Up in the Air:
Methane and Ozone over California

The Alpha Jet Atmospheric eXperiment (AJAX)

Today's Flight Plan

- Pre-flight briefing (Introduction)
- Instrument Check-Out (Instrumentation)
- Weather Briefing (Structure of the Earth's Atmosphere)
- Mission: Locate Stratospheric Air which May Affect Surface Air Quality
- Mission: Identify and Quantify Methane from Dairy Sources
- Mission: Sample gases Emitted from Forest Fires: Compare and Contrast
  - Rim Fire (2013)
  - El Portal (July 2014)
  - Bald and Eiler Fires (Aug 2014)
- Debrief (Follow AJAX with NASA Mission Tools)



Pre-Flight: AJAX Overview

- Long term, periodic observations in partnership with aircraft owner (H211, LLC) since 2008
  - to further the NASA Earth Science program by studying Climate Change, Air Quality, and other topics and by supporting the observation of greenhouse gases from satellites.
- Operational Parameters: Ceiling: 50,000 ft Speed: 150 - 550 knts (~75 - 280 m/s)
  Range: ~1,000 km Endurance: 2 - 2.5 hrs.
- The working relationship between H211 and ARC/code SG has been fundamental to our success
  - Extremely proficient pilots & crew
  - Dedicated project & science teams
  - Quick response
  - Shared commitment
- Co-location at ARC is ideal for frequent calibrations, upgrades, quick turn-around troubleshooting, etc.
- Frequency of science flights depends on weather, science goals, and pilot and aircraft availability. We average 3-4 flights per month.





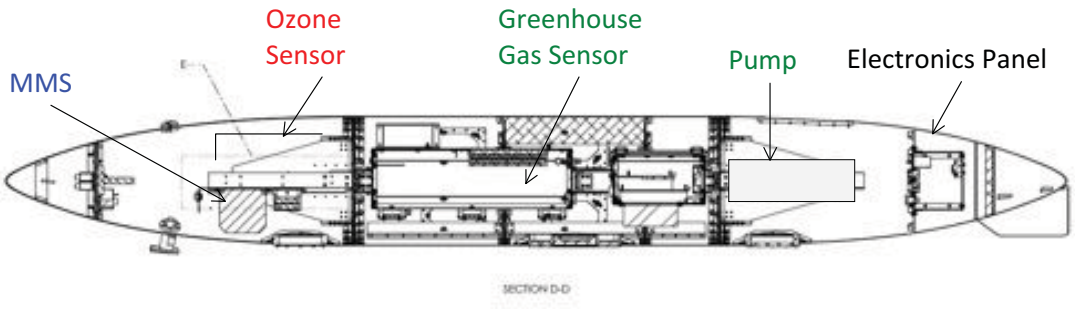
Instrument Check Out

Instrumentation

- Commercial ozone and greenhouse gas sensors modified for flight and repackaged according to NASA flight safety standards
- 3-Dimensional winds and research-grade ambient pressure and temperature
- Chamber tests, flight tests, and comparisons to standard methods show excellent in-flight performance
- Water vapor also available



Experiment Control Panel
(Rear Cockpit)



Ozone Instrument

Commercial unit (2B Technology Model 205) measures ozone (O_3) in ambient air (0.5 Hz) using UV absorption (254 nm) by ozone electronic transitions (Hartley Bands)





O_3 Instrument

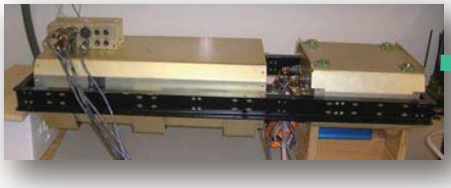
- Simultaneously measure differences between O_3-scrubbed air and un-scrubbed air
- Air intake is Teflon tubing (perfluroalkoxy-polymer, PFA) to prevent degradation on steel
- Eight-point calibration tests (ranging from 0 – 300 ppb) before and after each flight
- Modifications: vibration isolators, UV lamp heaters, upgrade of pressure sensor, temperature controlled box, replacement of fittings to meet aircraft operating conditions and requirements

Greenhouse Gas Sensor

Commercial unit (Picarro model G2301-*m*) measures carbon dioxide (CO_2), methane (CH_4), and water vapor (H_2O) in ambient air using cavity ring-down spectroscopy.

- Near-infrared absorption in narrow, well-resolved, sharp lines, each at a characteristic wavelength.
- Effective pathlength of many km.
- Repackaged to meet environmental and safety specifications and to fit in wing-mounted payload pod.







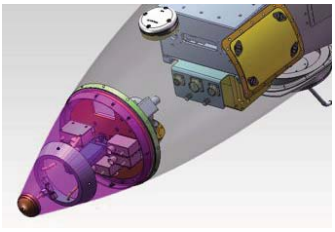
Meteorological Measurement System (MMS)

System Description:

- Provides high-resolution and accurate meteorological parameters (pressure, temperature, turbulence index, and the 3-dimensional wind vector).
- Consists of three major systems:
  - air motion sensing system to measure the air velocity with respect to the aircraft
  - aircraft motion sensing system to measure the aircraft velocity with respect to the earth
  - data acquisition system to sample, process and record the measured quantities.

System Components:

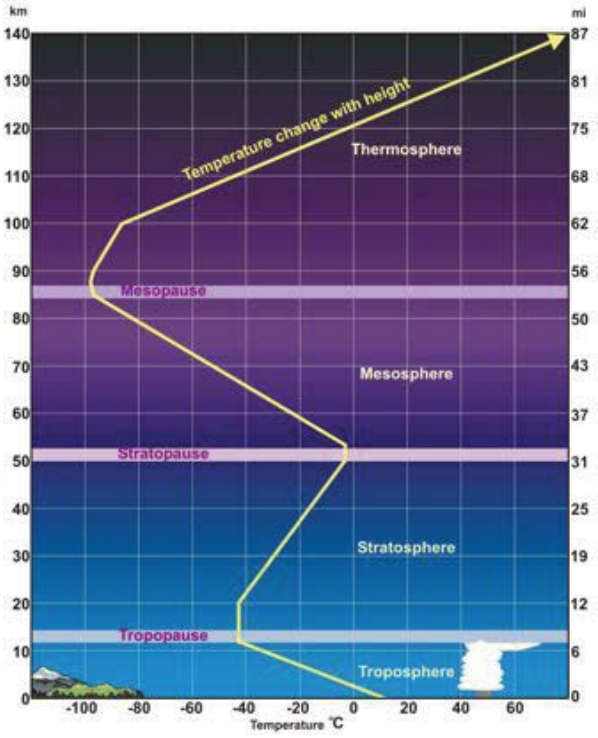
- 7 static pressure ports with pressure transducers:
  - pod nose tip
  - four in a cross hair pattern @ 6" aft
  - 3 and 9 o' clock position @ 41.25" aft
- INS/GPS system (SDN500)
- Fast Temperature Probe
- Temperature Controllers
- GPS L1/L2 Antenna
- Digital Compass
- Computer Enclosure Battery Pack





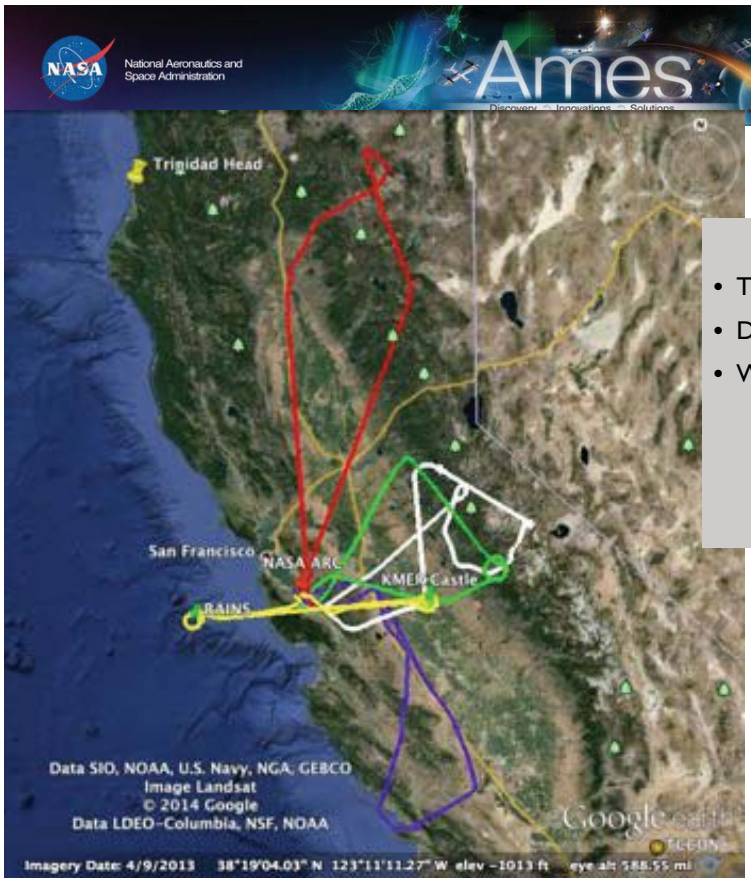
Weather Briefing





Atmospheric Structure

- Planetary Boundary Layer: lowest portion of troposphere, well mixed, ~500 ft to ~7,500 ft thick depending on location, time of day, heating, etc.
- Tropopause: at relevant latitudes, found at ~ 12 km (204 mbar) in winter and ~14 km (155 mbar) in summer
- Ozone layer forms naturally ~ 20 - 30 km (12 - 19 miles), in lower stratosphere.
- It contains relatively high concentrations of ozone (O_3), although it is still very small with regard to ordinary oxygen, and is less than ten parts per million



Mission Plans

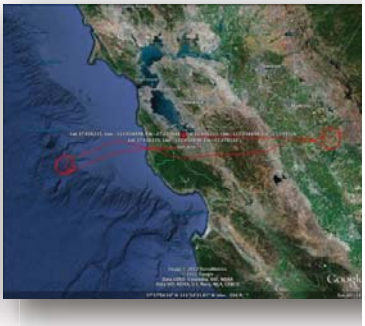
- Tracking Ozone Events (KMER, RAINS)
- Dairy Source (San Luis Obispo)
- Wildfires
  - Rim Fire
  - El Portal
  - Bald & Eiler

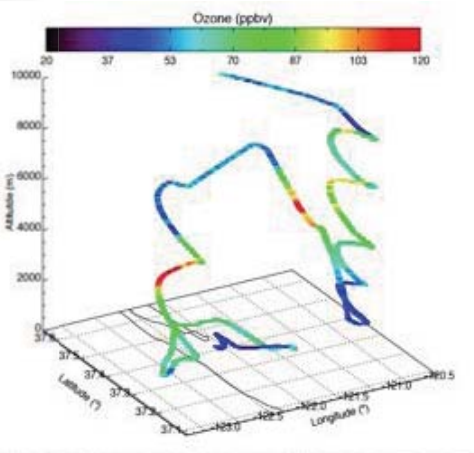


Mission: Locate Stratospheric Air which May Affect Surface Air Quality

Tracking Ozone: San Joaquin Valley/Off Shore







- Ozone forms naturally in the stratosphere, where it protects us from UV radiation. (It also forms photochemically in polluted air.)
- Certain weather patterns can bring stratospheric air down to the surface, where ozone is an irritant and leads to poor air quality.
- A year-long data set has been assembled, and we see several clear cases of stratospheric air in the troposphere.
- Yates et al., *Atmos. Chem. Phys., 2013* doi:10.5194/acp-13-12481-2013

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eric Intrusions

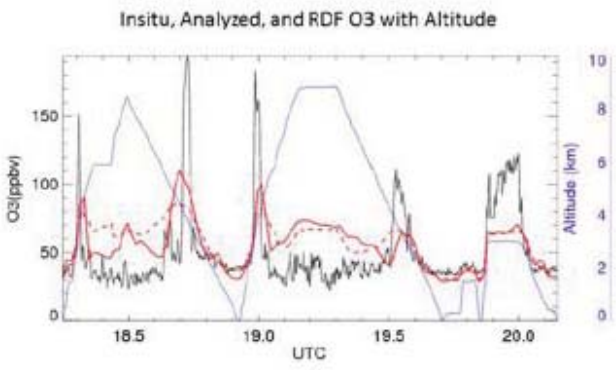


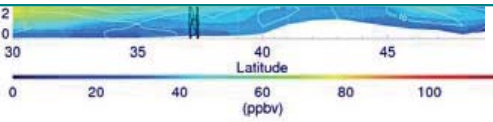
Fig. 10. Time series of in situ (black), RAQMS reverse domain filled (RDF) (solid red), and RAQMS-analyzed (dashed red) O_3 (ppbv) for AJAX flight on 5 June 2012. The first vertical profile is over the San Joaquin Valley and second vertical profile over the offshore location.

ir Quality Exceedance in
2012 due to stratospheric
d to surface.

same air on June 5 over CA.

e (RAQMS, upper panel)
W cross-section (lower) on
t 11 am MST. Aircraft flight
in black.

pause fold indicated by the
ozone extending from the
here into the mid-



- Aircraft data validates model prediction and shows areas for improvement.

Figure courtesy of Brad Pierce and the NASA Air Quality Applied Sciences Team.



Mission: Identify and Quantify Methane from Dairy Sources

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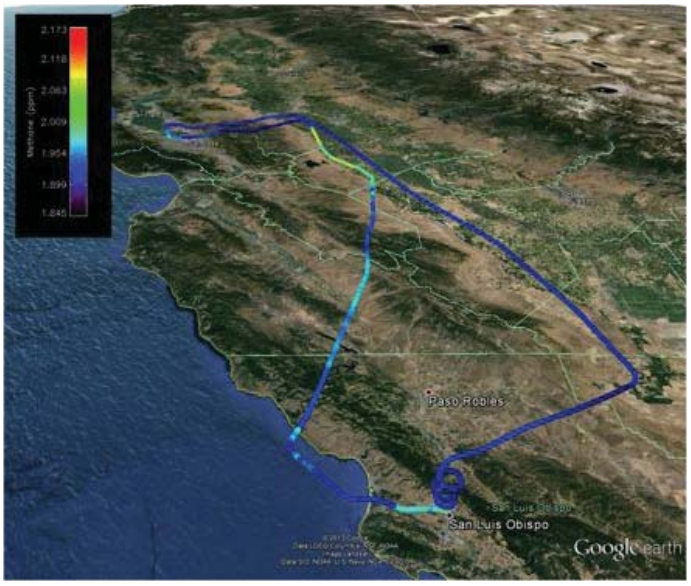
COW-Gas Campaign

- Methane (CH_4) is a more potent greenhouse gas than carbon dioxide (~120x)
- Significant CH_4 is generated from livestock waste (B). Studies (including AJAX's Johnson et al., *Atmos. Environ.*, 2014) indicate CH_4 is under-represented in emissions inventories by ~5x.
- California Polytechnic State University operates an isolated dairy (A) in San Luis Obispo..
- The COW-Gas campaign was a precursor study designed and coordinated by Dr. Ira Leifer (BRI), who operates two mobile ground-based sampling systems (AMOG and MAClab).
- Science Goals: Identify and quantify total methane emissions and their variability from an isolated dairy over a day using continuous mobile and stationary monitoring by in situ and column measurements. Relate emissions to emissions from different dairy operations including wet manure management. These goals are in support of the COMEX (CO_2 and Methane eXpedition) campaign in summer 2014.



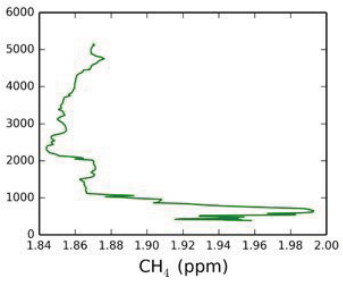
COW-Gas Regional Context and Vertical Profile

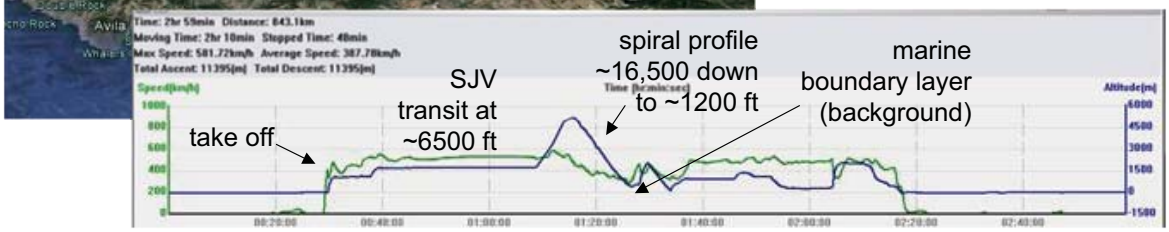
- March 5, 2014, AJAX Flt #116
- AJAX took off at 12:25 PST and transited down the central valley to above San Luis Obispo at 2000 m, before climbing to 5000 m
- AJAX collected a vertical profile ending in a large circle around the dairy at ~13:20 at ~500 m altitude.
- AJAX then followed the valley to the northwest and sampled lower marine boundary layer air offshore before heading home.



AJAX Flt #116

- Methane plotted at left (red = more) and below







Mission: Sample Gases Emitted from Forest Fires: Compare and Contrast

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Rim Fire

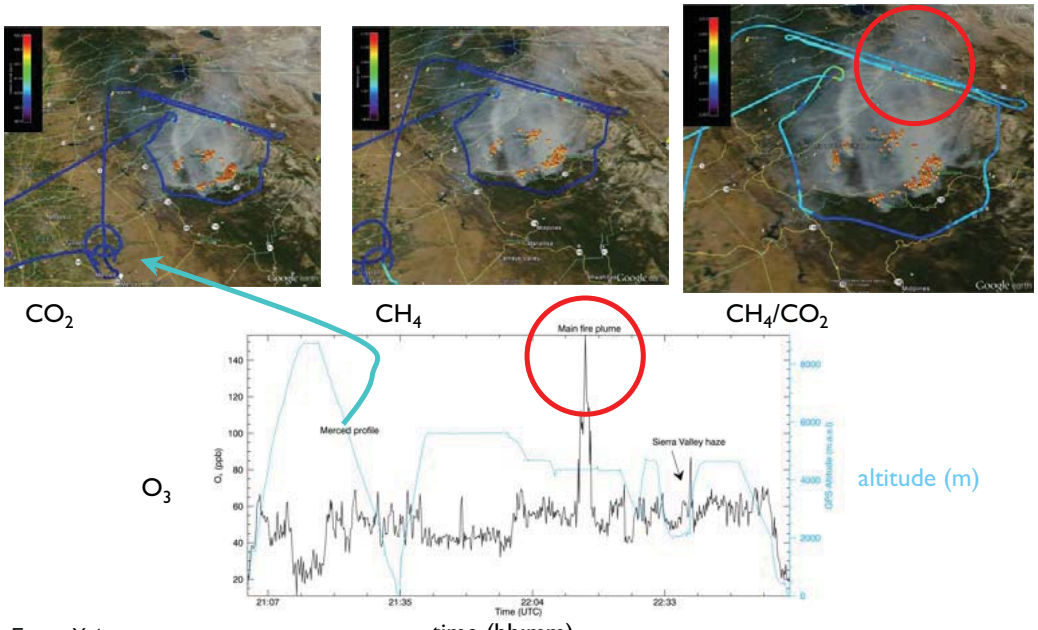


Rim Fire



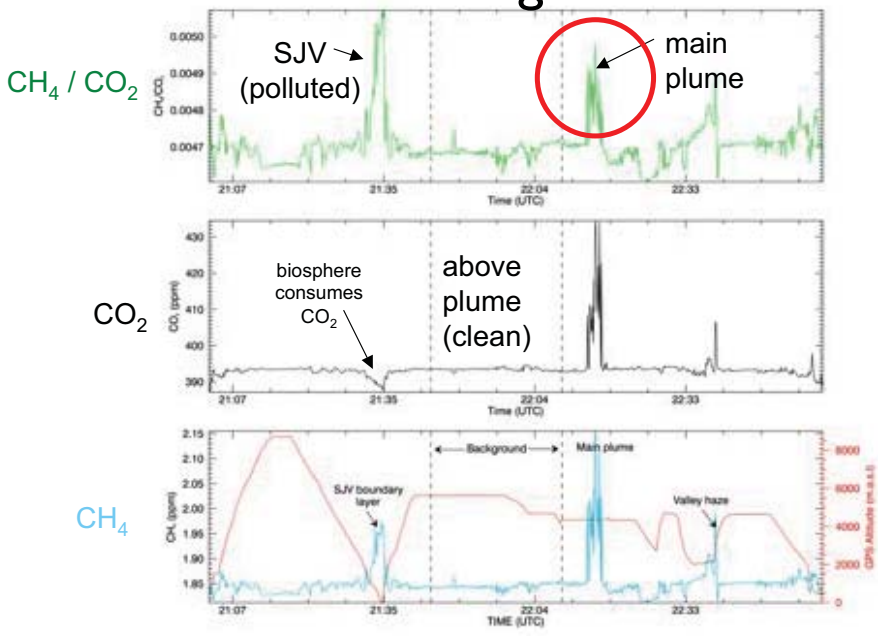
Courtesy Rob Simone

Rim Fire (Flt #100 – 29 Aug 2013)



Courtesy Emma Yates

Trace Gases During First Rim Fire Flight



- CH_4 enhanced over populated area (SJV)
- CO_2 reduced when biosphere influence
- CH_4 and CO_2 both enhanced in fire plume
- *Ratio* of CH_4/CO_2 is enhanced in plume

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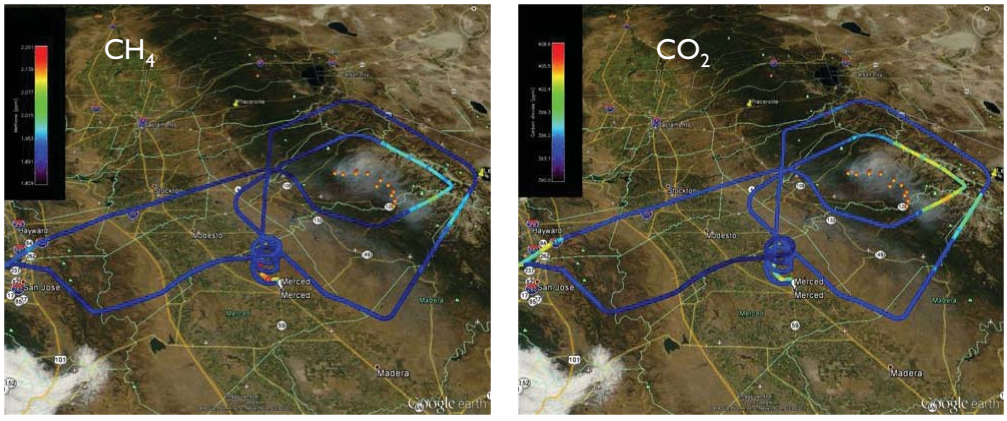
Flt #101 – 10 September 2013

12 days later: vertical profile, inner & outer circuits

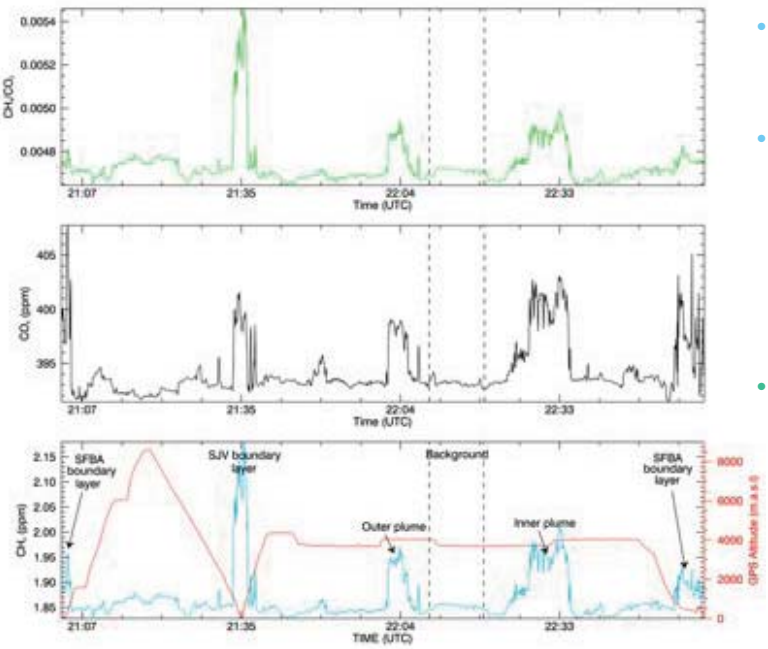


Trace Gases During Second Rim Fire Flight

CH_4 / CO_2

CO_2

CH_4



- CH_4 and CO_2 both enhanced in fire plume
- CH_4 and CO_2 both enhanced over populated area (SJV) due to stagnant conditions, influence of two smoke plumes
- *Ratio* of CH_4/CO_2 is much higher now that fire is closer to containment

altitude (m)

El Portal Fire





Courtesy Warren Gore

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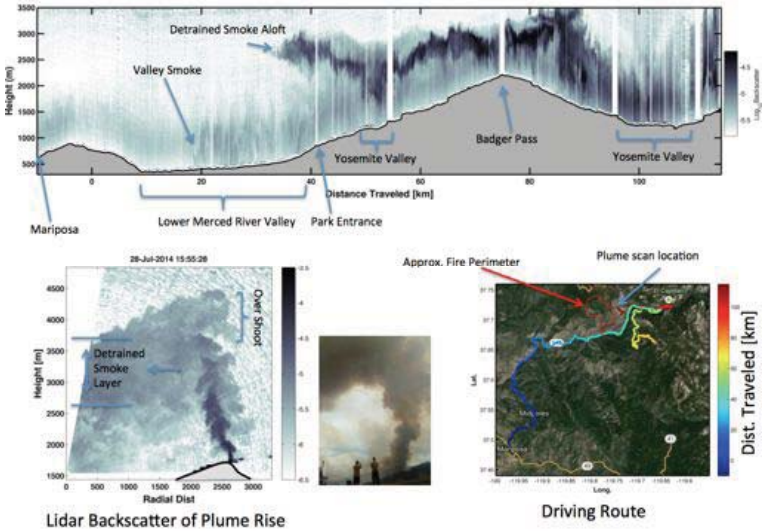
El Portal Plume Structure (28 July 2014)

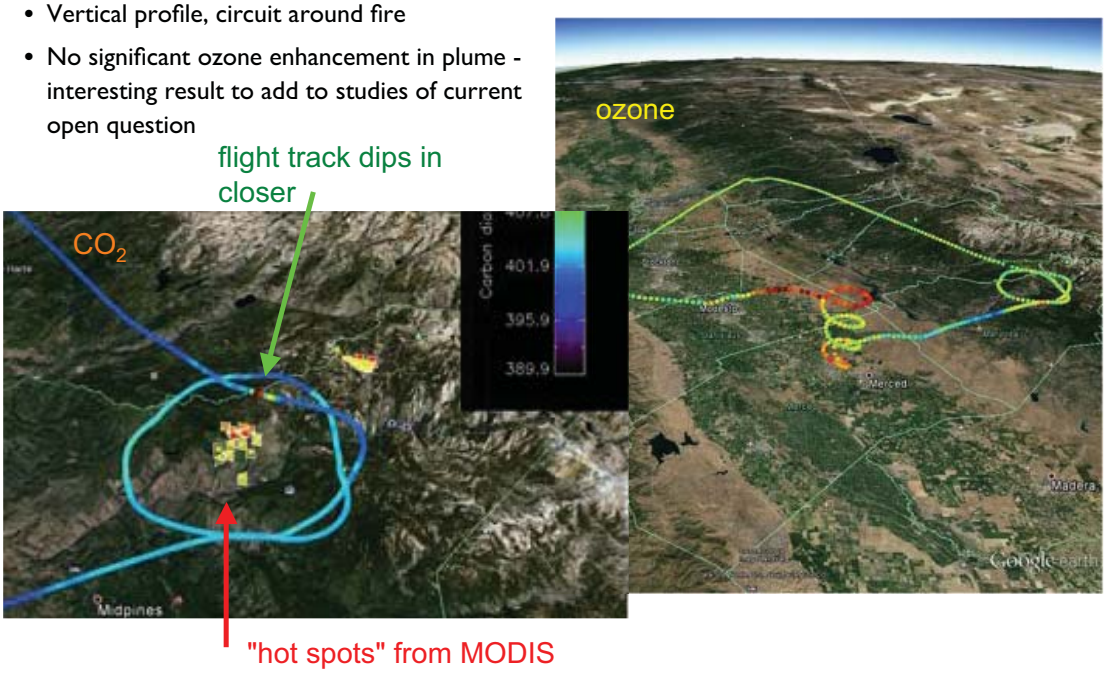


Courtesy Neil Lareau and Craig Clements (SJSU) with funding from NSF

See also http://www.fireweather.org/blog/2014/7/15/radfire

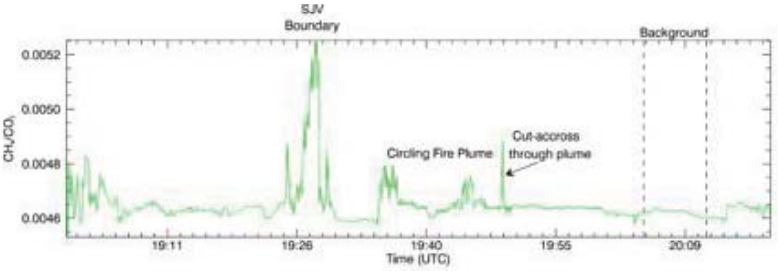
AJAX Flt #136 29 July 2014

- Vertical profile, circuit around fire
- No significant ozone enhancement in plume - interesting result to add to studies of current open question

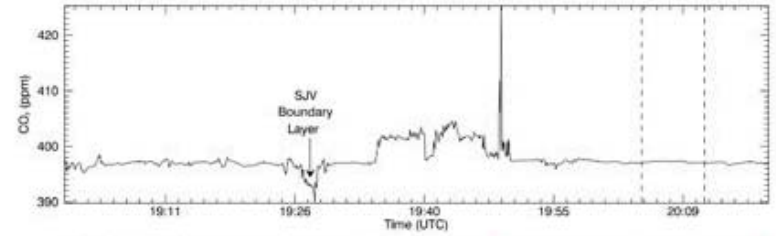


Trace Gases During El Portal Fire Flight

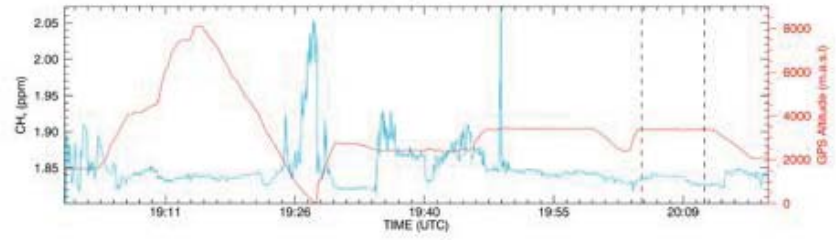
CH_4 / CO_2



CO_2



CH_4

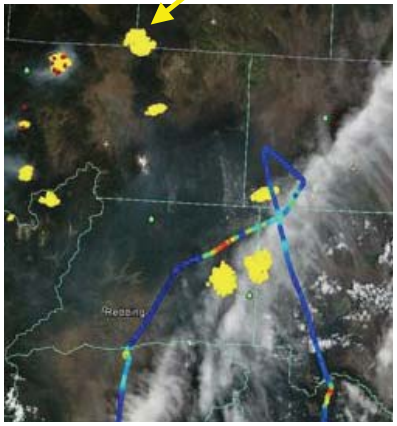


- GHG enhancements in plume circles
- CH_4/CO_2 similar to fresh Rim Fire plume
- CO_2 biosphere draw-down in SJV BL

AJAX Flt #137: Bald & Eiler Fires 6 Aug 2014

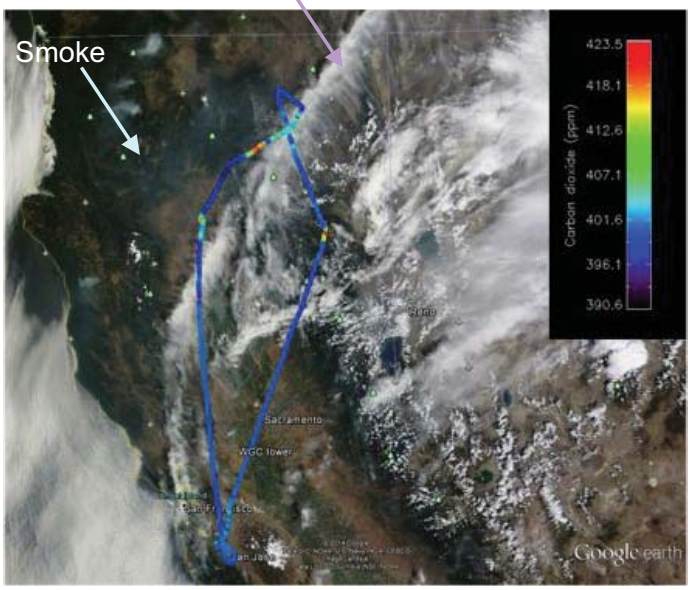
- Shasta County, CA
- winds from NNW

MODIS hot spots



Clouds

Smoke

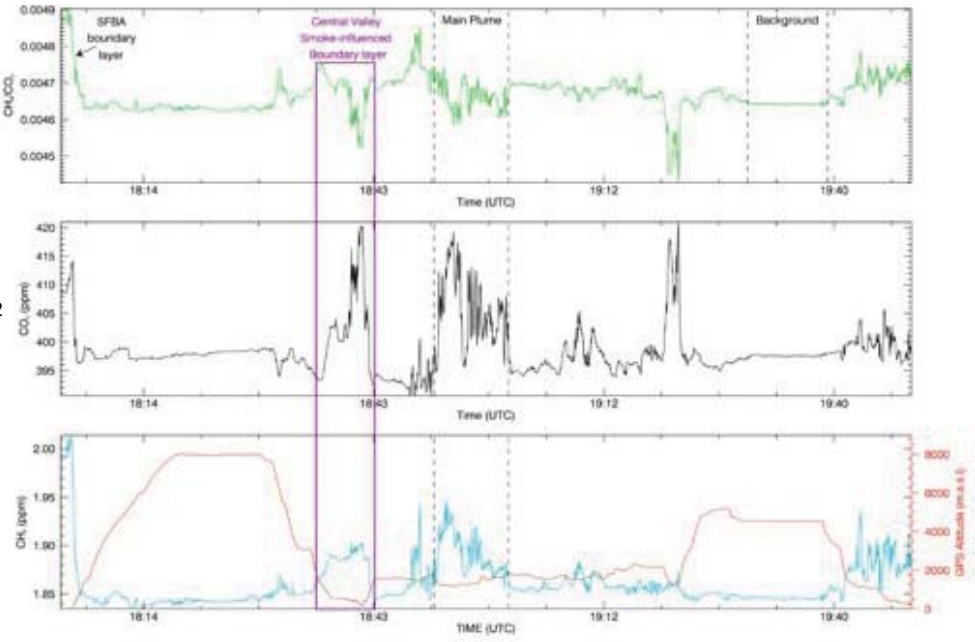


Trace Gases During Shasta Fires Flight

CH_4 / CO_2

CO_2

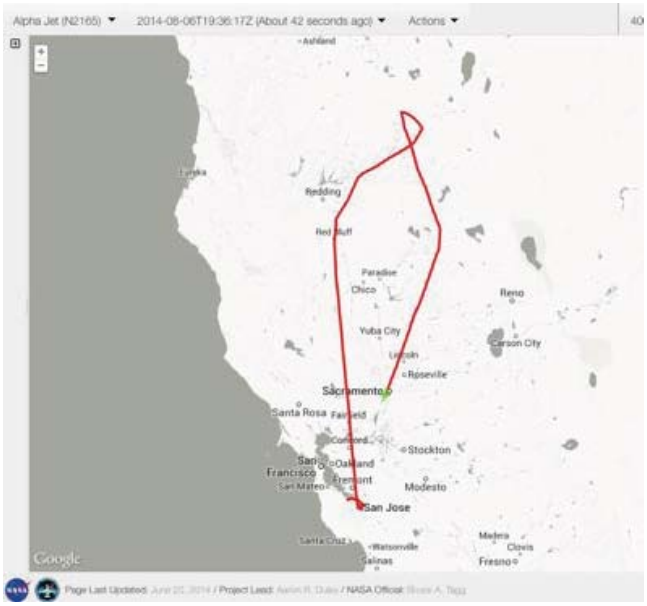
CH_4



Comparison of Fire Observations

	Rim Fire				El Portal	Eiler/Bald
	29-Aug-13		10-Sep-13		27-Jul-14	6-Aug-14
	Valley Haze	Main smoke	Outer circle	Inner circle	Main plume	Main plume
Size or fire (acres)	199,237		255,146		3,060	39, 926
% containment	32		80		19	68
Notes	Active fire		Smouldering fire		Active fire	Rain overnight and foggy morning
Delta(CO_2) (ppmv)	13	41	6	10	30	25
Delta(CH_4) (ppbv)	145	310	118	159	220	110
ER_{CH4} (ppbv/ppmv)	7.9	7.6	16.8	14.3	8.5	4.8

Debriefing



- Follow us in NASA's Airborne Science "Mission Tools Suite": http://airbornescience.nasa.gov/tracker/
- Twitter: @NASAAJAX
- YouTube:
  - "NASA Ames Stars in Documentary About Climate Change" https://www.youtube.com/watch?v=slLTUMgEoFM&feature=youtu.be
  - "Years of Living Dangerously" https://www.youtube.com/watch?v=brvhCnYvxQQ

Flight Crew

- Emma Yates
- Tomoaki Tanaka
- Warren Gore
- Chris Camacho
- Quincy Allison
- Emmett Quigley
- Matthew Johnson
- Tysen Mulder
- Tony Trias
- Ed Sheffner
- Pat Hamill
- Zion Young, Roy Vogler, Peter Tong

- Pilots & Crew of H211, LLC
- Prof. Craig Clements, Neil Lareau (SJSU)

