Airborne ozone measurements over California and Nevada by the Alpha Jet Atmospheric eXperiment (AJAX)

Emma Yates

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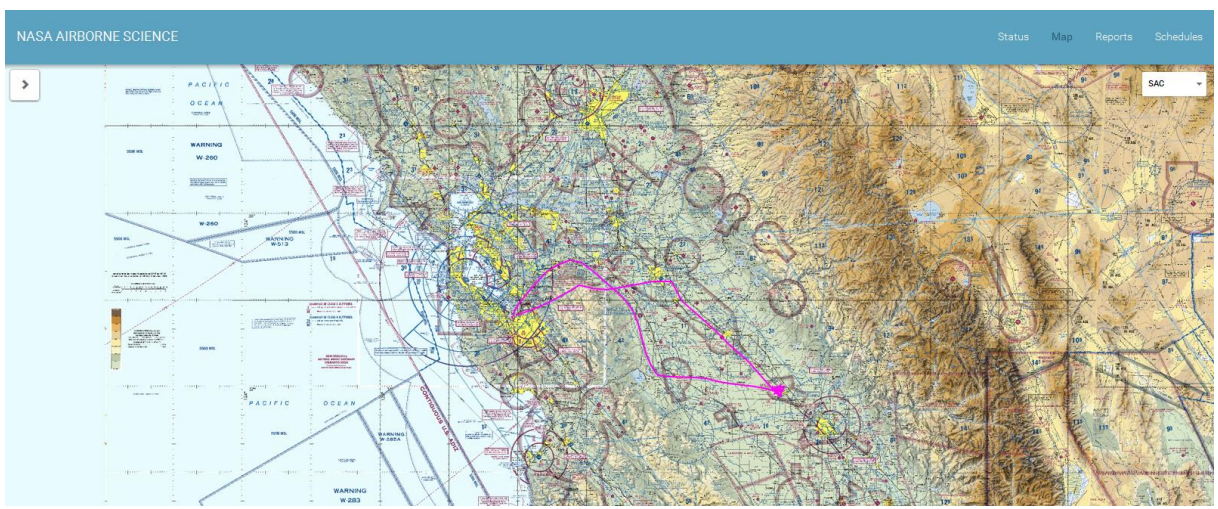
Today's flight plan

- Alpha Jet Atmospheric eXperiment (AJAX) overview
- Introduction to our measurements
- Example flight missions:
  - Flights capturing stratospheric intrusion and impacts on air quality.
  - Onshore-Offshore vertical profiling.
  - San Joaquin Valley & San Francisco Bay Area boundary layer profiling.
  - Flights to sample wildfire plumes.
  - Future flights
- Where to find out more



AJAX overview

- Partnership with H211, LLC since 2008
- Total flights to date: 178

Ceiling	50,000 ft (~14 km)
Speed	150-550 knts (~75-280 m/s)
Range	~1,000 km
Endurance	2-2.5 hrs

2007
H211 acquires Alpha Jet

2010
Modifications

2011
1st Flt of O_3 and GHG instruments
1st Science Mission

2012
RRV Mission
50th AJAX Flt

2013
DISCOVER-AQ-CA Mission
LVOS Mission
1st Flt of MMS
100th AJAX Flt
Harrison Ford flies an AJAX flt

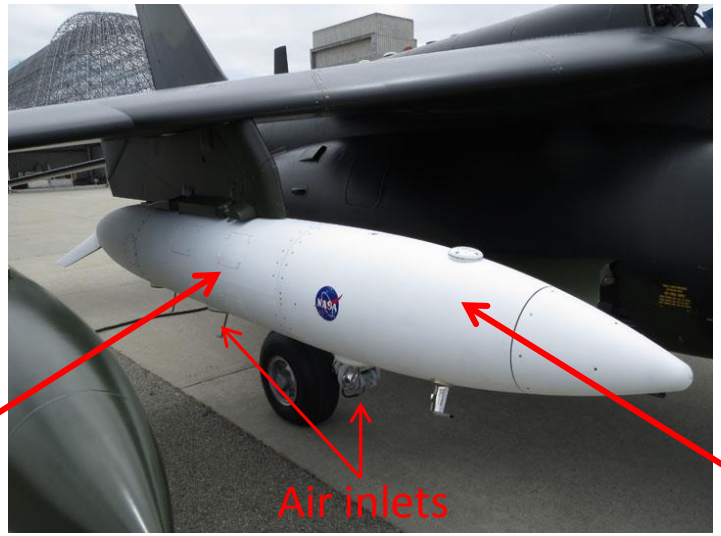
2014
COWGAS Experiment
COMEX Mission
150th AJAX Flt

2015
RRV Mission
COMEX Mission
1st Flt of HCHO

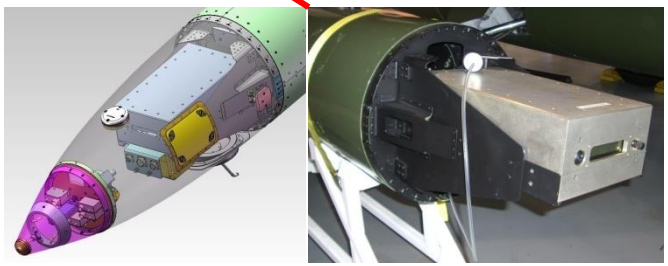
2016 plans
CABOTS
RRV Mission

Experimental set-up

NASA Ames Alpha Jet Atmospheric eXperiment (AJAX)



Modified Picarro (2301-*m)* measures CO_2 and CH_4 located in center- and tail- sections of the wing-pod



Modified 2B technologies (model 205*)* measures O_3 and Meteorological Measurement System (MMS) located in the front/nose section of the wing-pod

Plus recently installed formaldehyde instrument in separate wing-pod!

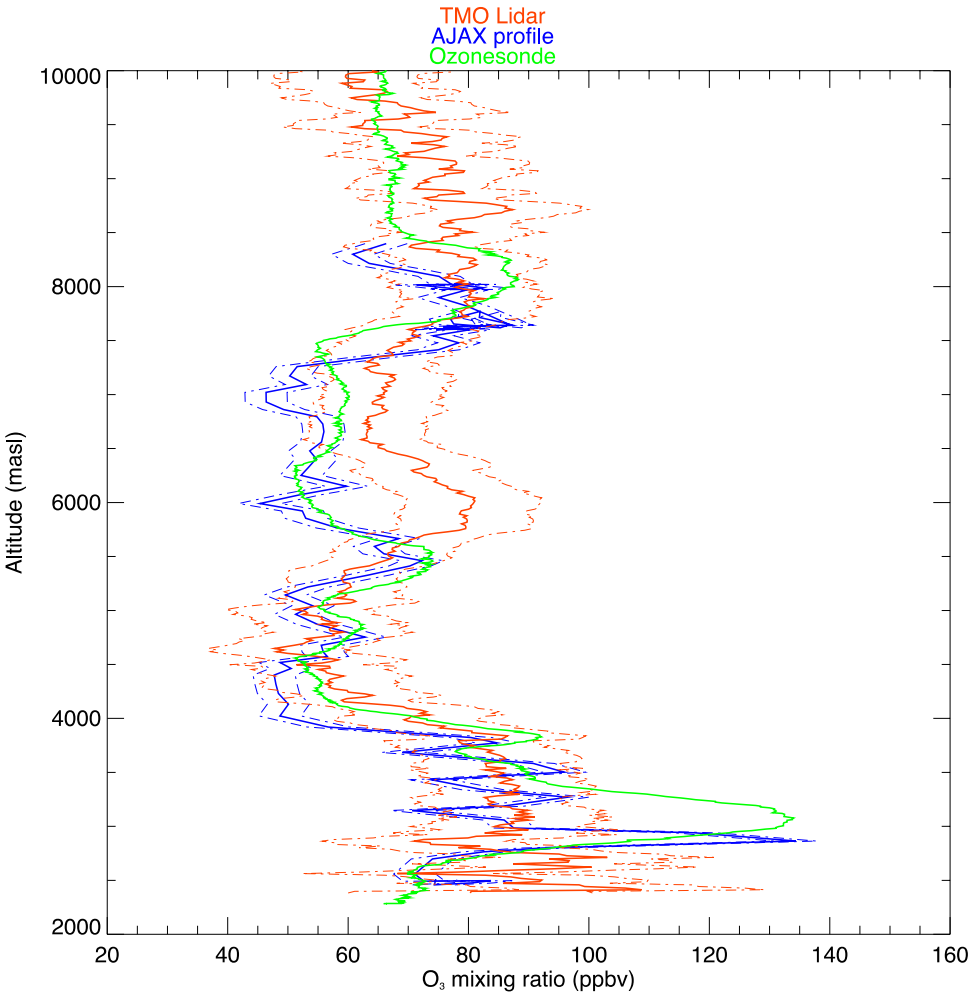
Ozone instrument

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

O_3 Instrument

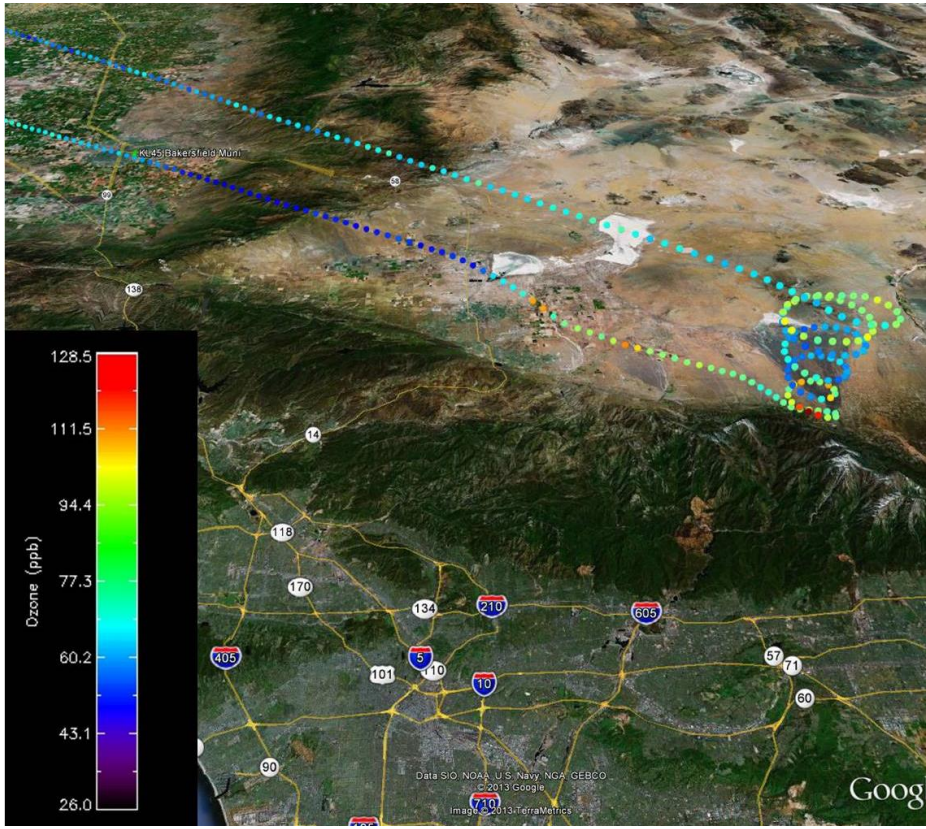
- Simultaneously measure differences between O_3-scrubbed air and un-scrubbed air.
- Air intake is Teflon tubing (perfluroalkoxy-polymer, PFA).
- Eight-point calibrations (ranging from 0 – 300 ppb) before and after each flight, referenced to WMO scale.
- Modifications: vibration isolators, UV lamp heaters,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

Ozone instrument comparisons



Moffett Field to JPL-Table Mountain

Lidar and Ozonesonde comparisons from LVOS campaign

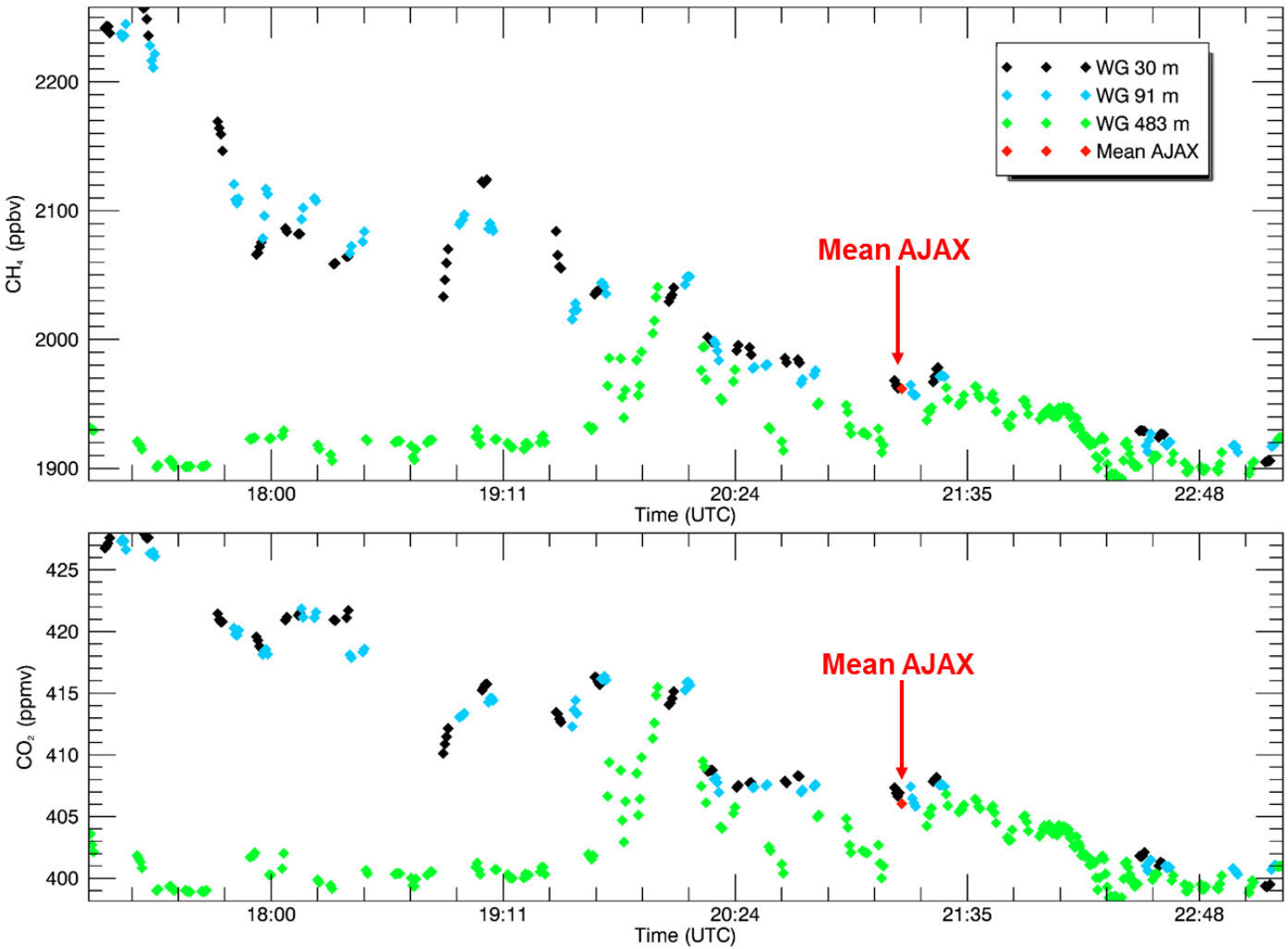


Greenhouse gas instrument

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.

GHG instrument comparisons



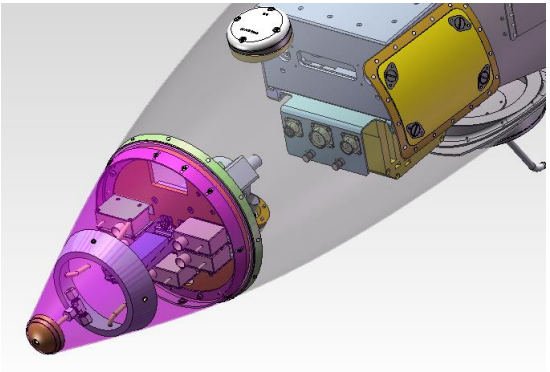
Circling around Walnut Grove Tower

Meteorological Measurement System (MMS)

Provides high-resolution pressure, temperature and 3D winds.

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:

INS/GPS system (SDN500)

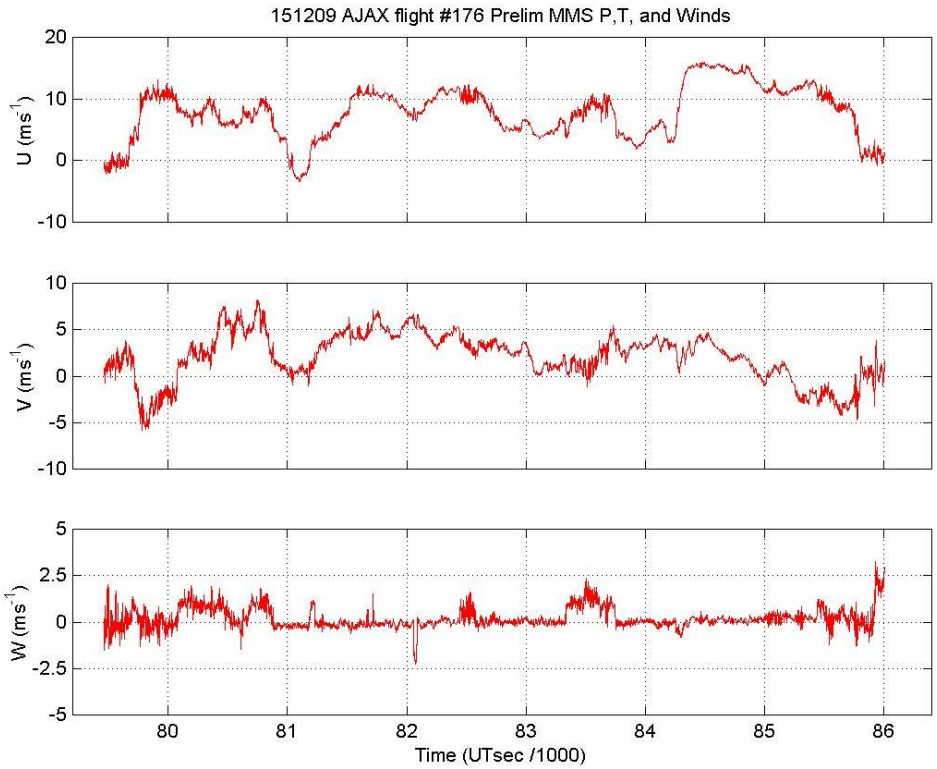
Fast Temperature Probe

Temperature Controllers

GPS L1/L2 Antenna

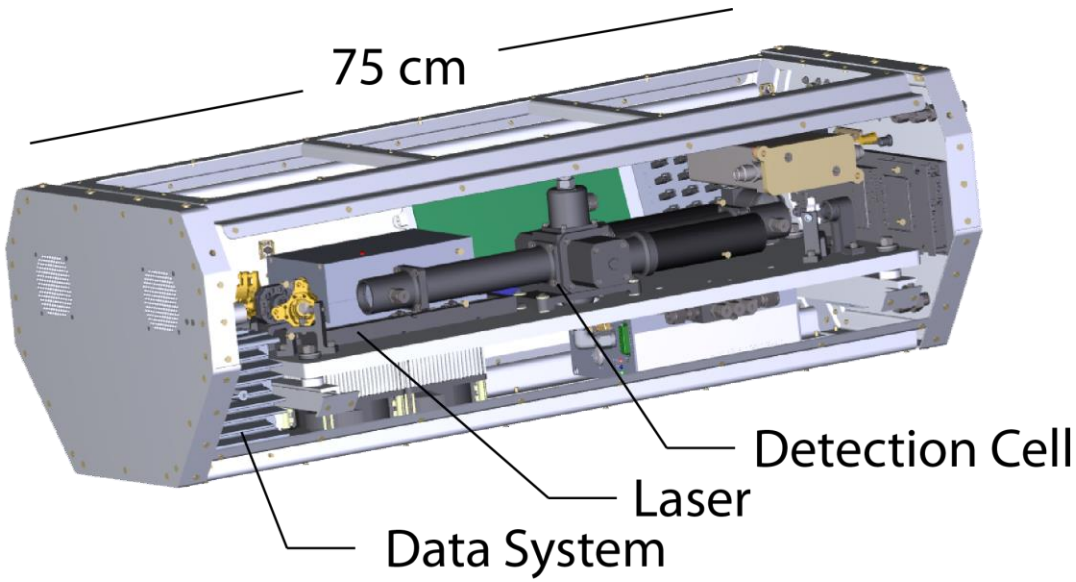
Digital Compass

Computer Enclosure Battery Pack



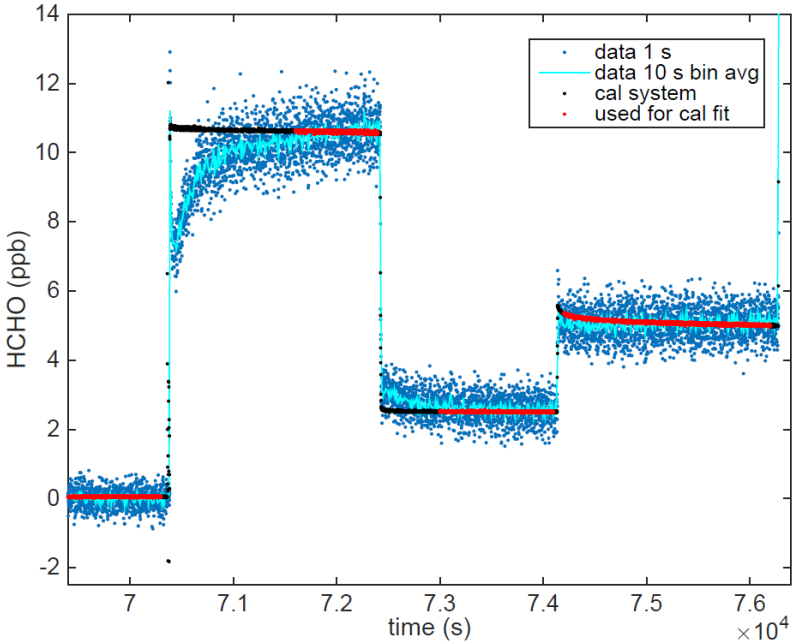
Formaldehyde instrument

COmpact Formaldehyde FluorescencE Experiment (COFFEE) was developed and built at NASA GSFC specifically for integration into a wing pod on the Alpha Jet at NASA ARC.



Instrument Characteristics

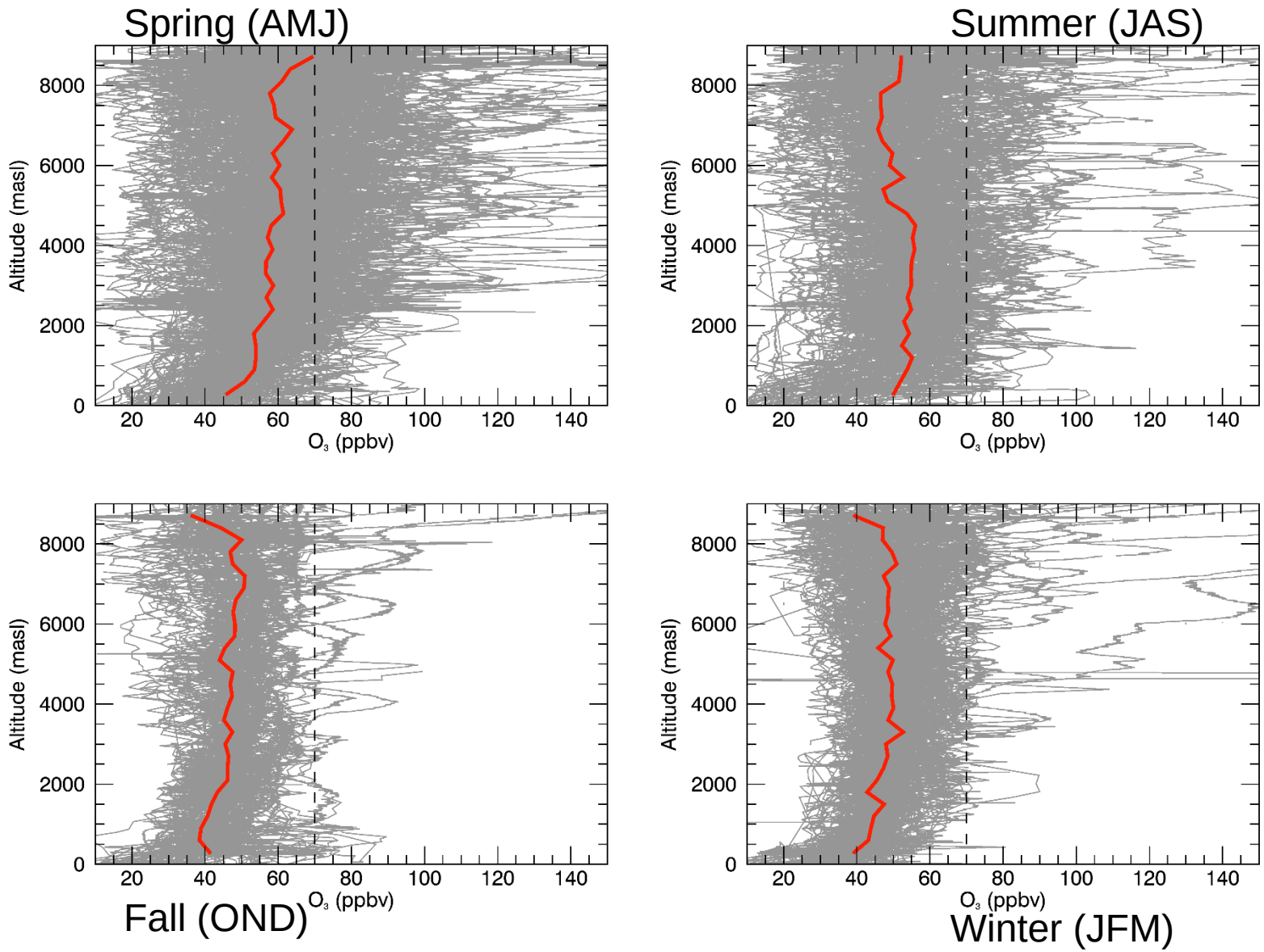
- Time response: < 1 sec
- Sensitivity: 100-150 pptv/1 sec
- Accuracy: +/-20%



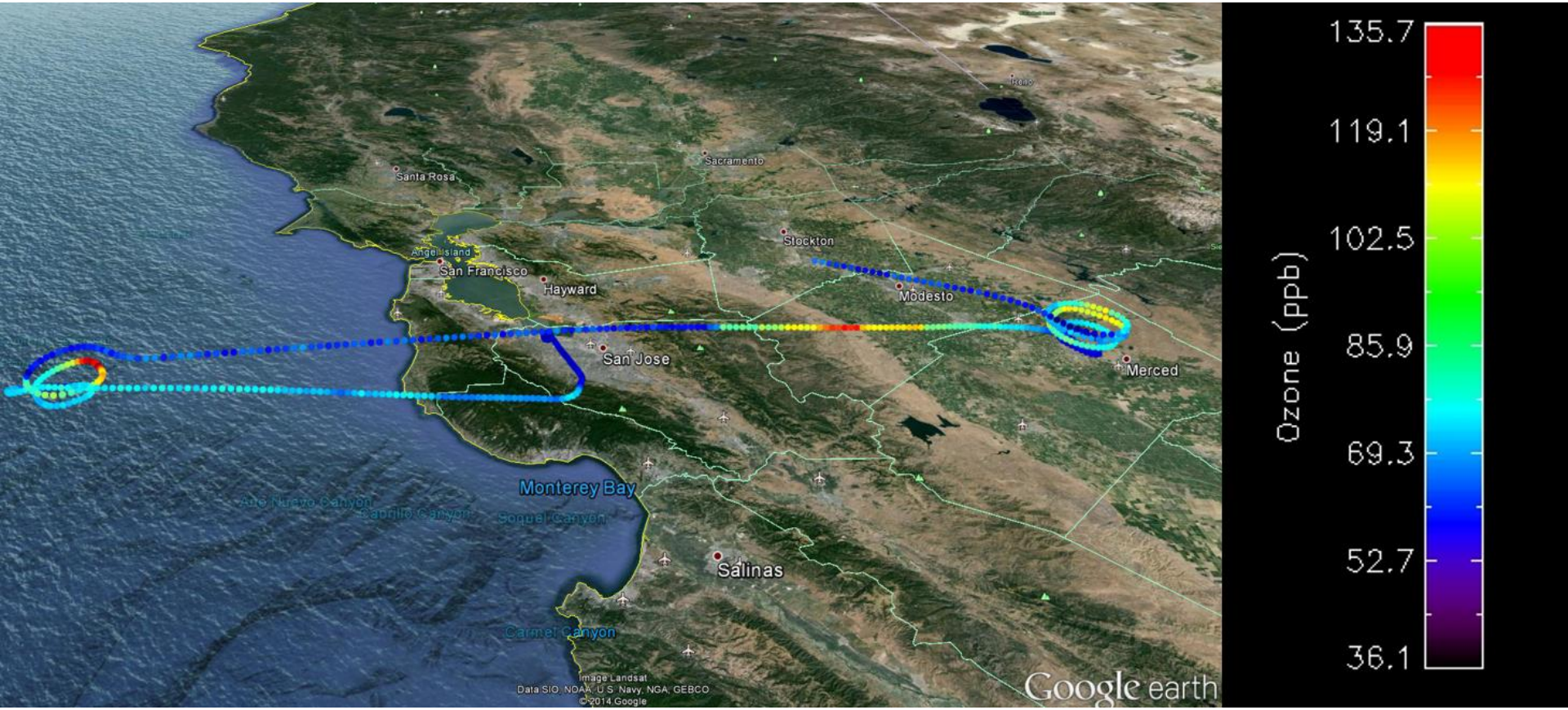
Where we fly

Klamath Mountains
Black Rock Desert
Great Sa
Nevada
Sierra Nevada Mountains
California
Los Angeles

Ozone flight data summary



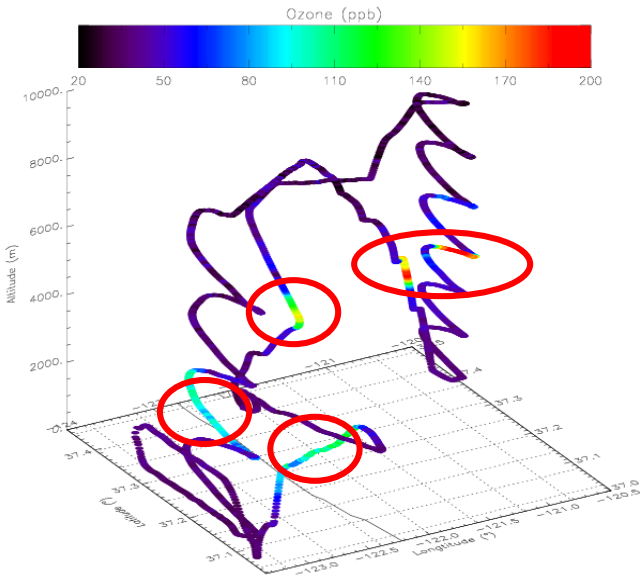
AJAX measured seasonal O_3 profiles (January 2011 – May 2015).



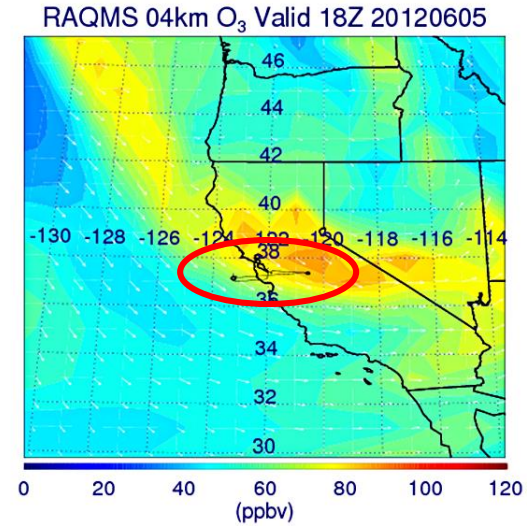
Identify Impacts of stratospheric air on surface air quality

1) AJAX samples filament of high ozone

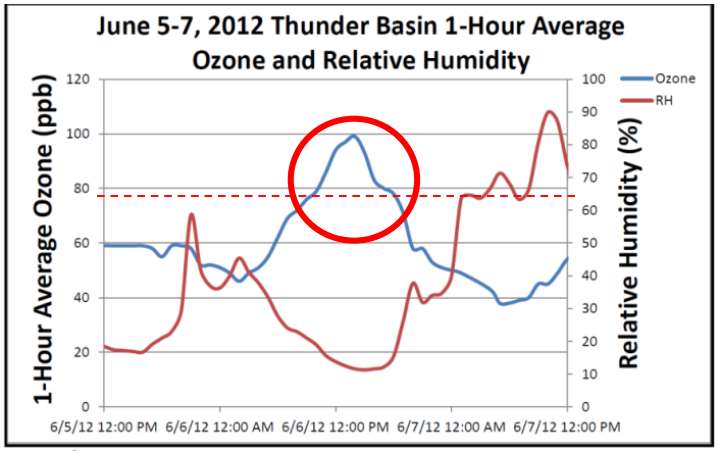
5 June 2012



*2) Modelled ozone indicates filament of stratospheric air descending into the troposphere**



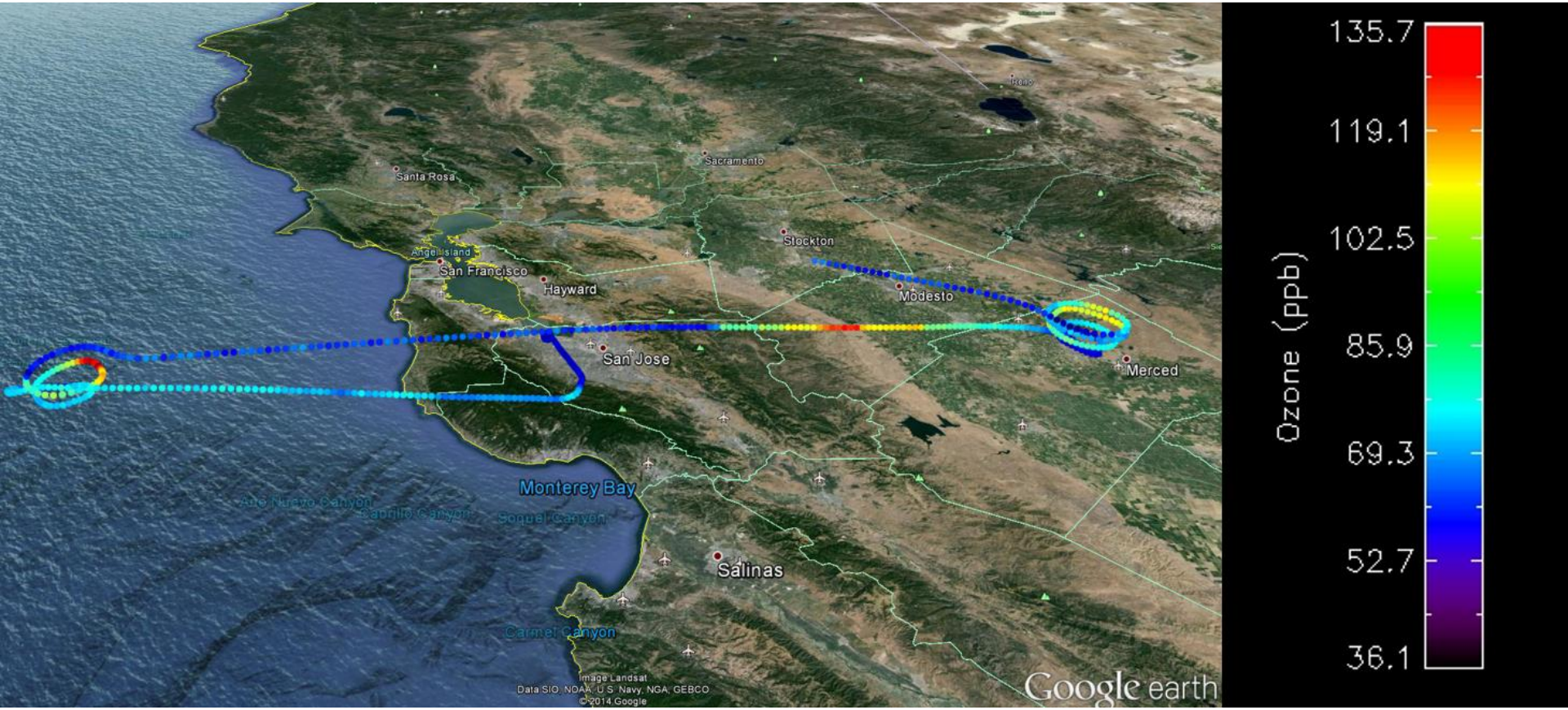
Wyoming State determined that a stratospheric intrusion created elevated ozone readings resulting in an ozone standard exceedance at the Thunder Basin, Wyoming on June 6, 2012



3) Ozone exceedances at Thunder Basin, WY

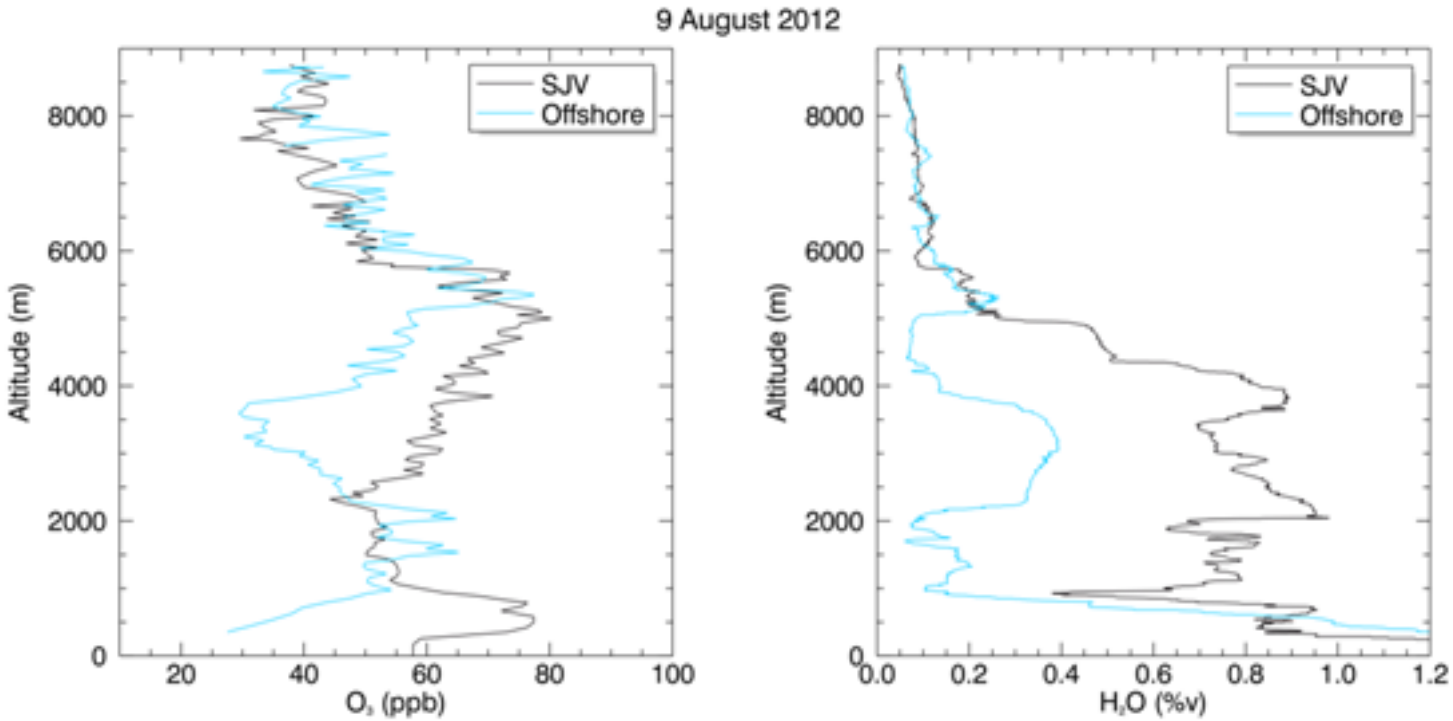
* Modelling conducted by Brad Pierce (NOAA/NESDIS)

Yates, E. L., et al., (2013) A.C.P., 13, 12481-12494, doi: 10.5194/acp-13-12481-2013.



1. Onshore-Offshore flights

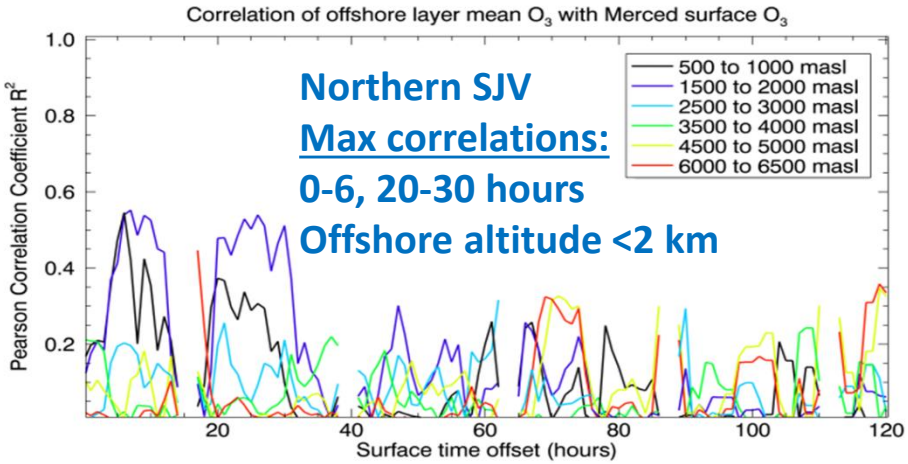
Comparing offshore and inland vertical profiles

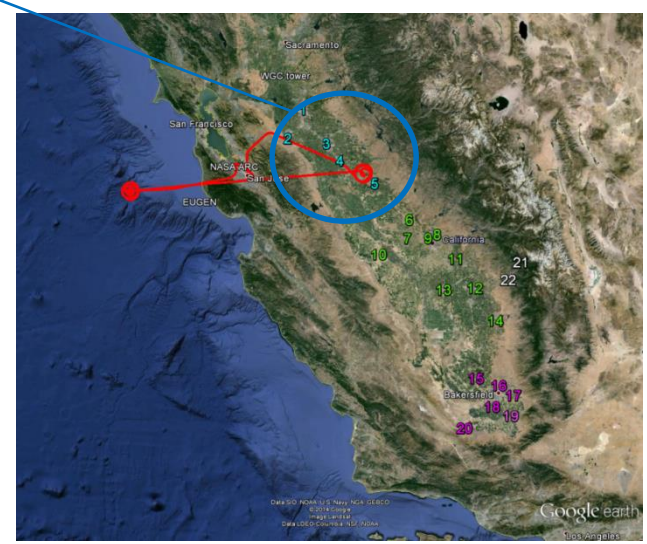


- Dobson Unit summation method (Cooper et al., 2011, doi: 10.1029/2011JD016095)
- **May-October:** Dobson Unit sum of O_3 below 2 km inland (SJV) exceeds that offshore by up to 21%, implying **net O_3 production over the SJV and/or vertical transport.**
- During extreme events (STT) **laminae of enhanced or depleted O_3 are observed** in the offshore and SJV profiles **at different altitudes**, demonstrating the scale of vertical mixing during transport.

Yates et al., (2015) Atmos. Environ., 109, 342-350, doi: 10.1016/j.atmosenv.2014.09.002

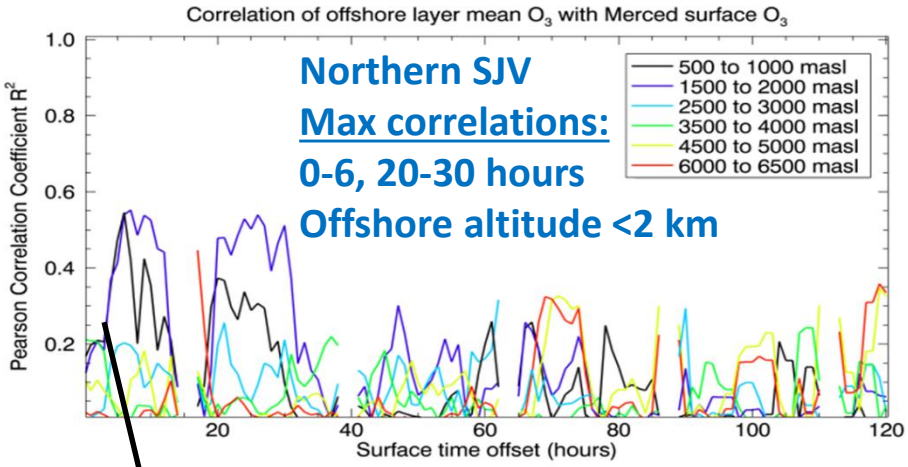
Correlations between offshore O_3 profile and SJV surface O_3

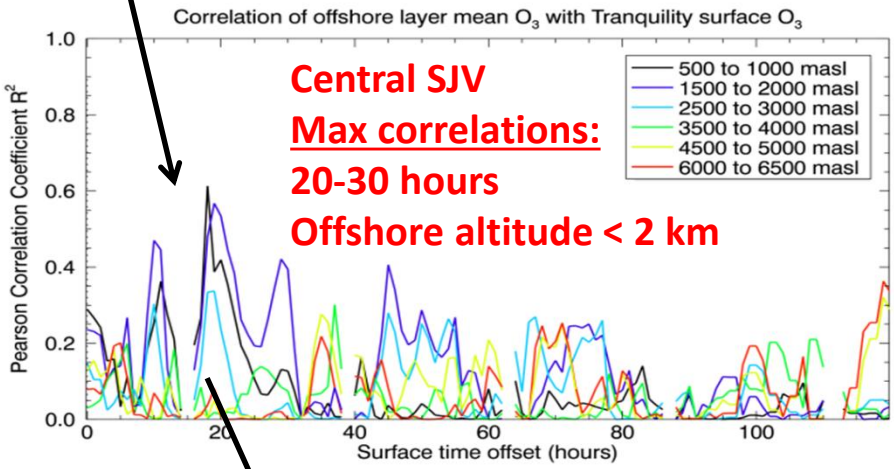


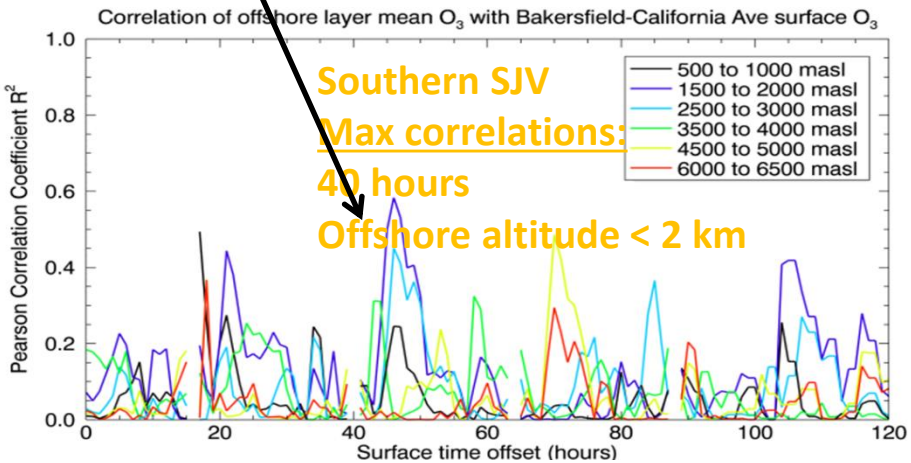


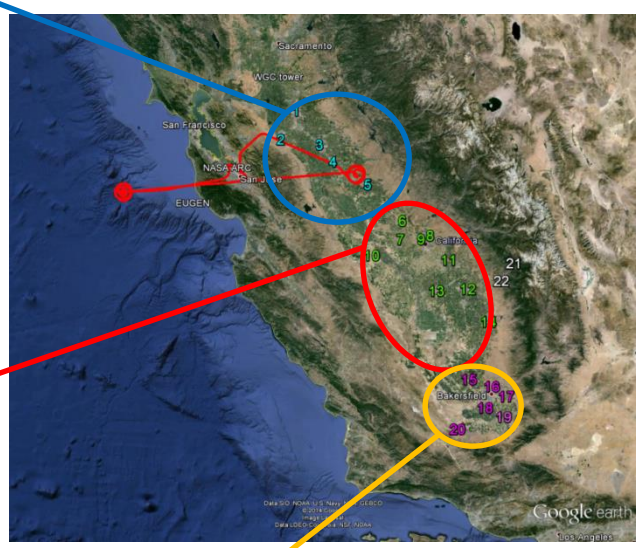
Correlation analysis method (Parrish et al., 2010, doi: 10.5194/acp-10-10093-2010)

Correlations between offshore O_3 profile and SJV surface O_3

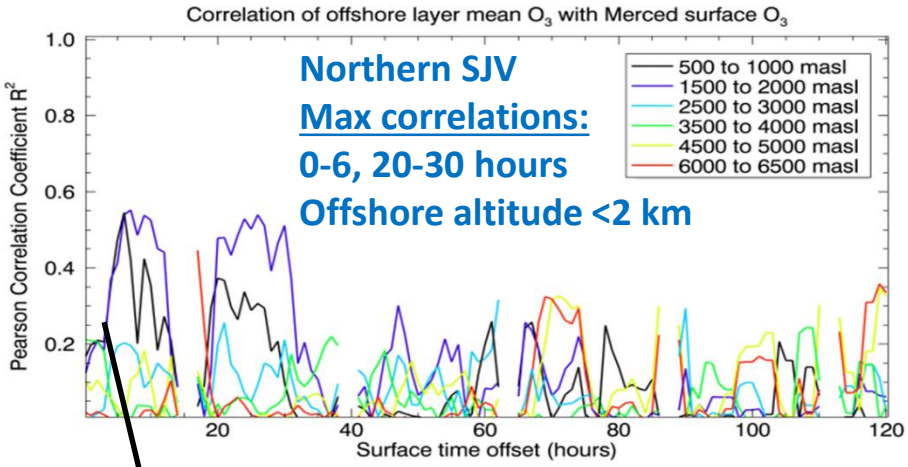


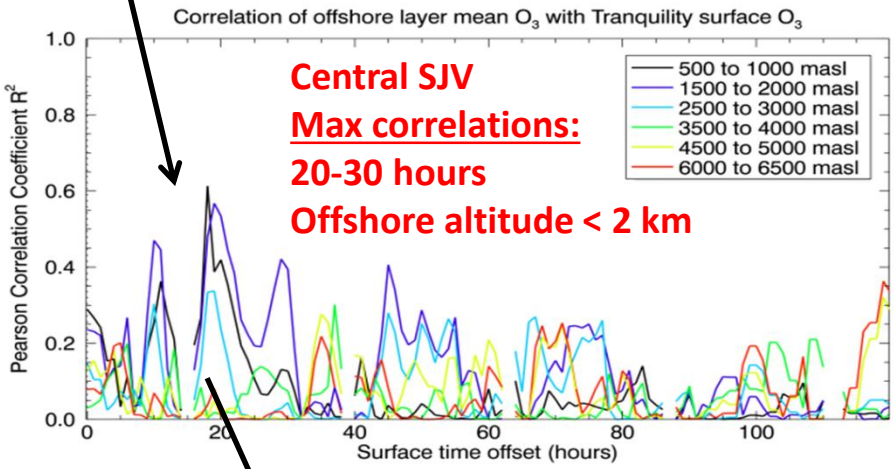


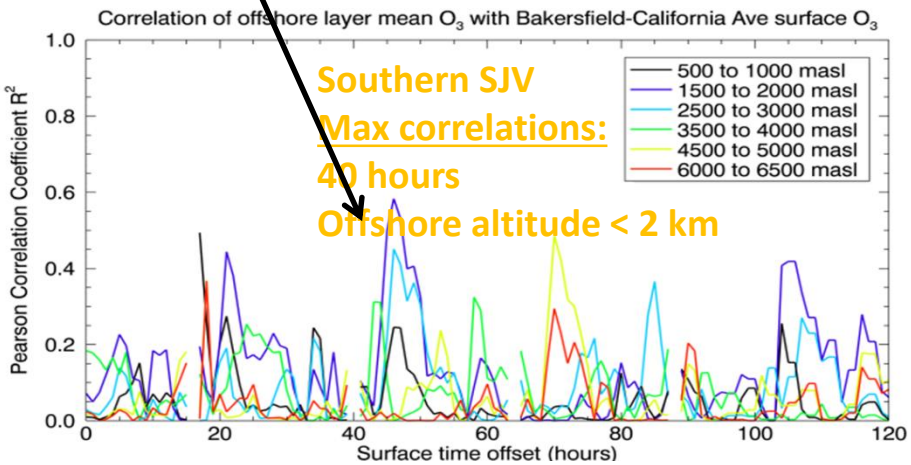


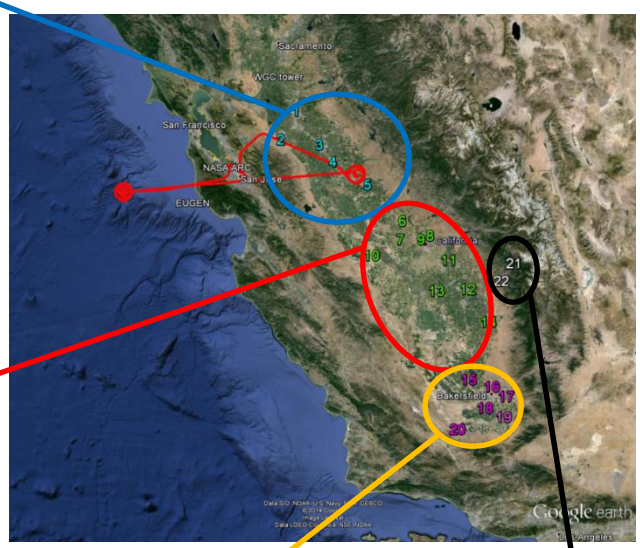


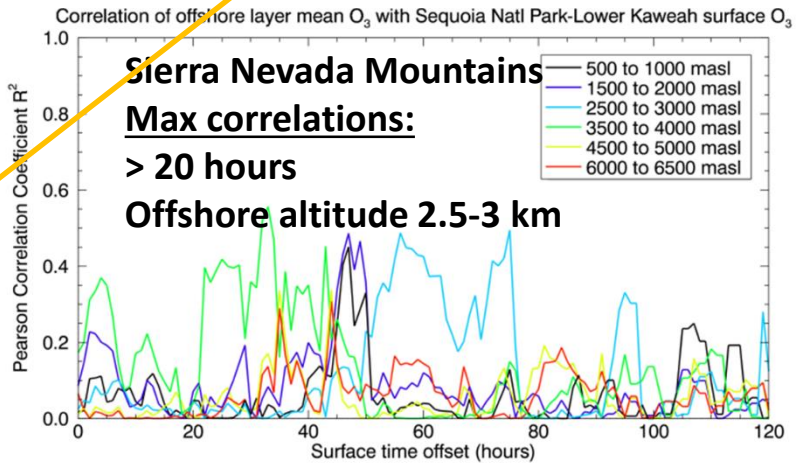
Correlations between offshore O_3 profile and SJV surface O_3





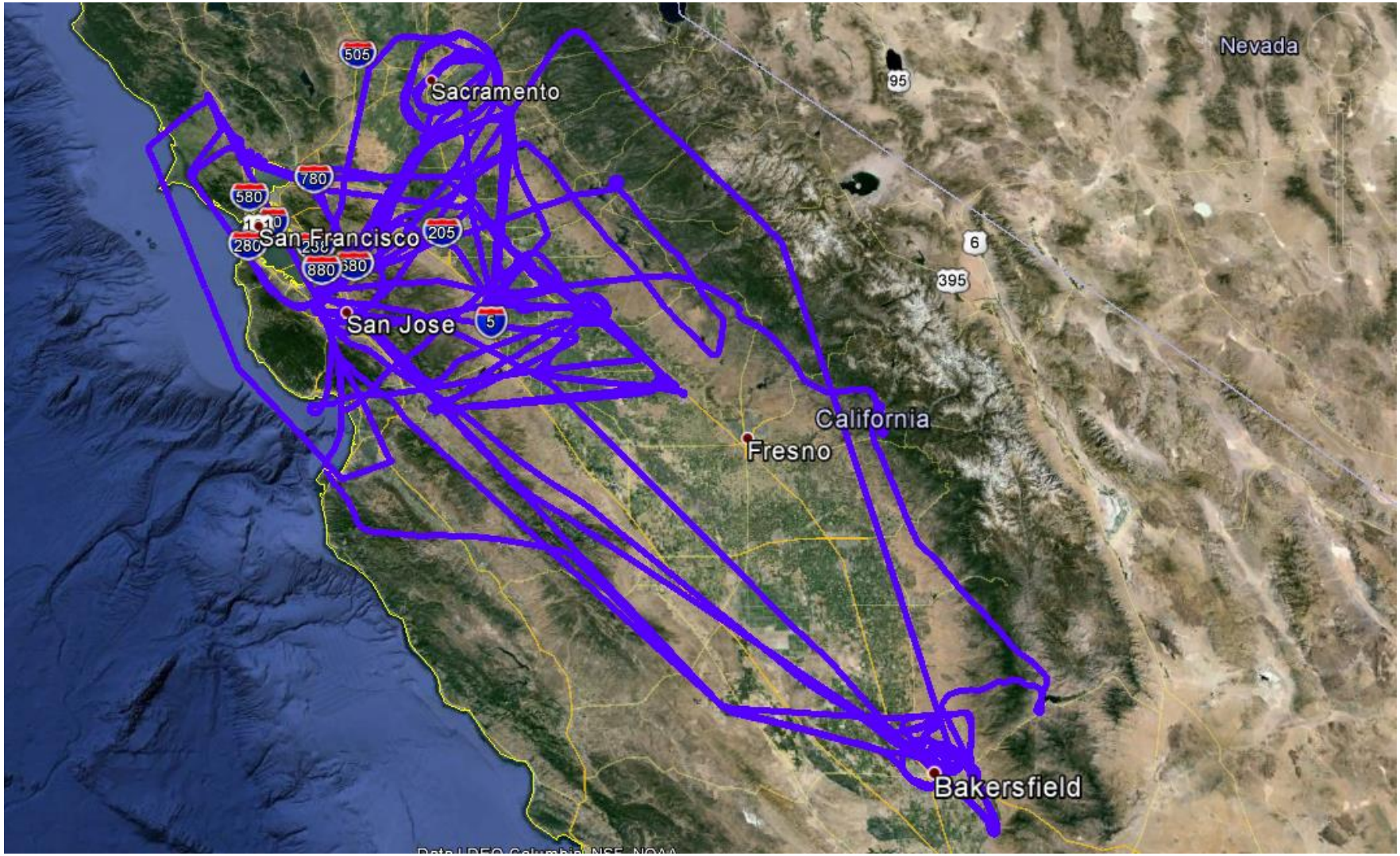




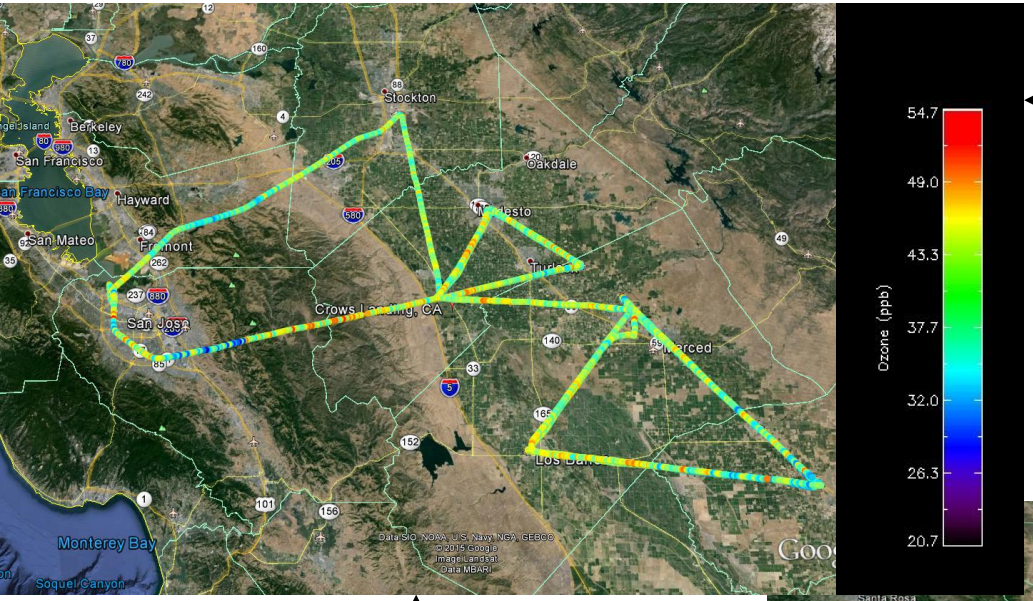


Profiling the San Joaquin Valley & San Francisco Bay Area boundary layer

Summarizing SJV & SFBA flights

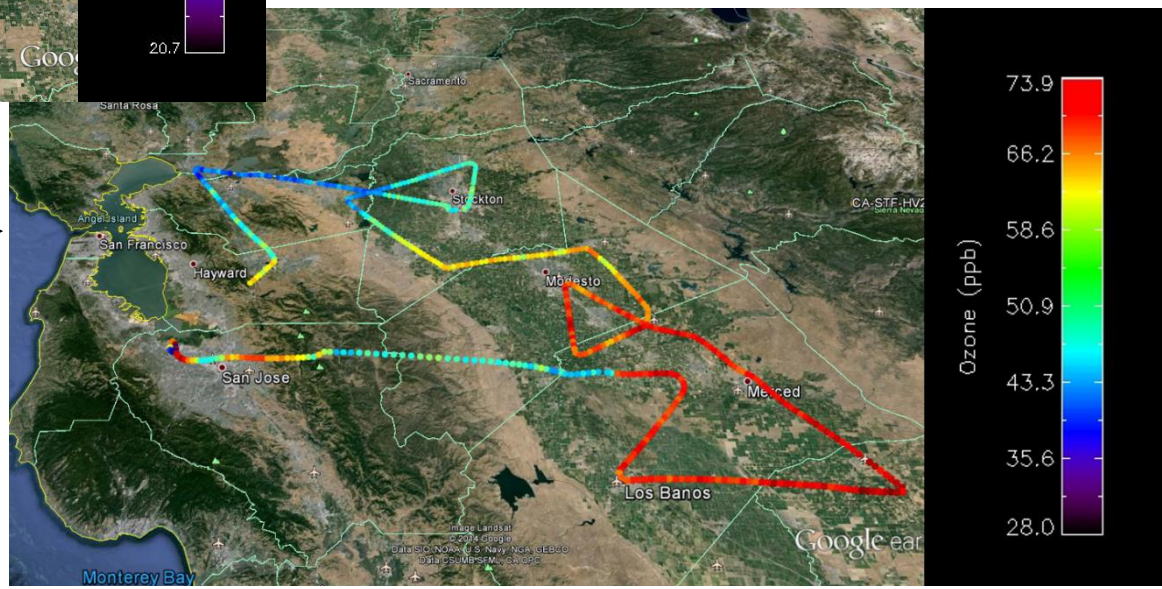


Comparing boundary layer flights



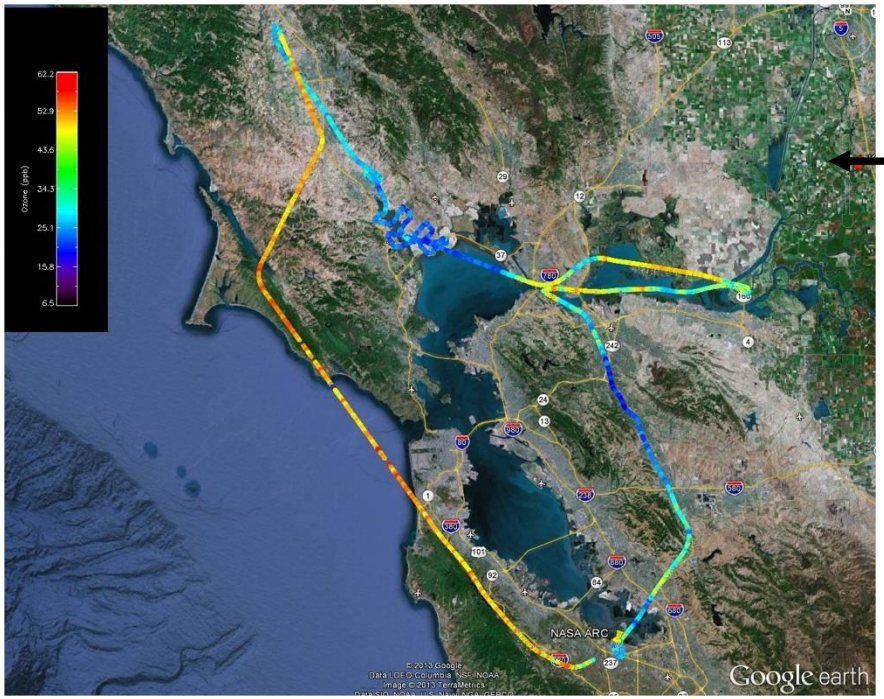
- **Jan 2013** (during DISCOVER-AQ-CA): well-mixed O_3.
- **Nov 2014:** latitudinal gradient down SJV (Stockton=less O_3, Madera=more O_3).

Daily Max	28-Jan-13	10-Nov-14
San Jose	33	35
Stockton	37	49
Modesto	34	62
Merced	31	67
Madera	35	67



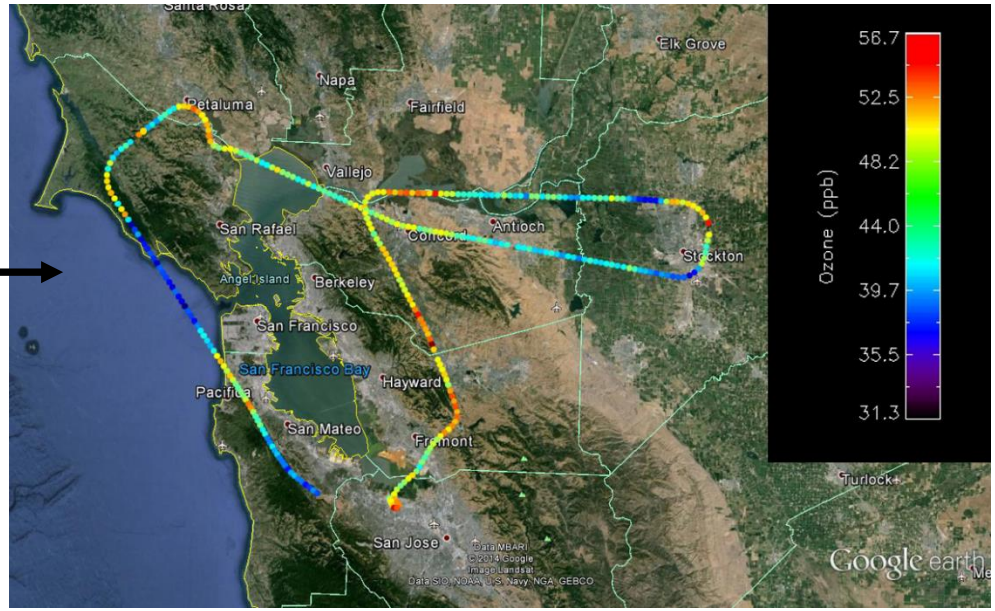
CH$_4$ analysis: Johnson, M.S. et al., 2014, Atmos. Environ., 99, 2014, doi: 10.1016/j.atmosenv.2014.09.068.

SFBA outflow



- **Offshore flow:** Offshore O_3 20-30 ppb higher than inland, elevations also in Carquinez Strait.

- **Onshore flow:** O_3 enhancements of 15-20 ppb higher than "offshore background"

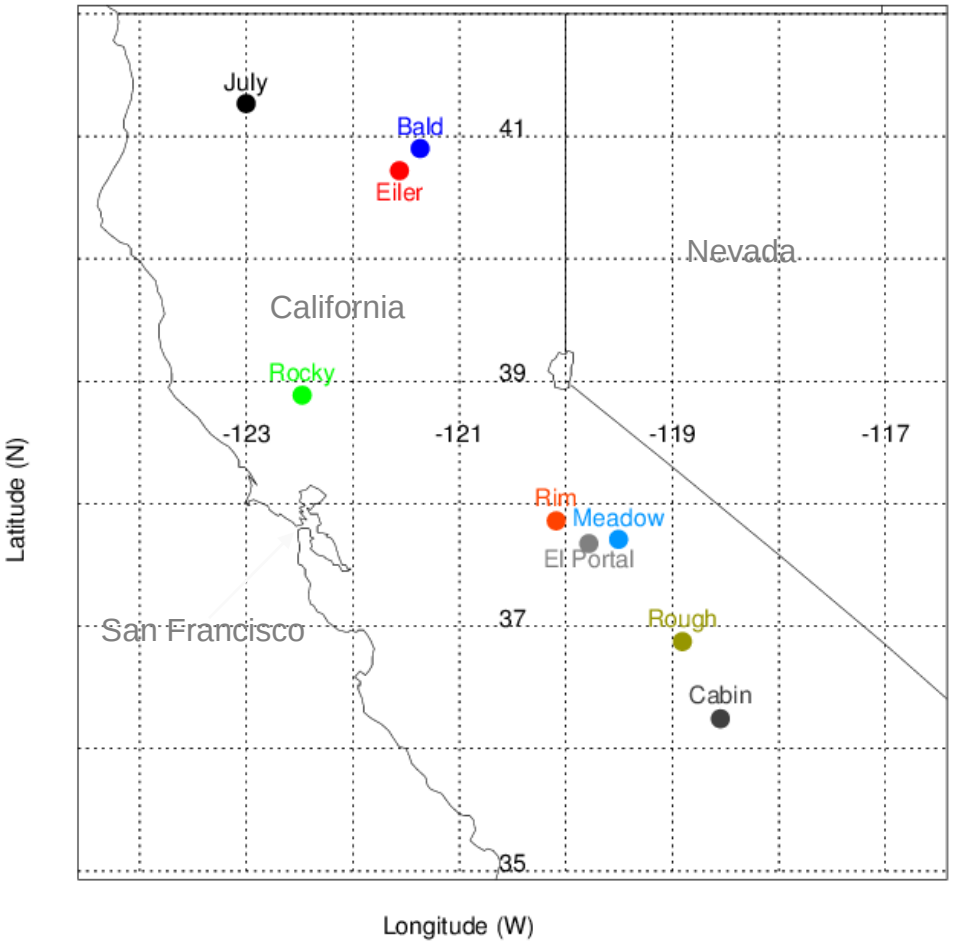


CH_4 analysis: Johnson, M.S. et al., 2014, Atmos. Environ., 99, 2014, doi: 10.1016/j.atmosenv.2014.09.068.

Rim Fire, 19 August 2013, north of Yosemite (Bear Valley)

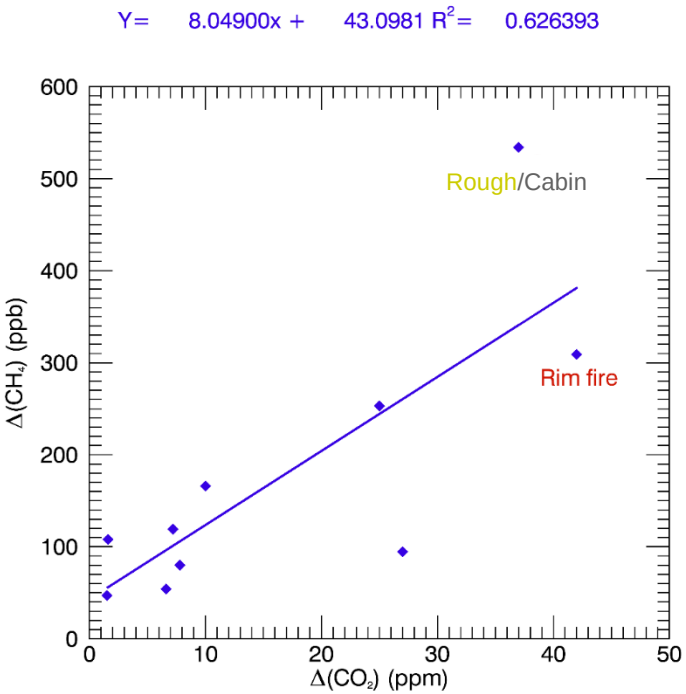
Sampling emissions from forest fires

Targeted wildfire flights



- Excess mixing ratio compared to background: $\Delta X = X_{plume} - X_{bkgd}$
- Rough/Cabin (19 Aug 2015) and Rim (29 Aug 2013): largest CH_4 and CO_2 emissions

	Rim Fire		El Portal	Eilder/Bald	July Complex	Meadow		Rocky	Rough	
	29-Aug-13	10-Sep-13	29-Jul-14	6-Aug-14	13-Aug-14	09-Sep-14	16-Sep-14	5-Aug-15	19-Aug-15	2-Sep
Size or fire (acres)	199237	255146	3060	39926	16991	4434	4772	69600	32414	79973
% containment	32	80	19	68	29	10	80	30	3	25

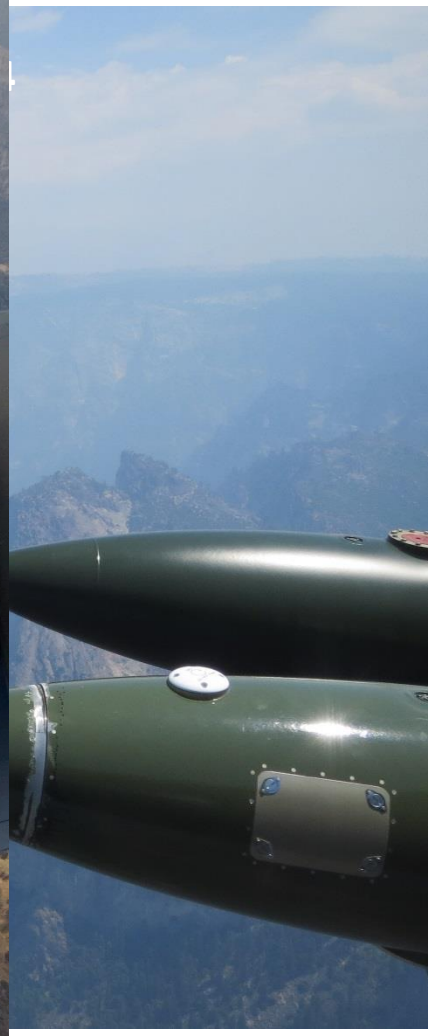


Courtesy Rob Simone

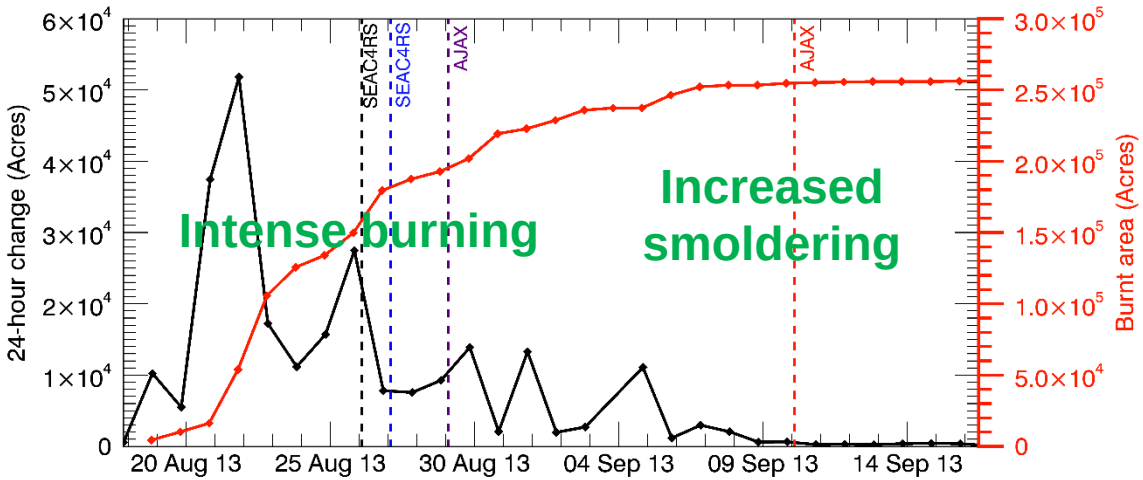
Rim Fire – 29 August 2013

El Portal Fire – 29 July 2014

Rough Fire – 19 August 2015



Rim Fire: Emissions vs time

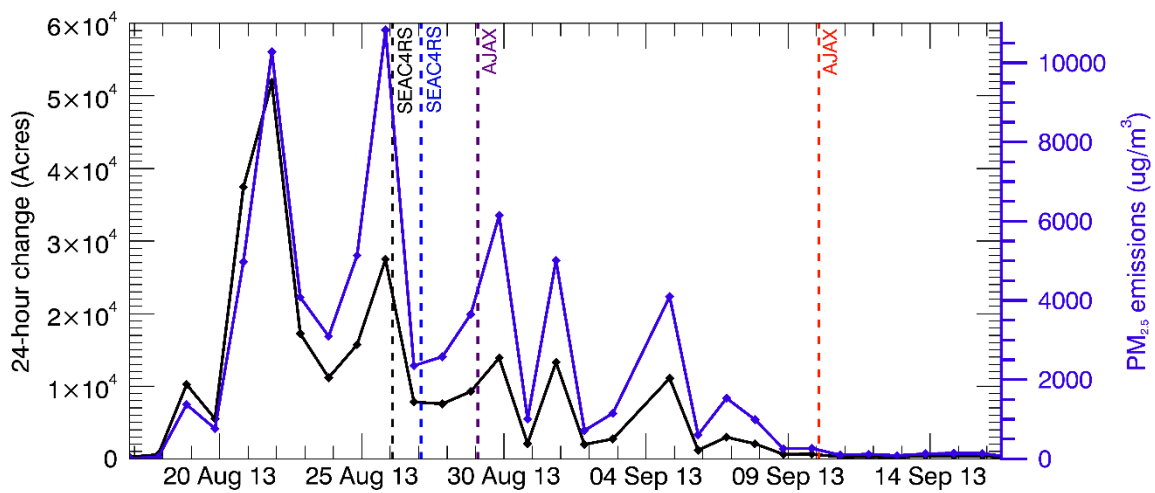


4 flights (SEAC^{4}RS & AJAX):

- 3 during intense burning period
- 1 during increased smoldering period

Peak emissions* not coincident with **peak acreage burnt:**

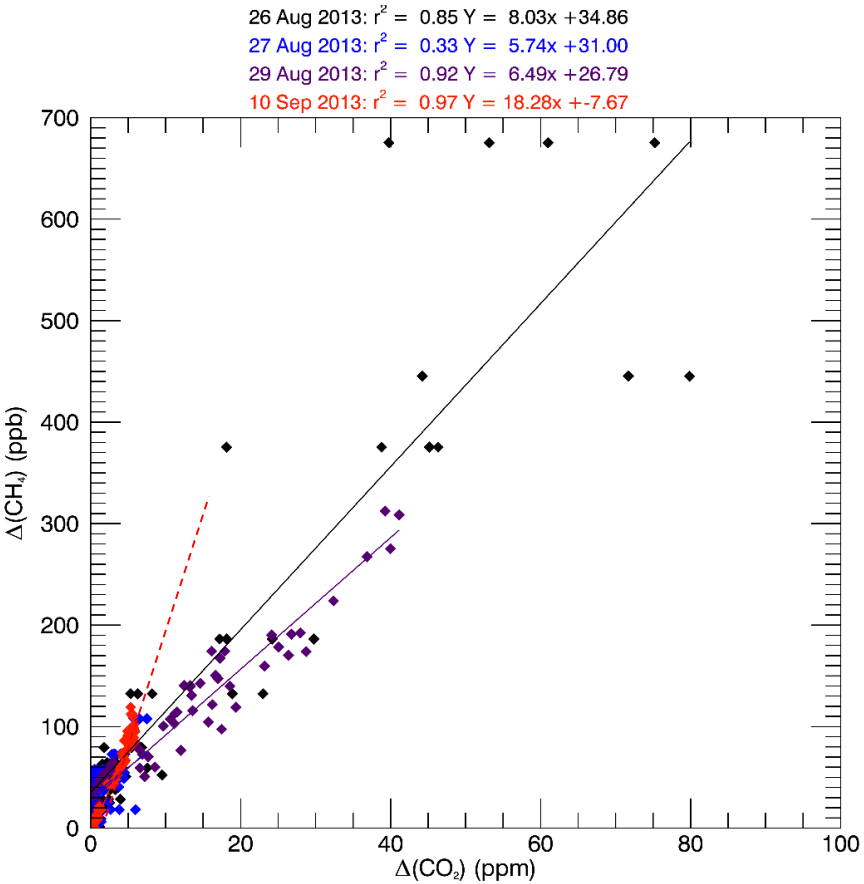
- **22 Aug: $PM_{2.5}$/Acres = 0.2 ug m^{-3} Acre^{-1}**
- **26 Aug: $PM_{2.5}$/Acres = 0.4 ug m^{-3} Acre^{-1}**



* Smoke Emission Estimation (EES) model

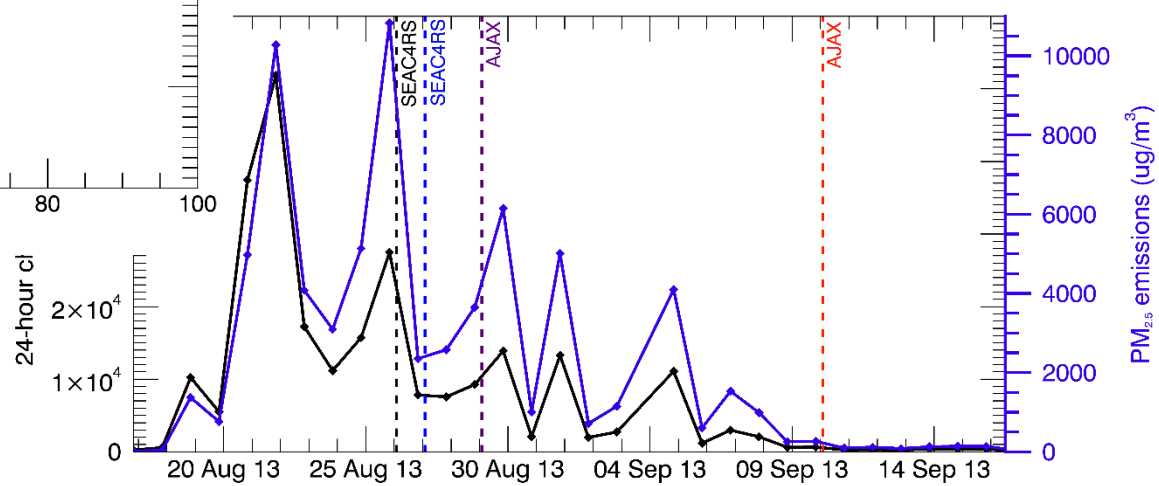
E.L. Yates, et al., 2016, Atmos. Environ., In Press, doi:10.1016/j.atmosenv.2015.12.038.

Rim Fire: GHG emissions



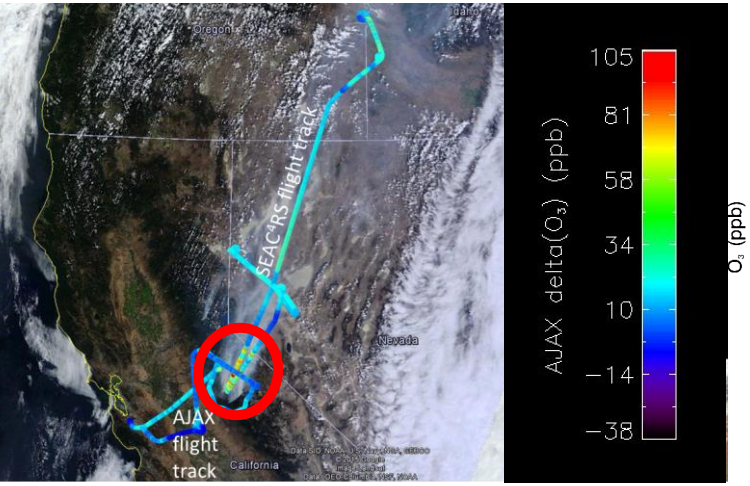
Aircraft data:

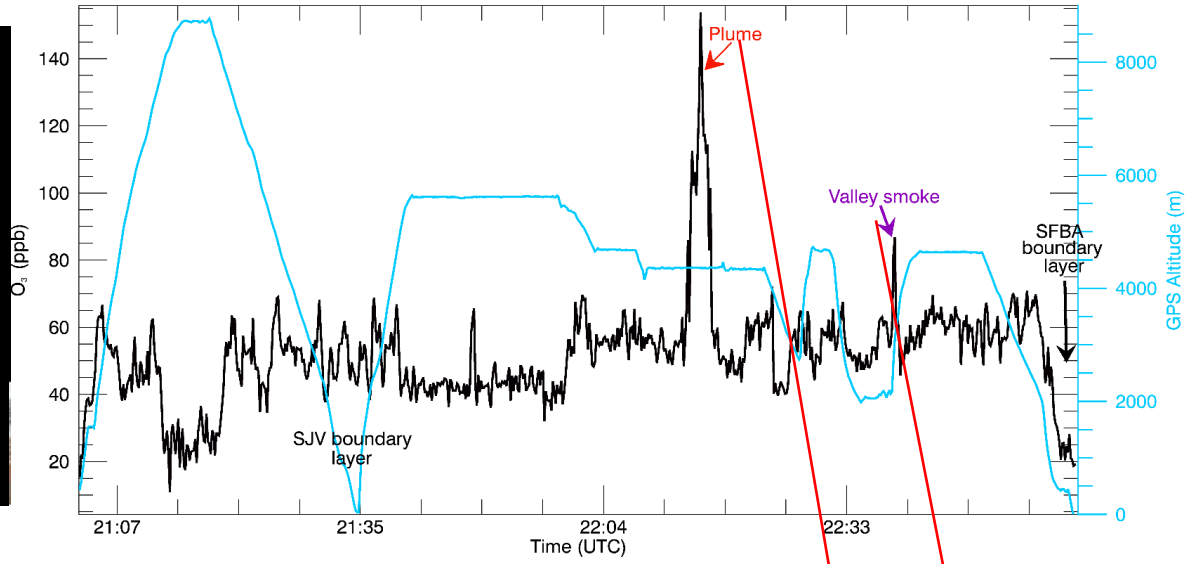
- Highest enhancements **26 Aug**
- Fresh emissions **26 & 29 Aug**
- Aged emissions on **27 Aug**
- Increased CH_4 emission ratio during **increased smoldering**

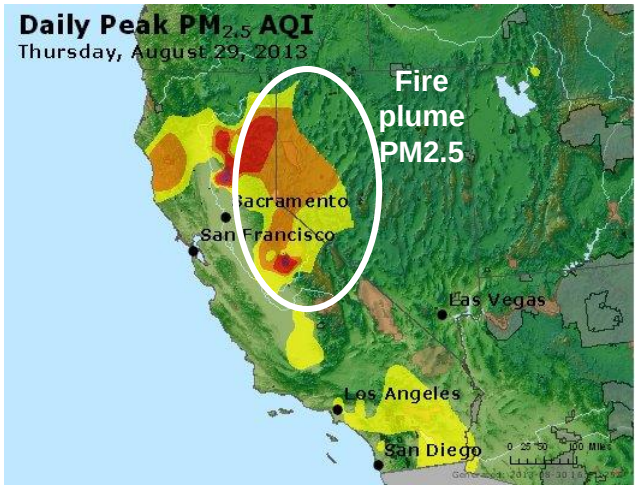


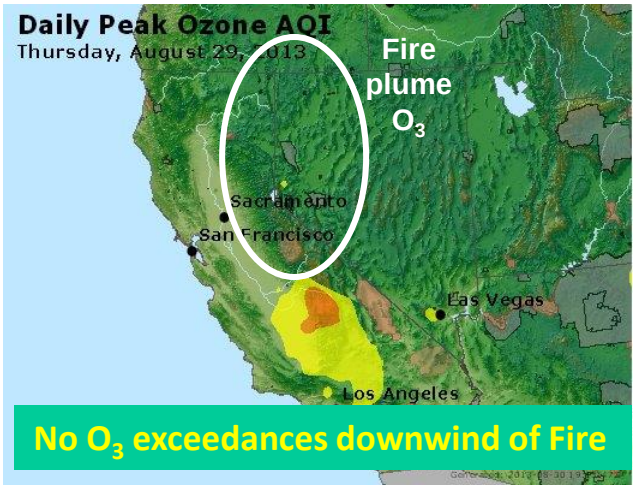
E.L. Yates, et al., 2016, Atmos. Environ., In Press, doi:10.1016/j.atmosenv.2015.12.038.

Rim fire: High ozone within plume not observed at surface sites

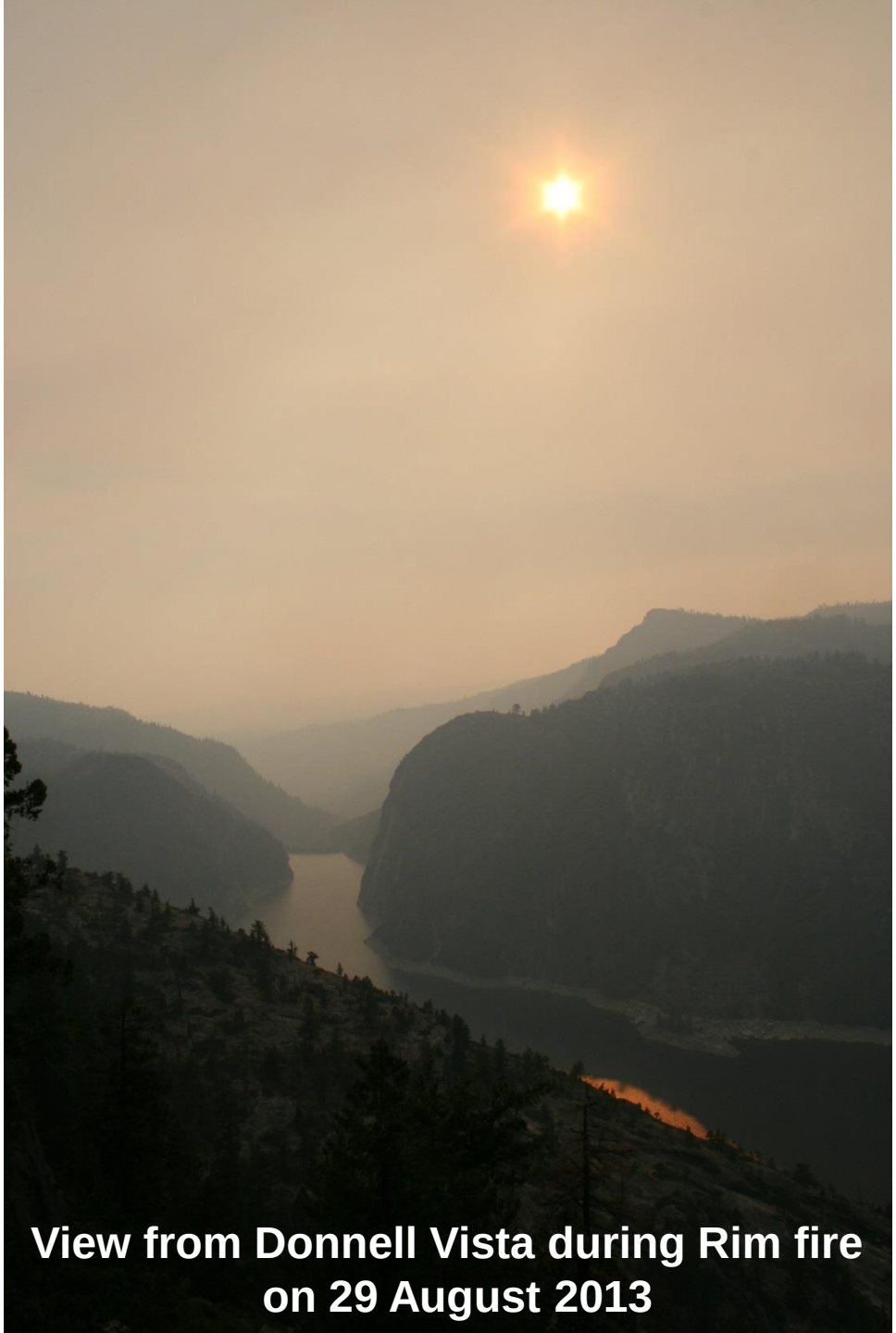








E.L. Yates, et al., 2016, Atmos. Environ., In Press, doi:10.1016/j.atmosenv.2015.12.038.



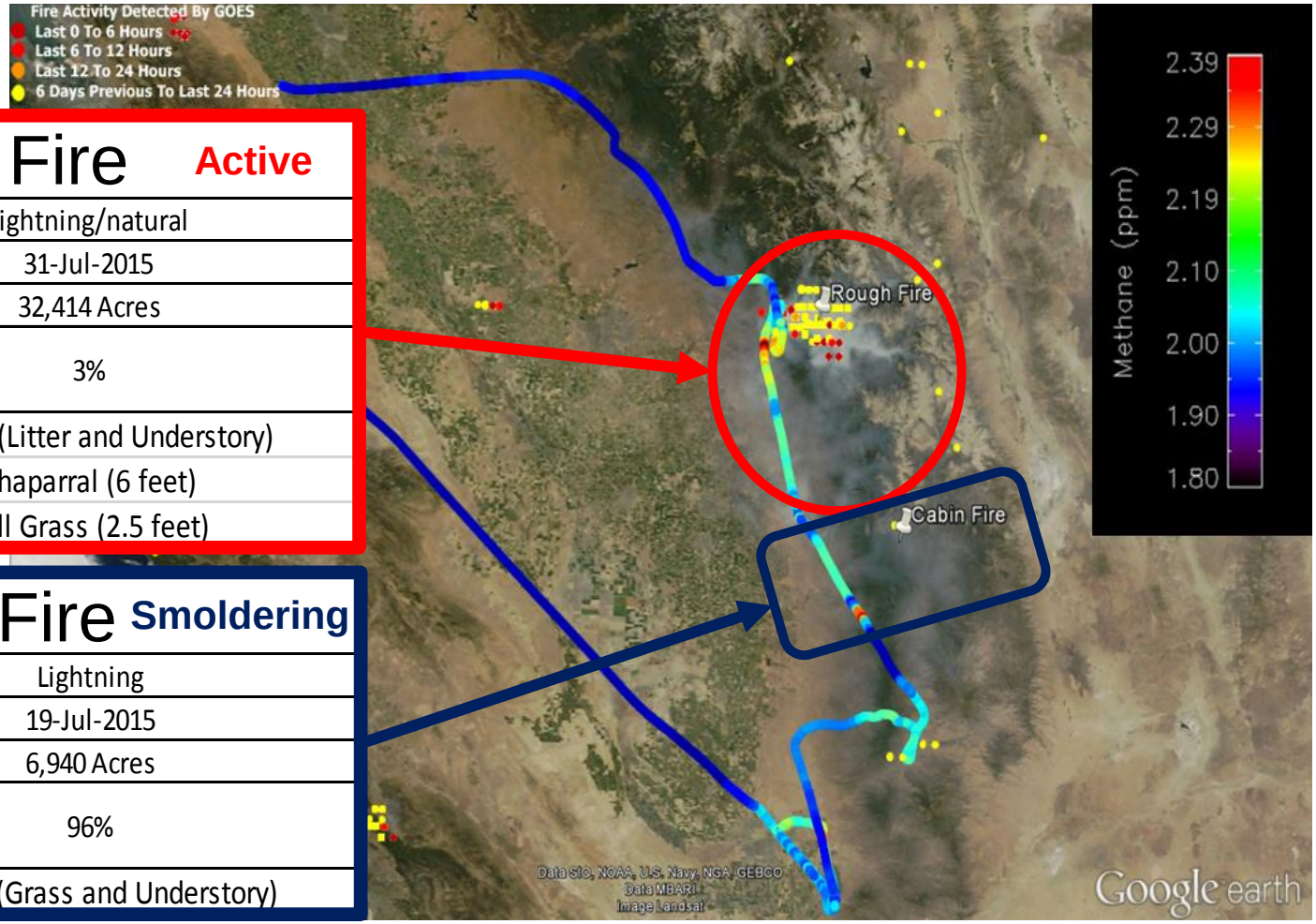
View from Donnell Vista during Rim fire on 29 August 2013

Courtesy Matt Roby

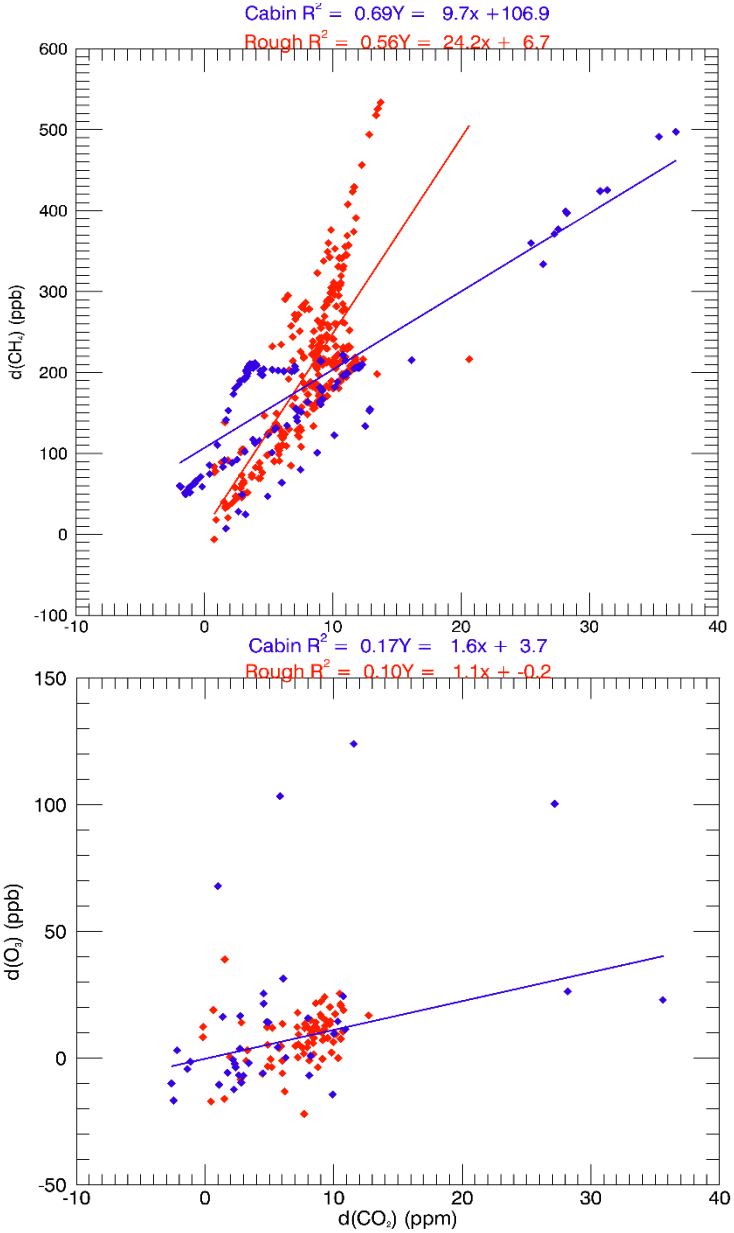
Rough & Cabin fires: 19 August 2015

Rough Fire **Active**	
Cause	Lightning/natural
Date of Origin	31-Jul-2015
Size	32,414 Acres
Percent of Perimeter Contained	3%
Fuels Involved	Timber (Litter and Understory)
	Chaparral (6 feet)
	Tall Grass (2.5 feet)

Cabin Fire **Smoldering**	
Cause	Lightning
Date of Origin	19-Jul-2015
Size	6,940 Acres
Percent of Perimeter Contained	96%
Fuels Involved	Timber (Grass and Understory)



Rough/Cabin fires: Comparing ratios



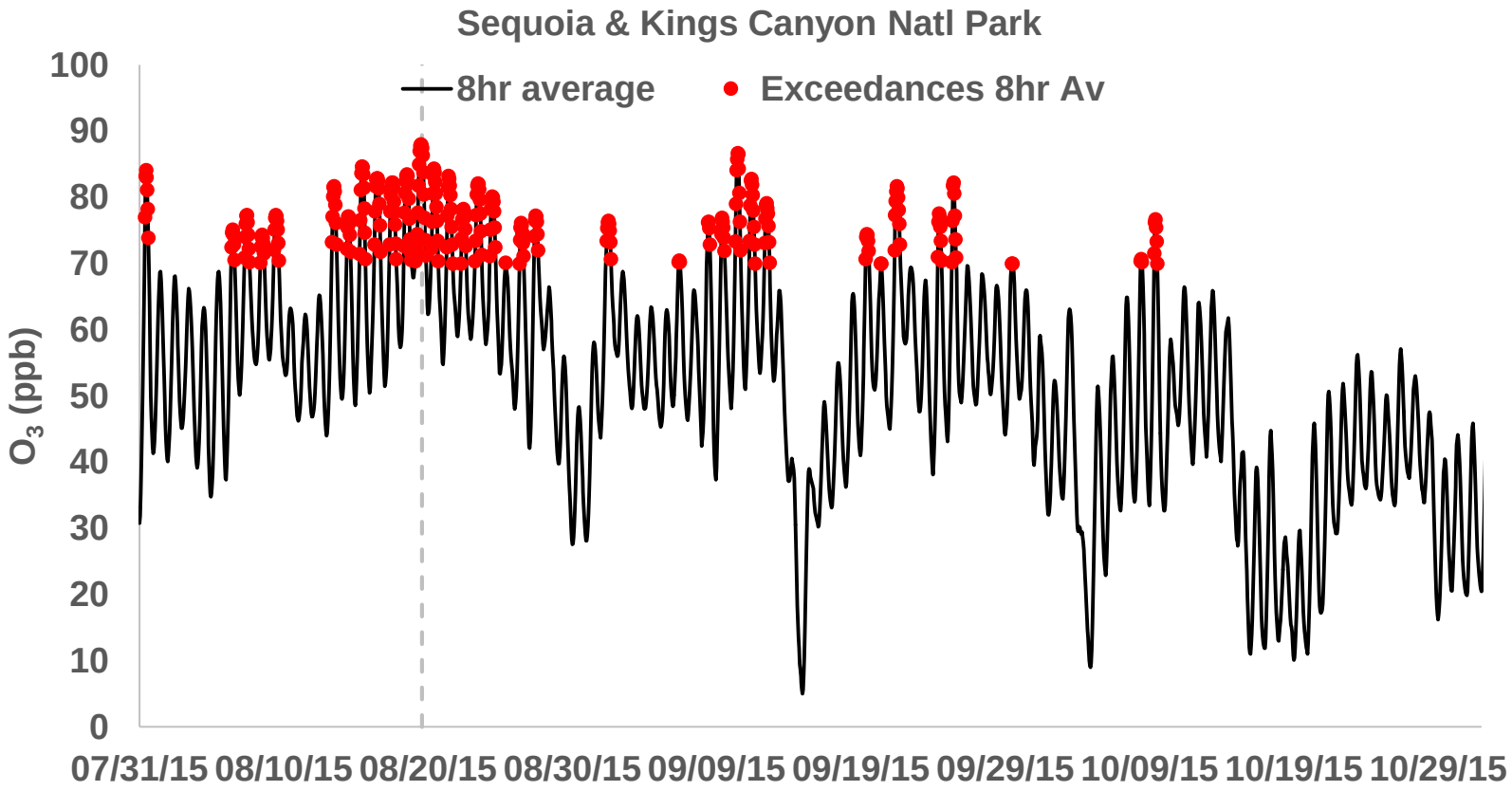
Smoke surrounding the Rough fire has highest emission ratio for CH_4 (relative to CO_2) observed by AJAX from wildfires: 24 ppb CH_4 per ppm CO_2.

Previous night, smoke settled into San Joaquin Valley, stagnant conditions during flight = likely mixture of urban/agriculture and fire emissions.

Smoke around the Cabin fire has more overall CO_2 & O_3 than that surrounding the Rough fire.

Both fire regions have similar emission ratios for O_3 (relative to CO_2) and indicate O_3 production.

Rough/Cabin fires: Impacts on air quality

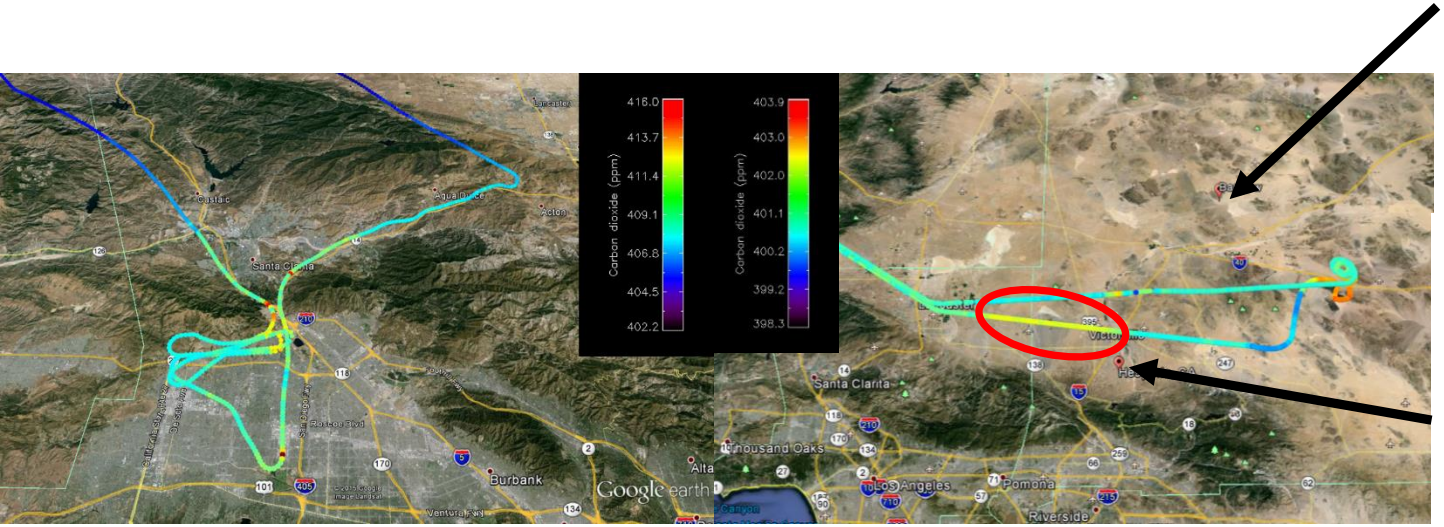


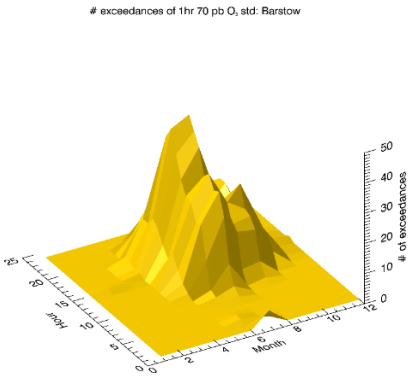
O_3 & $PM_{2.5}$ near Rough fire – SJV impacted for prolonged period

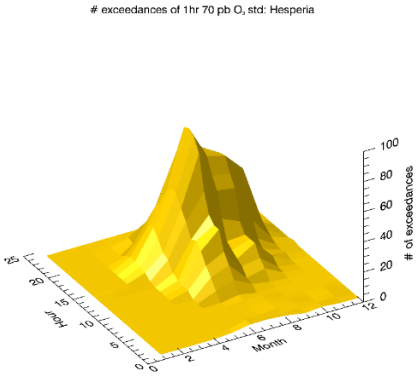
Current & future plans: Sampling LA outflow to Mojave desert

R. (Tony) VanCuren / Atmospheric Environment 109 (2015) 331–341

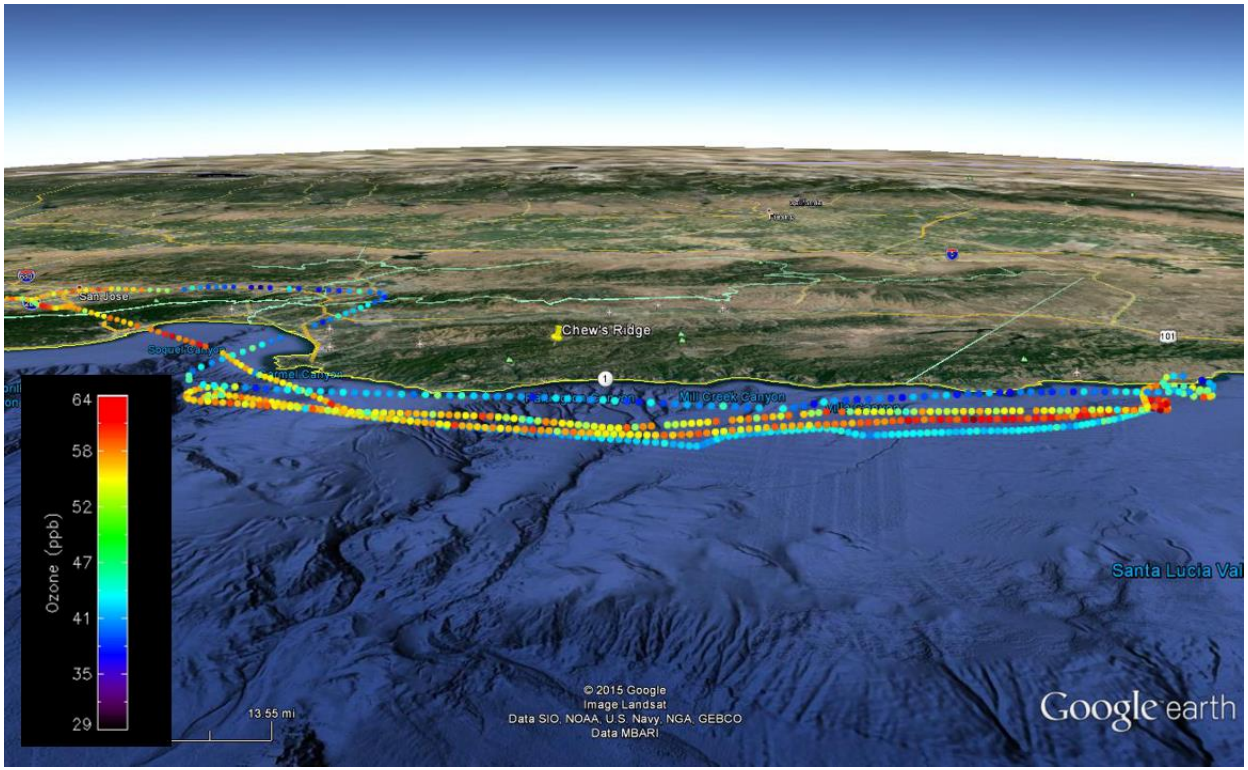
- LA & SJV have large pollution impacts downwind in Mojave.
- 4 AJAX flights to date (including Aliso Canyon CH_4 sampling).
- Working with Tony VanCuren to plan flights this summer.



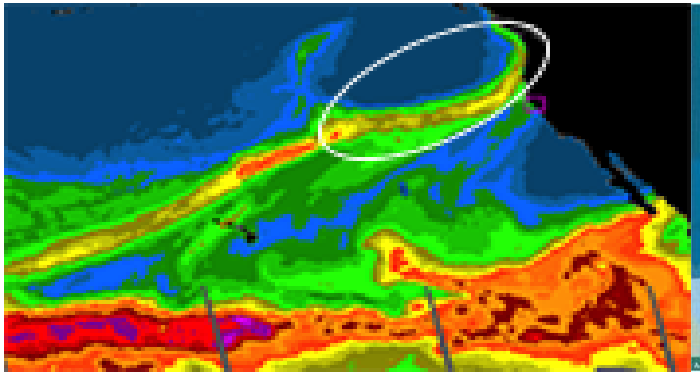


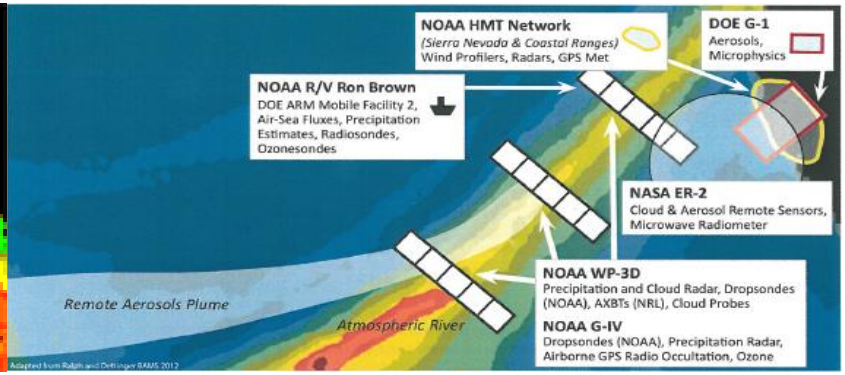


Current & future plans: Capturing the coastal barrier jet during atmospheric rivers

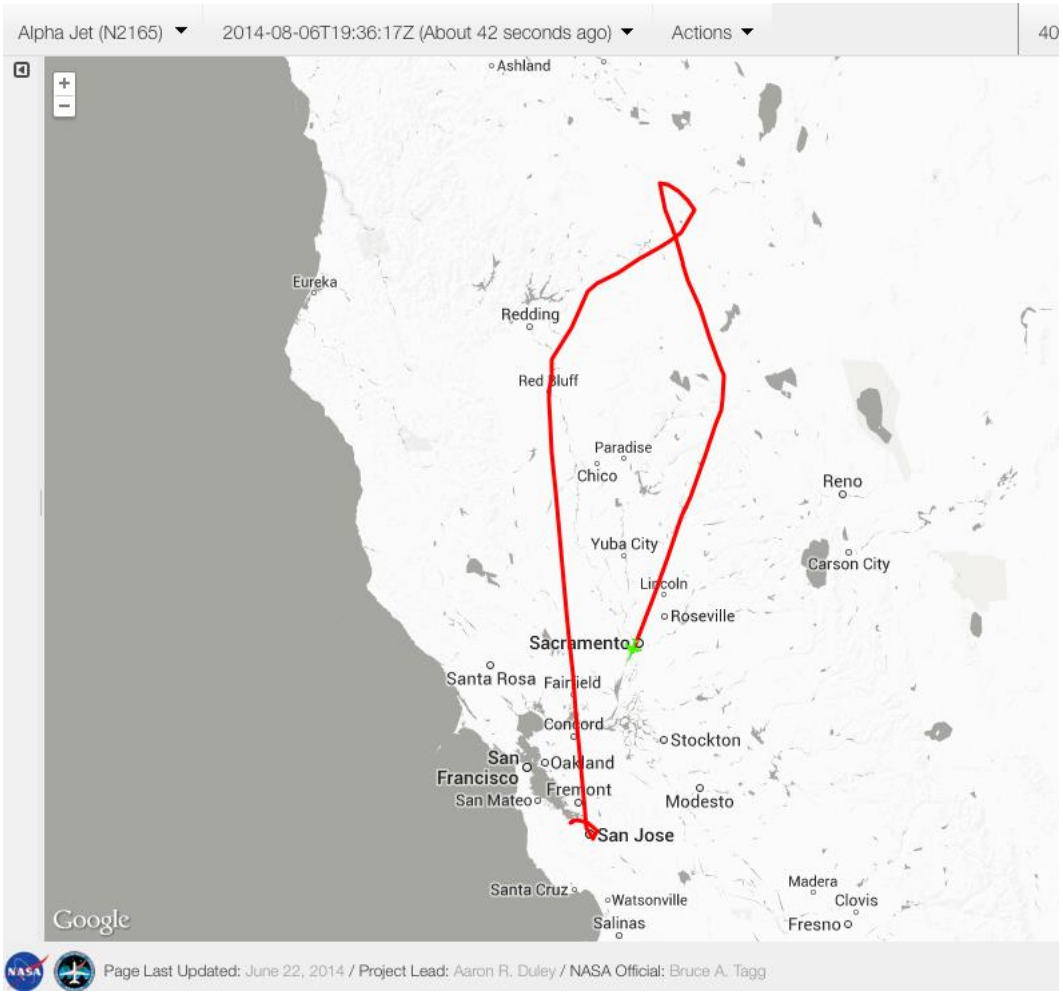


CalWater 2015





Find out more



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