlots, wetlands, etc. and use mass spectrometer analysis for air flask samples for $\delta^{13}C$ and δD of CH_4



Use RAQC FLIR Camera to detect and verify point sources as found with infrared imagery.

NOAA GMD & CU BAO and Mobile Sampling

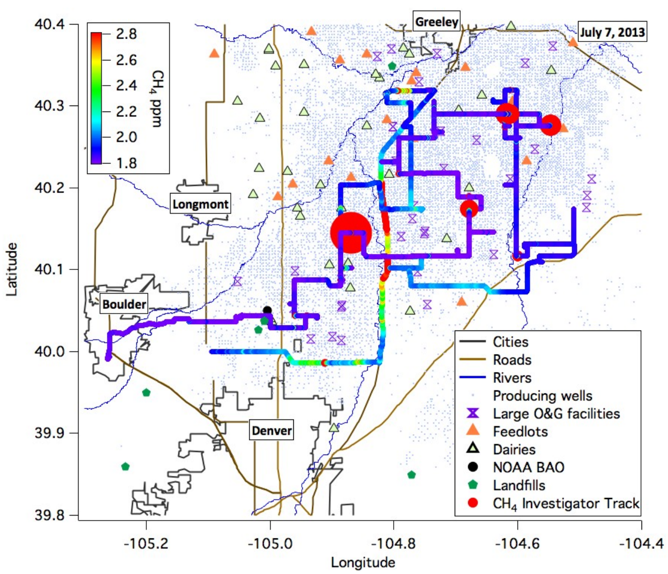
Gaby Pétron, Jon Kofler, Audra McClure, Ben Miller, Steve Montzka, Ed Dlugokencky, Arlyn Andrews et al.
Contact: Gabrielle.Petron@noaa.gov

Main goal: Characterizing hydrocarbon sources in the region

GMD Mobile Lab
- In situ:
CO_2, CH_4, CO, H_2O
(Picarro)
Ozone (2B)
- Flasks
- Met

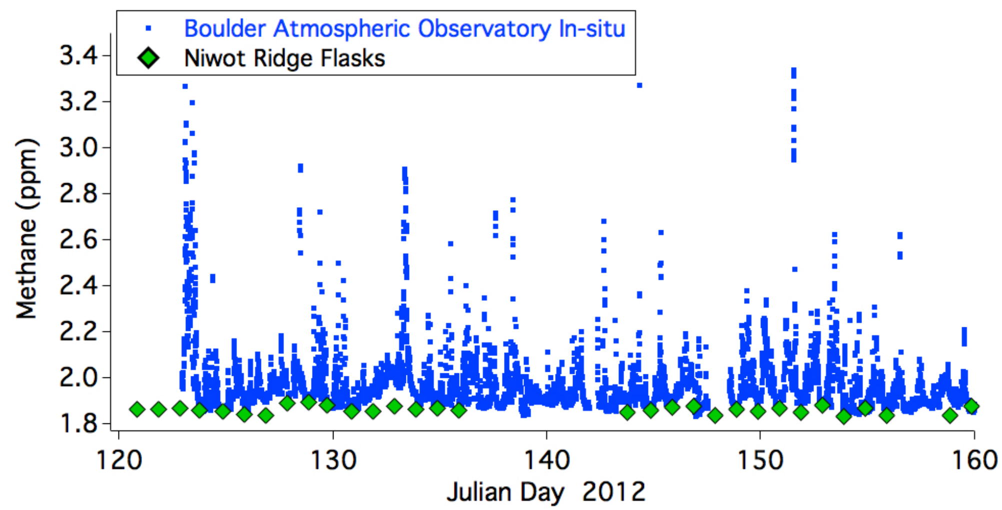
NOAA BAO Tower
GMD
CO_2, CH_4, CO (3 levels)
Ozone (10m, 300m)
Flasks at 300m
PSD
Met Fields (3+ levels)

Example of survey
(day and nighttime data)

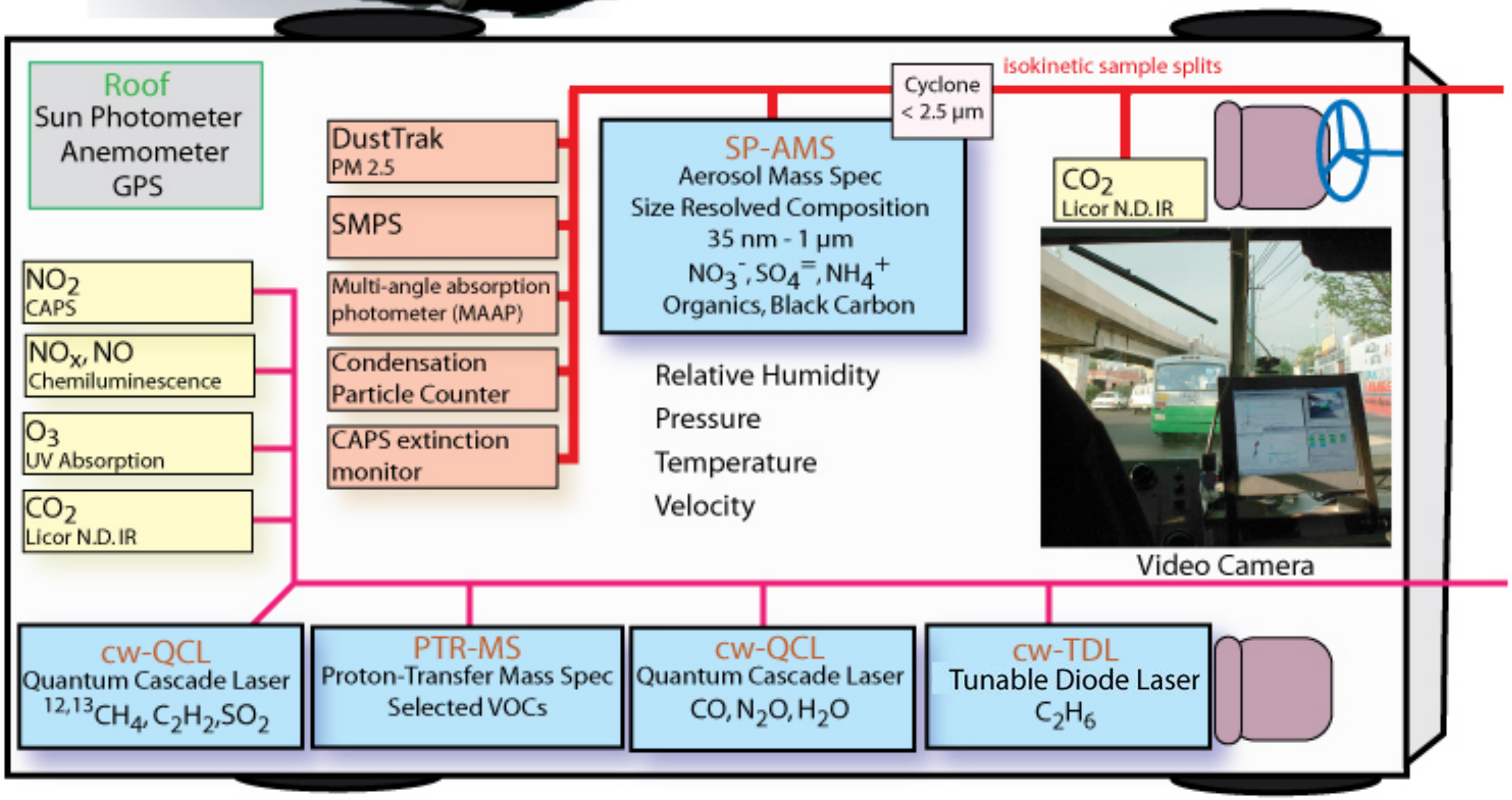


http://www.esrl.noaa.gov/psd/technology/bao/

Methane time series at BAO



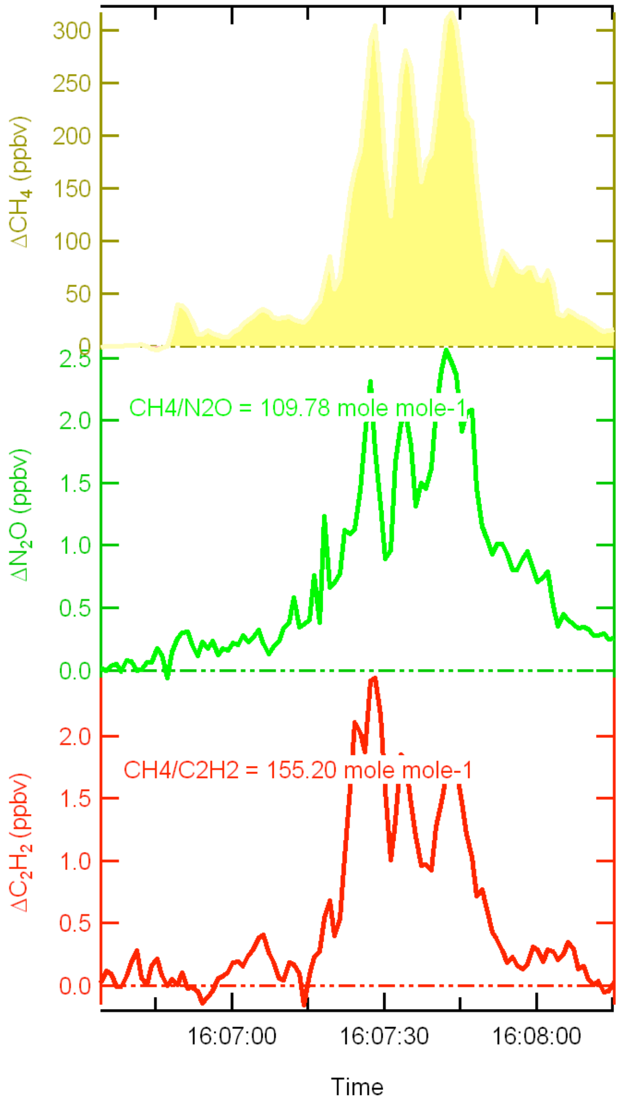
Aerodyne Mobile Lab: Full Payload



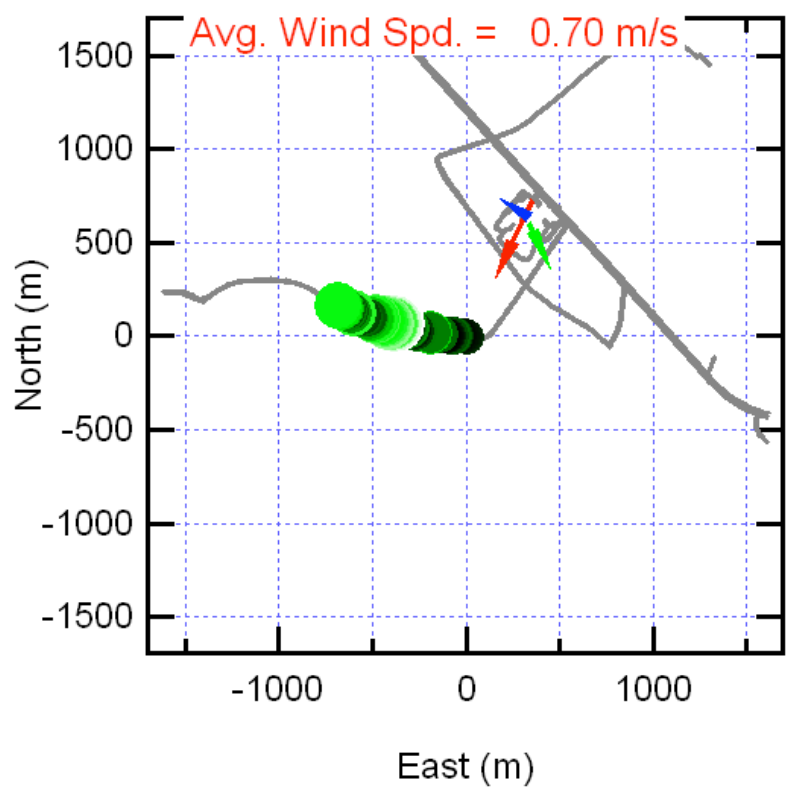
AML Goals at Frappe

- Characterization of oil and natural gas facilities near the Denver Julesburg Area (DJA)
- Emission measurements of feed lots and large scale dairy operations
- Explore particle and gaseous emissions from the commercial vehicle fleet
- Understand photochemical aging and daily transport of the urban plume

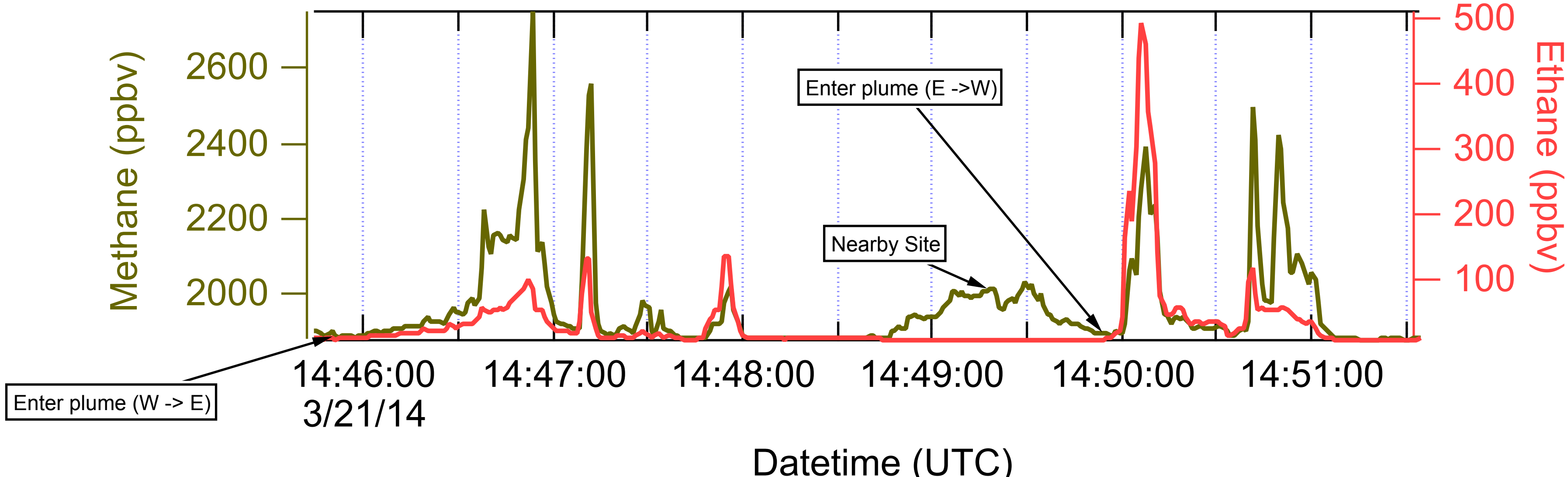
Dual Tracer Release Example



- One second time response on every species.
- Better than 1 ‰ sensitivity on all species while mobile.



Ethane for Source Attribution

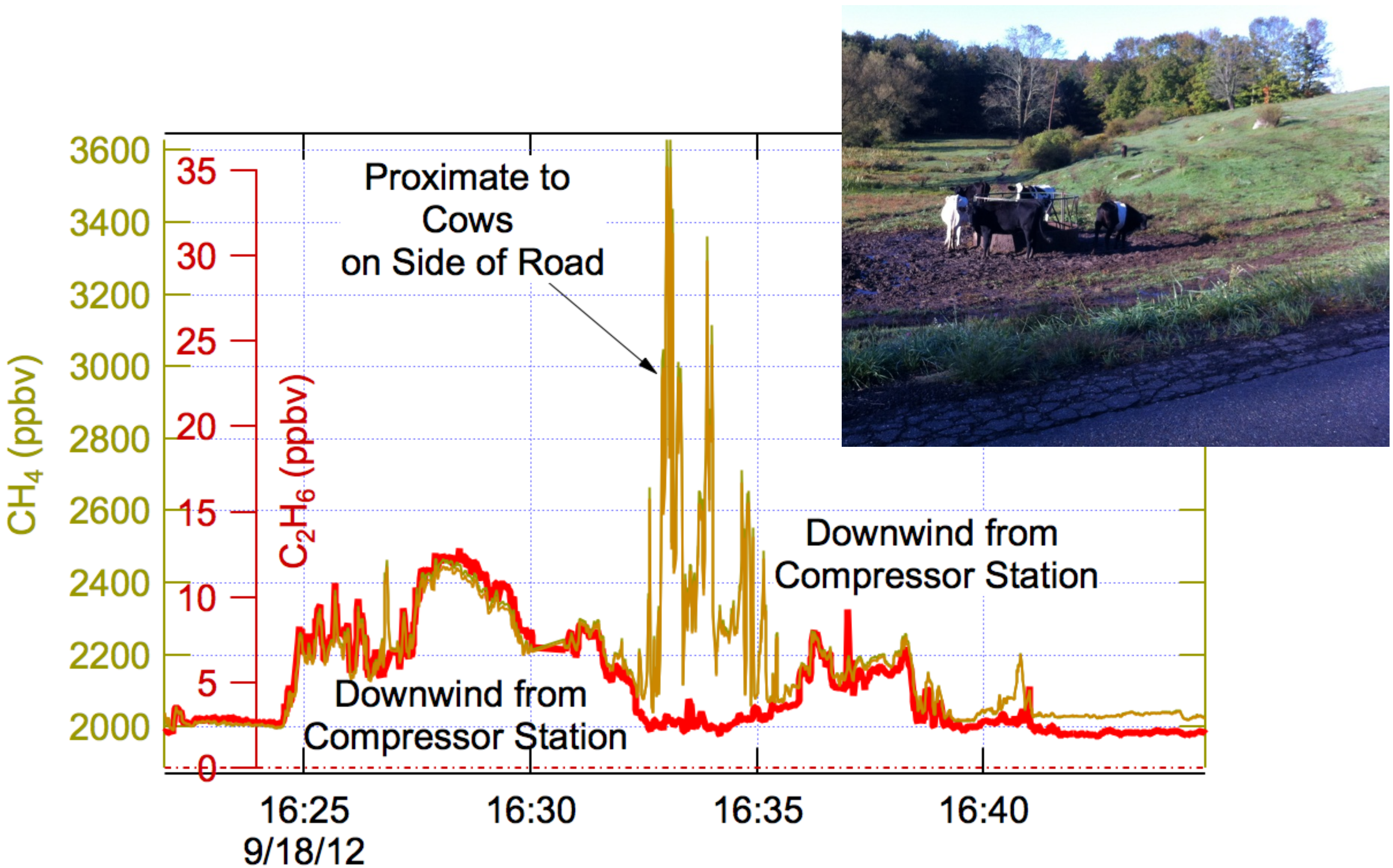


Natural Gas Liquid Tanks

NW Wind

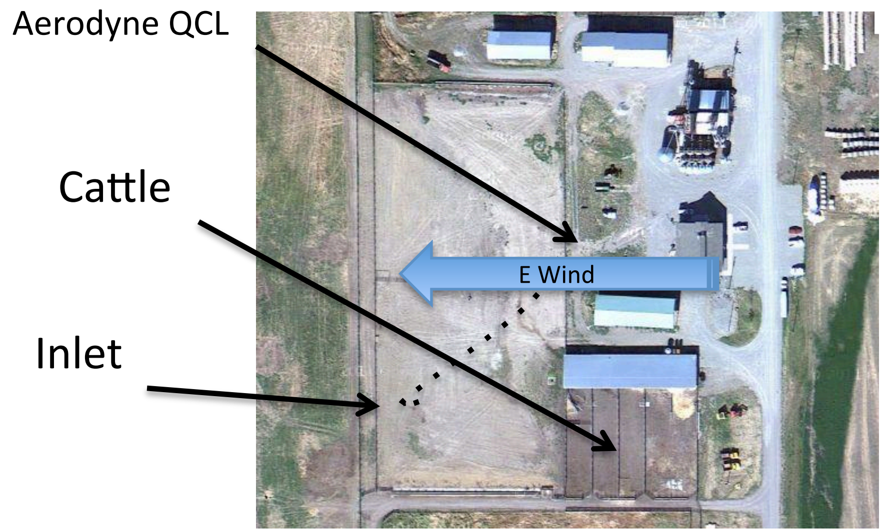
Yacovitch, et al. (Submitted)

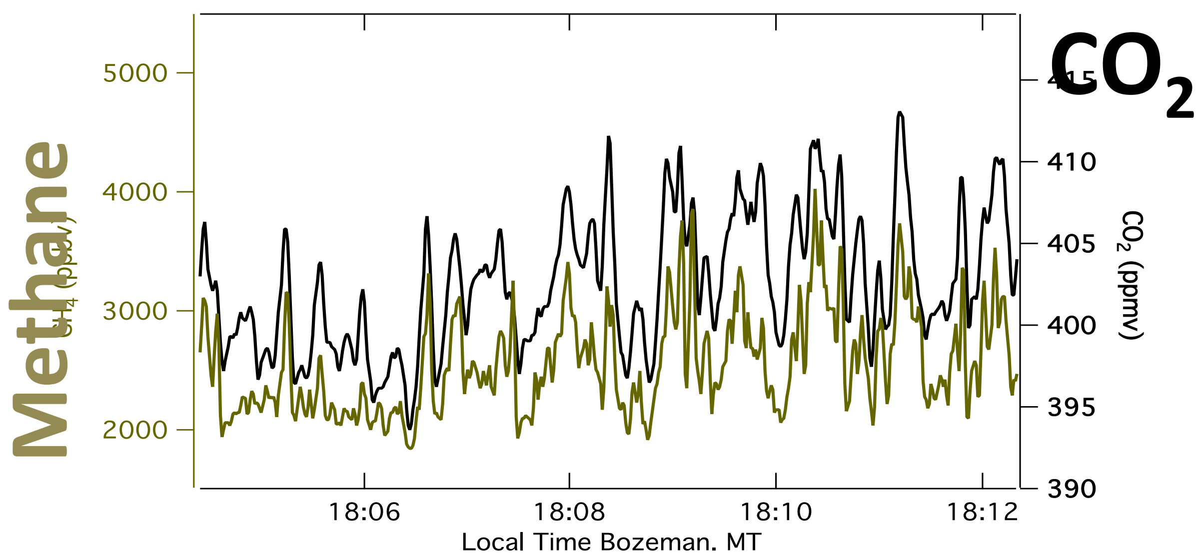
Source Attribution Cont.



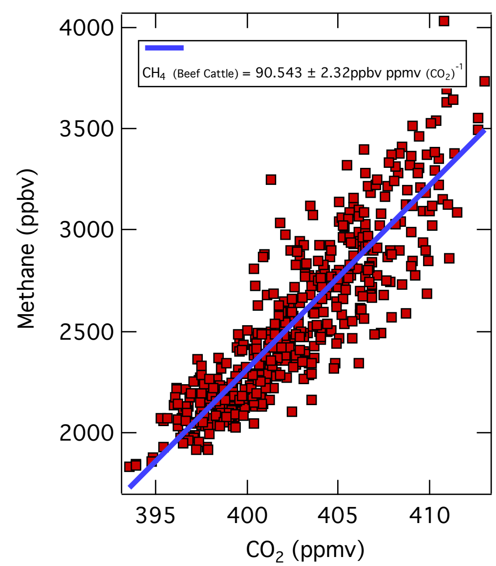
Herd CH_4/CO_2 Emission Ratio

- **Given adequate dispersion and advection, one can sample a mixed herd plume.**
- Herd emissions were monitored between 0 and 60M
- The herd plume represents the average emission ratio (Similar cattle)
- The results below are from 67 Beef Cattle





Methane / CO_2

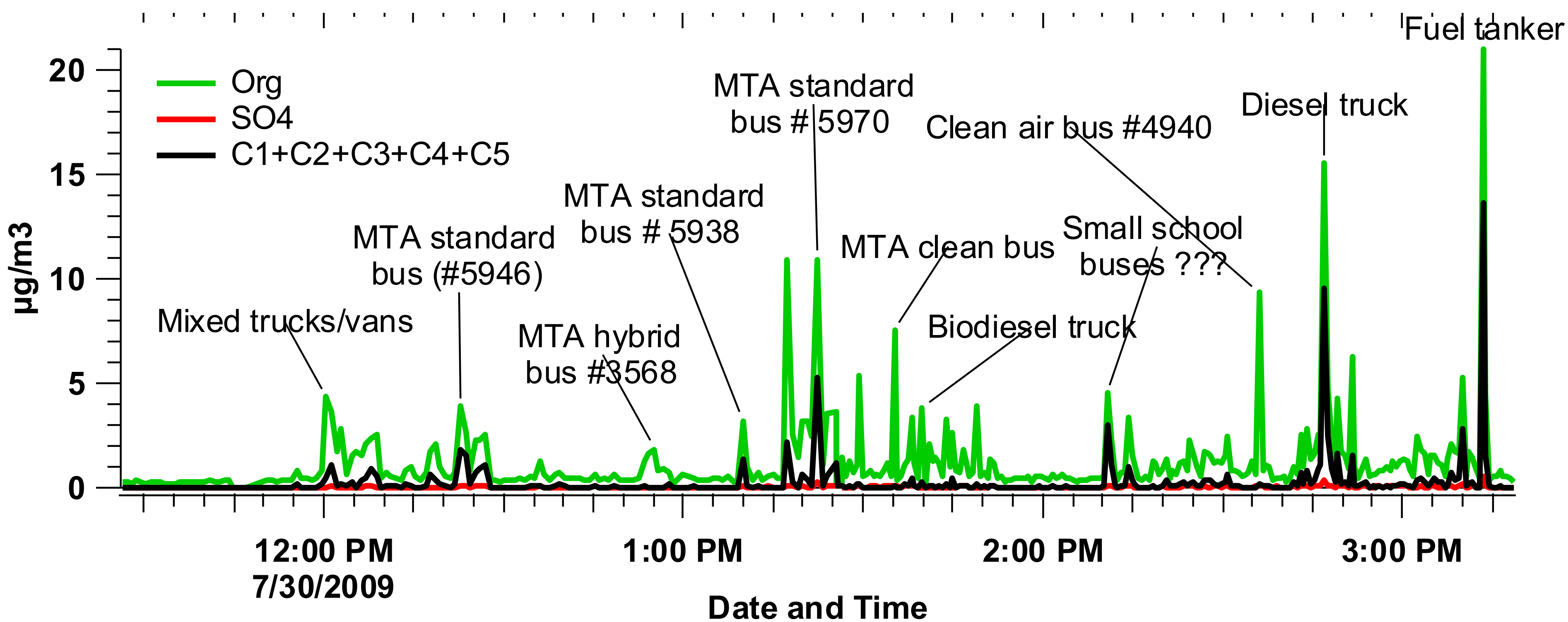


Vehicle Chase

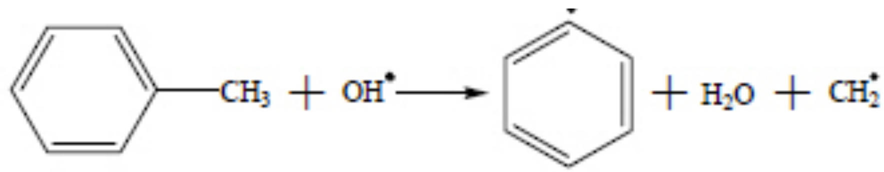
Particle Phase:
- BC
- Organics

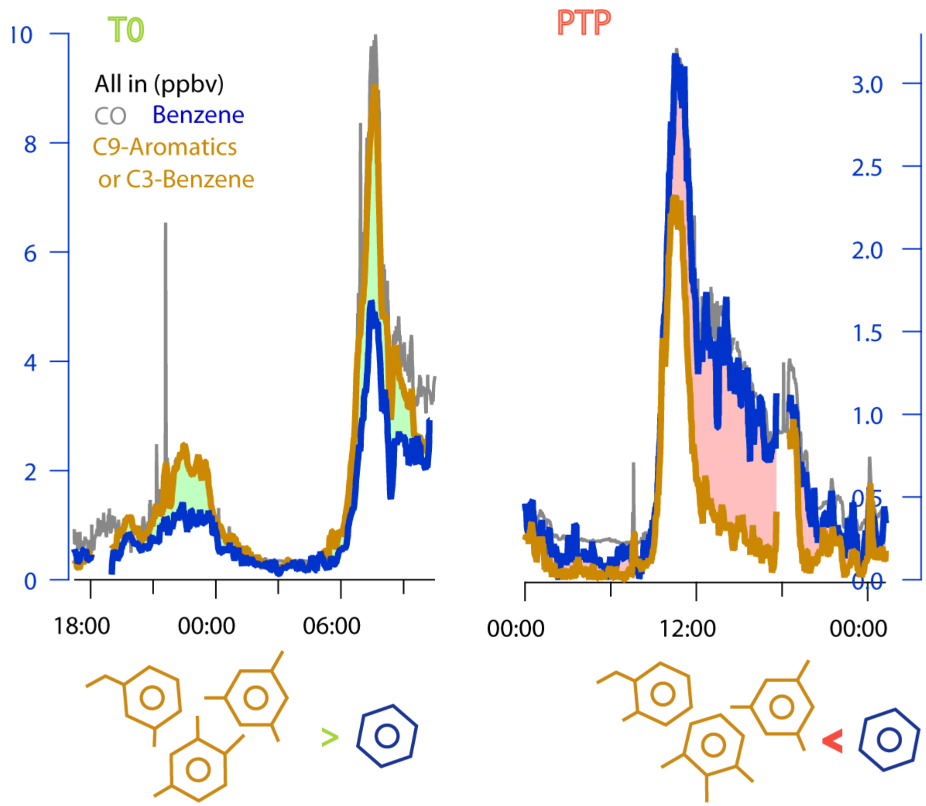
Gas Phase:
- NO_x
- CO
- CO_2
- VOC's
- Hydrocarbons

AMS Profile:



Photochemistry - VOC Ratios





$$\Delta t = [OH] / \left(1/(k_{VOC} - k_{benzene}) \left[\ln\{VOC_0/Benzene_0\} - \ln\{VOC_t/Benzene_t\} \right] \right)$$

de Gouw, J. Roberts, McKeen, Liu

Rocky Mountain National Park (ROMO)

Objective: Supplement continuous monitoring occurring at ROMO during campaign intensive period.

Key areas of NPS interest: Oil and gas impacts, N deposition, O_3

Ongoing measurement programs:
IMPROVE, AMoN, NADP, CASTNet (O_3, met, filter packs)

CSU will play a significant role in supplemental measurements at ROMO.

POTENTIAL MEASUREMENTS

VOC GC: 4 channel cryoless GC-FID-ECD system
C_2-C_{10} NMHCs, C_1-C_5 alkyl nitrates C_1-C_2 halocarbons, OVOCs, hourly measurements

Proton Transfer Reaction-Mass Spectrometer (PTR-MS): VOCs, OVOCs, CH_3CN, DMS
6 minute cycle time (44 channels)

GHG GC: 2 channel GC FID-ECD system, CH_4, CO_2, CO, N_2O, SF_6, 10 minute cycle time

PAN GC: GC-ECD, 10 minute cycle time

NO_x, NO_y: 1 minute data

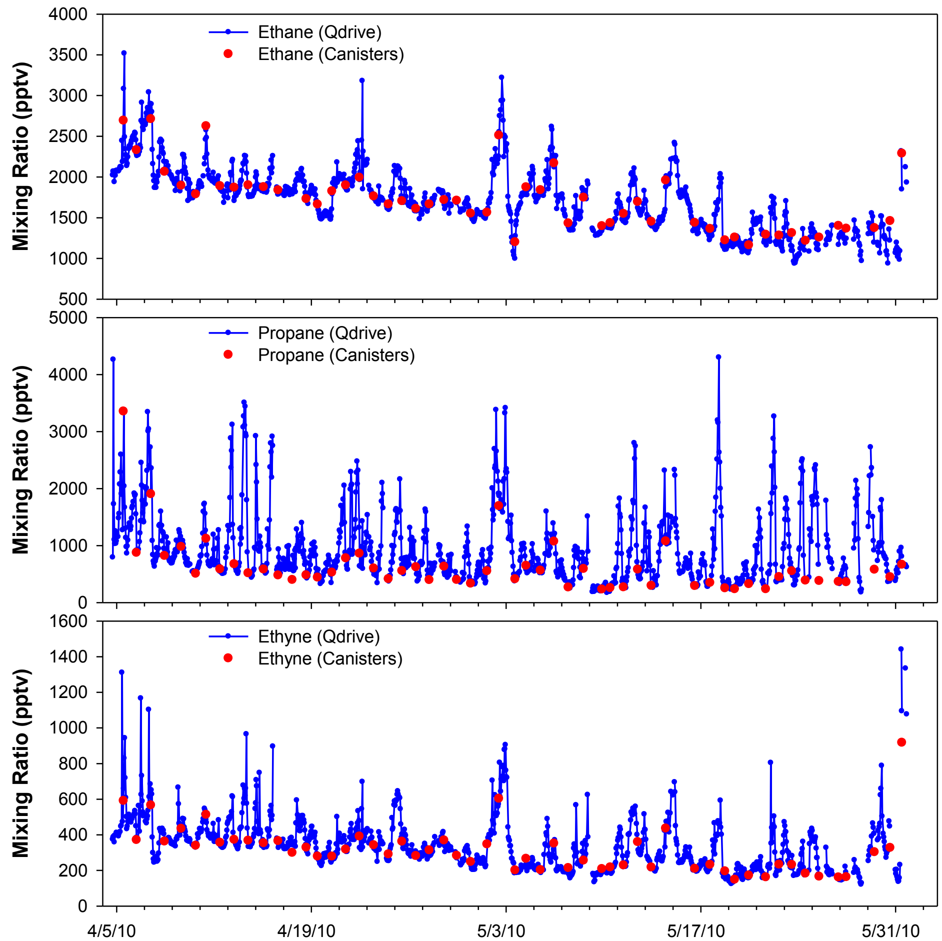
MARGA: hourly gas (NH_3, HNO_3, SO_2) and $PM_{2.5}$ (Cl^-, NO_3^-, SO_4^{2-}, NH_4^+, K^+, Ca^{2+}, Mg^{2+}, Na^+)

URG annular denuder system: 24 hr gas and PM2.5 ions (levoglucosan if smoke impacts occur); possibly an additional system deployed in Fort Collins

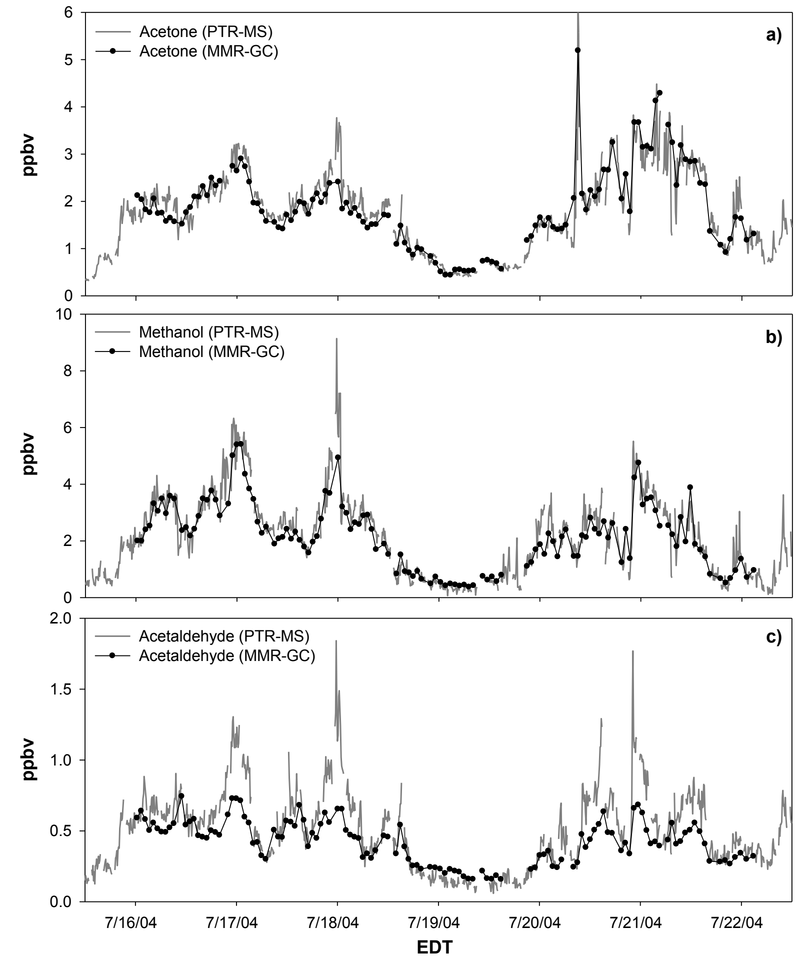
Additional spatial sampling:
Portable ozone (2B Technologies)
VOCs with canisters
NH_3

Typical data from the VOC GC, canisters and the PTR-MS

- **Similar data products are expected from the other measurements**

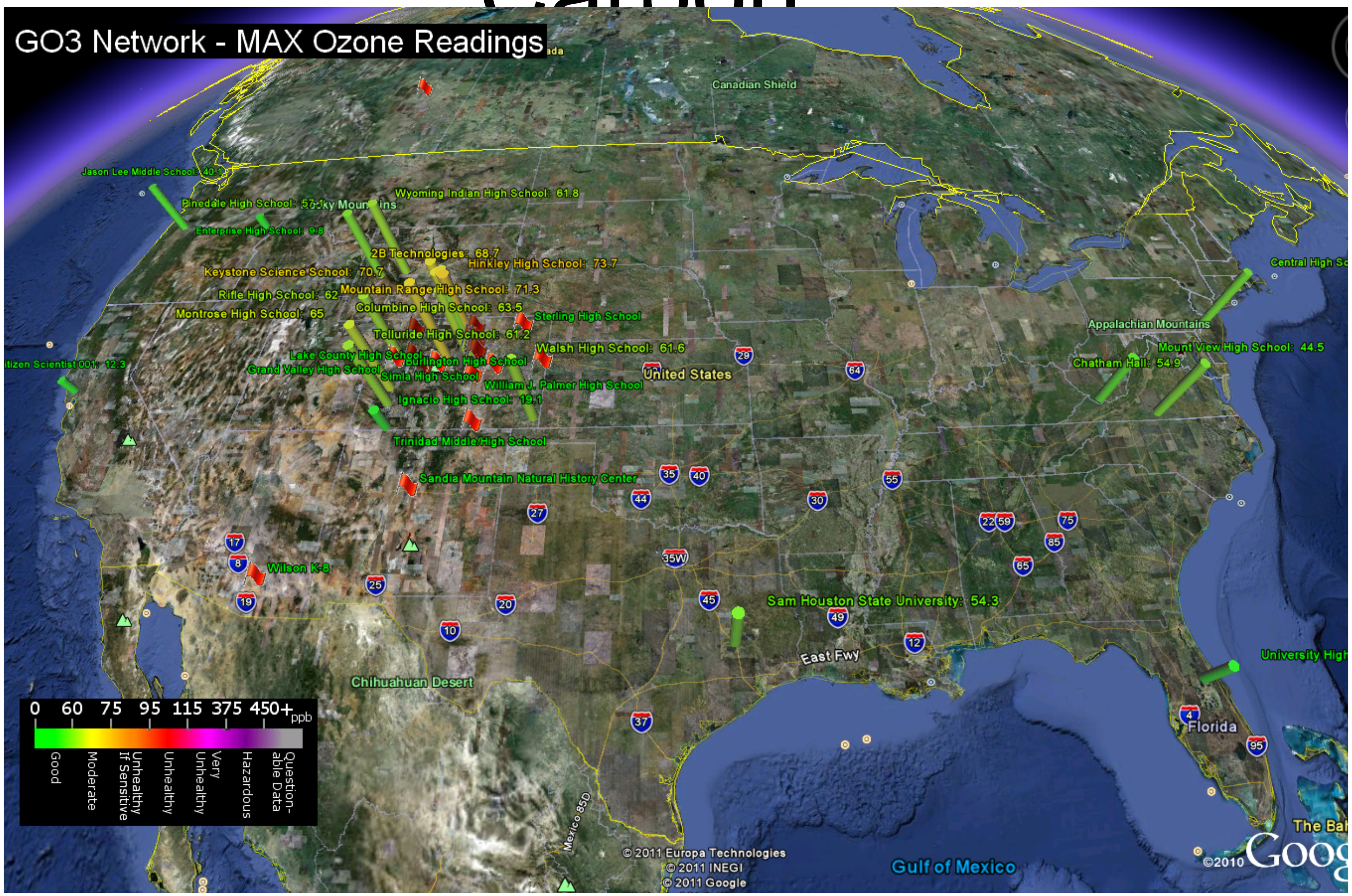


Cryoless VOC GC system (hourly) and daily canister samples

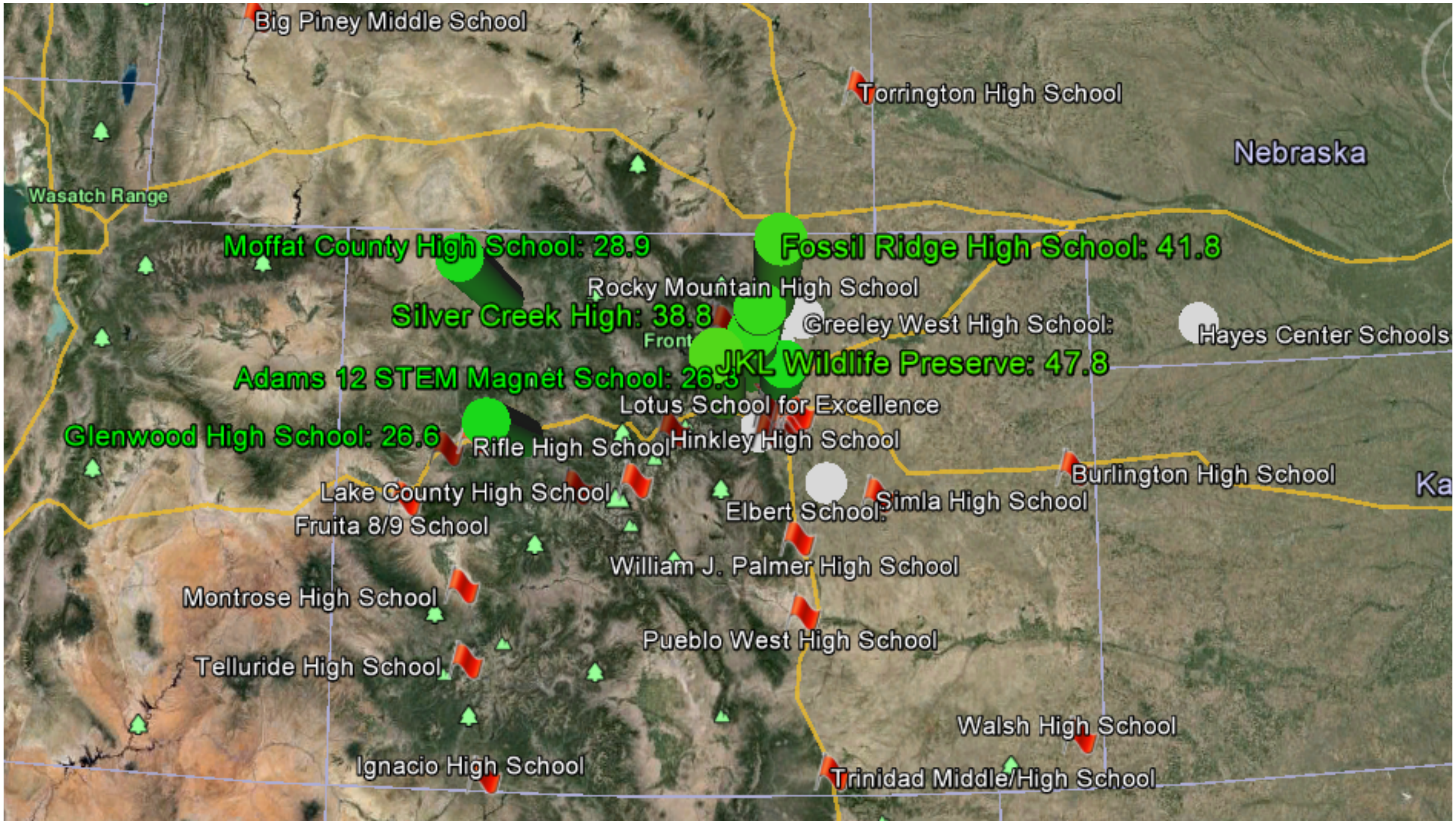


Cryoless VOC GC system (hourly) and PTR-MS

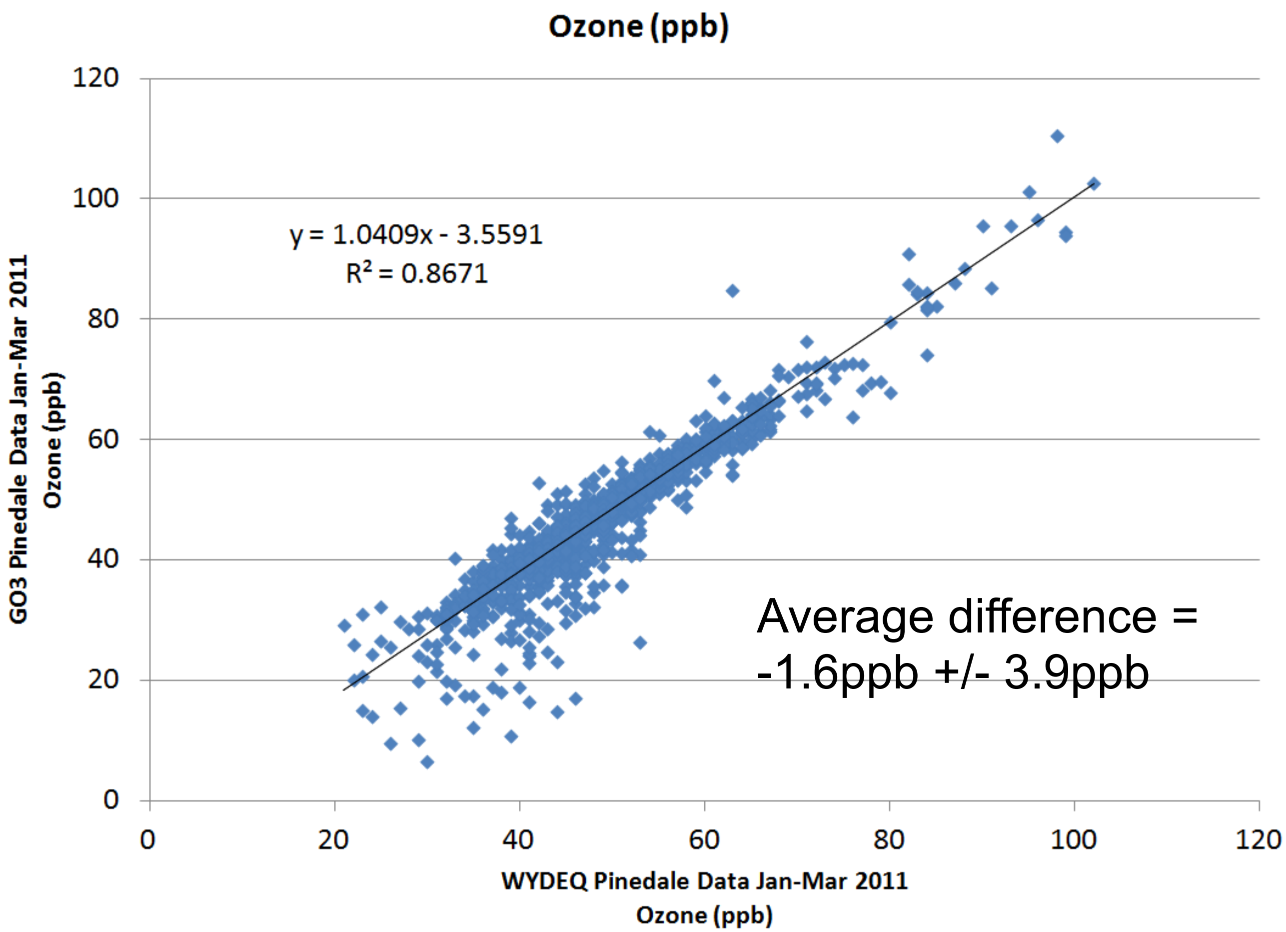
GO3 Project – Student Measurement of Ozone and Black Carbon



Colorado Monitoring Locations



Data Quality



Mapping Methane Sources in the D-J Basin Using Airborne and Ground Measurements (proposed)

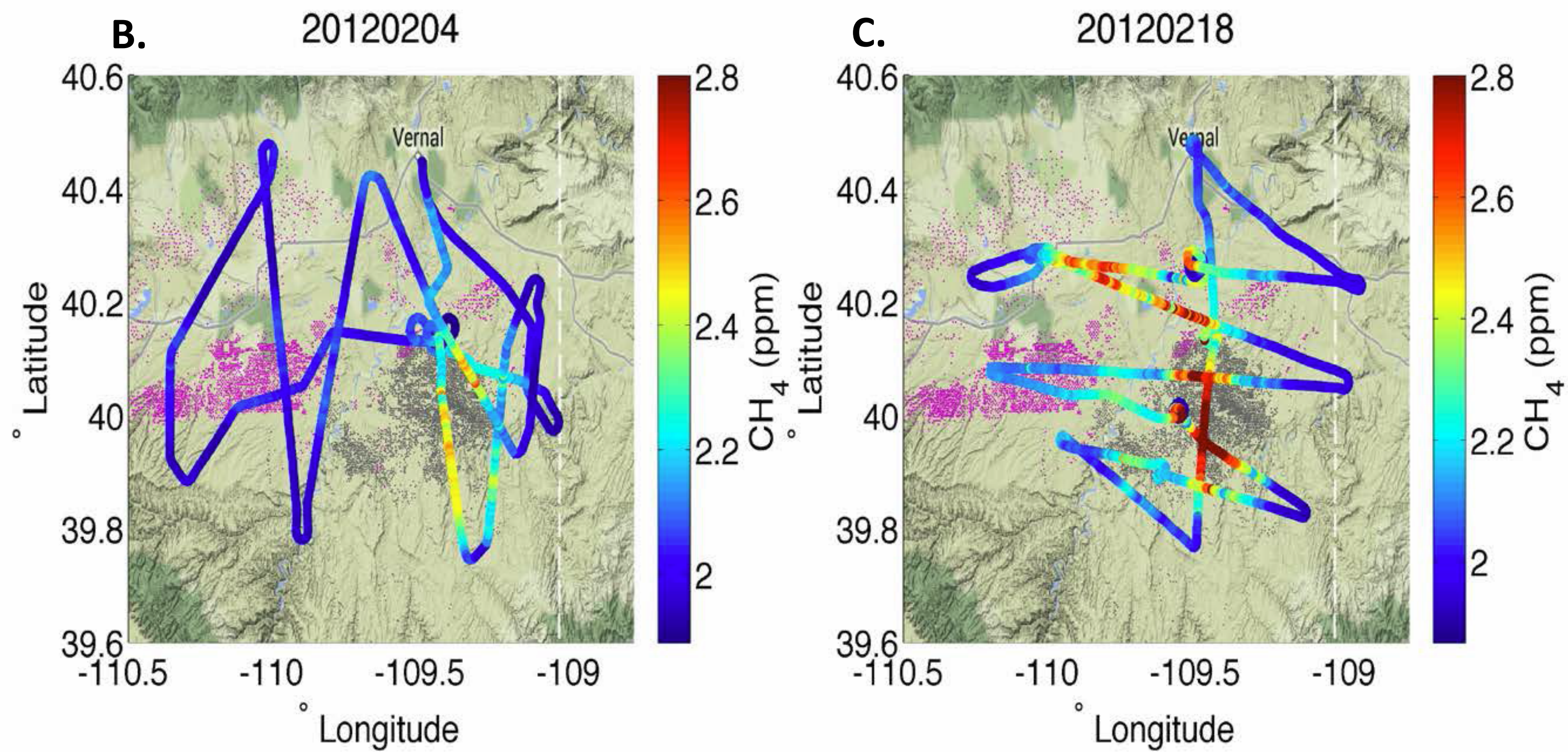
NOAA/CIRES/INSTARR/Aerodyne/Scientific Aviation

- NOAA and Scientific Aviation would fly an instrumented light aircraft in a regular gridded pattern across the D-J to map methane and ethane sources.
- Three mobile labs (NOAA, INSTARR and Aerodyne) would drive a gridded patter across the basin similarly mapping methane "hot spots" .
- Vans would have a combination of methane, ethane, Flask packs, and FLIR cameras.
- The aircraft and vans would interact to check each others observations and to check on persistence of the "hot spots".

Table 1. Instruments that would fly on the Mooney light aircraft .

Instrument	Measurement	Precision
Picarro 2301f	CO_2	150 ppb (5 sec)
Picarro 2301f	Methane	1 ppb (5 sec)
Picarro 2301f	Water	6 ppm (5 sec)
Aerodyne	Ethane	0.06 ppb (1 sec)
2B Model 205	Ozone	1 ppb (10 sec)
Vaisala HMP60	Temperature	±0.5C
Vaisala HMP60	Relative Humidity	±3%
Airplane	Horizontal Wind	±0.3 m s^{-1}
LGR	NO_2	0.05 ppb (1 sec)

Figure Legends. **A.** Light aircraft proposed for use in the D-J successfully used by NOAA in Texas and Utah methane studies. **B.** Methane survey in the Uintah Basin, Utah flying above a strong temperature inversion. **C.** Methane measured beneath the temperature inversion.



Supplemental Slides

Intrinsic CO_2 Tracer

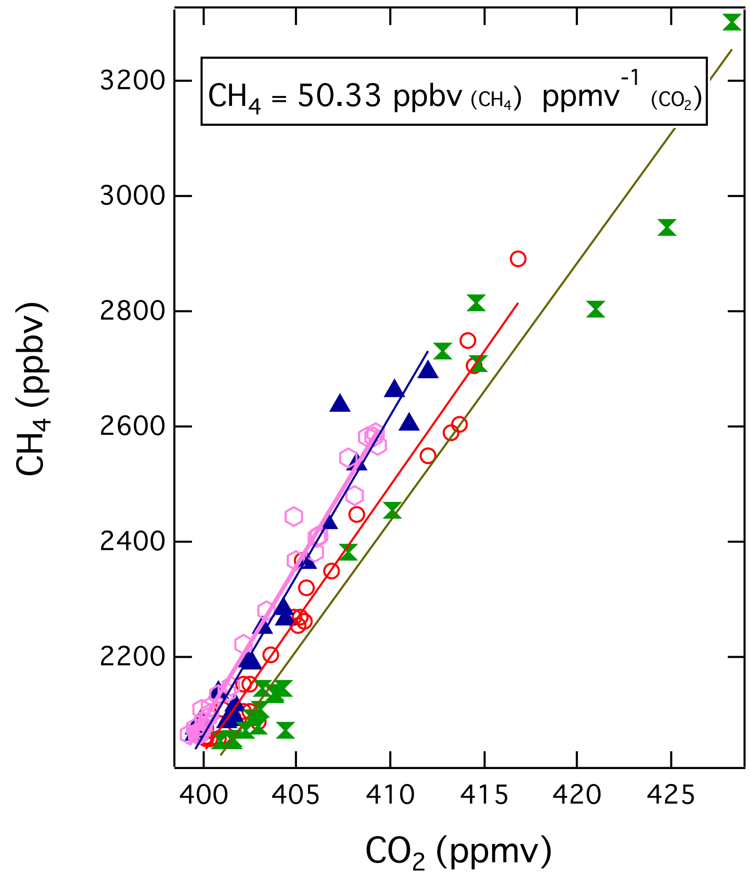
- Figure right shows strong correlation of CH_4 and CO_2 during **HERD** tracer release studies (single emission rate)

- One can estimate CO_2 flux from metabolic weight of the animal

- Mean CO_2 flux = 70±30 L kg^{-1} $BW^{0.75}$ d^{-1}

- $BW^{0.75}$ = Metabolic weight

- $$CH_{4(SLPM)} = CO_{2(SLPM)} * \frac{CH_{4(ppbv)}}{CO_{2(ppmv)}} * \frac{1}{1000}$$



Stewart et al.(2008)
Kinsman et al. (1995)
Boadi et al. (2002)

Ethane measurement assists methane source attribution