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Airborne Estimation of surface emissions

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Aircraft Missions

- Given a known emission source, estimate the emission rate using only data obtained during flight.
- Without prior knowledge of source locations, locate significant sources.

- Research funded by the California Energy Commission (CEC)

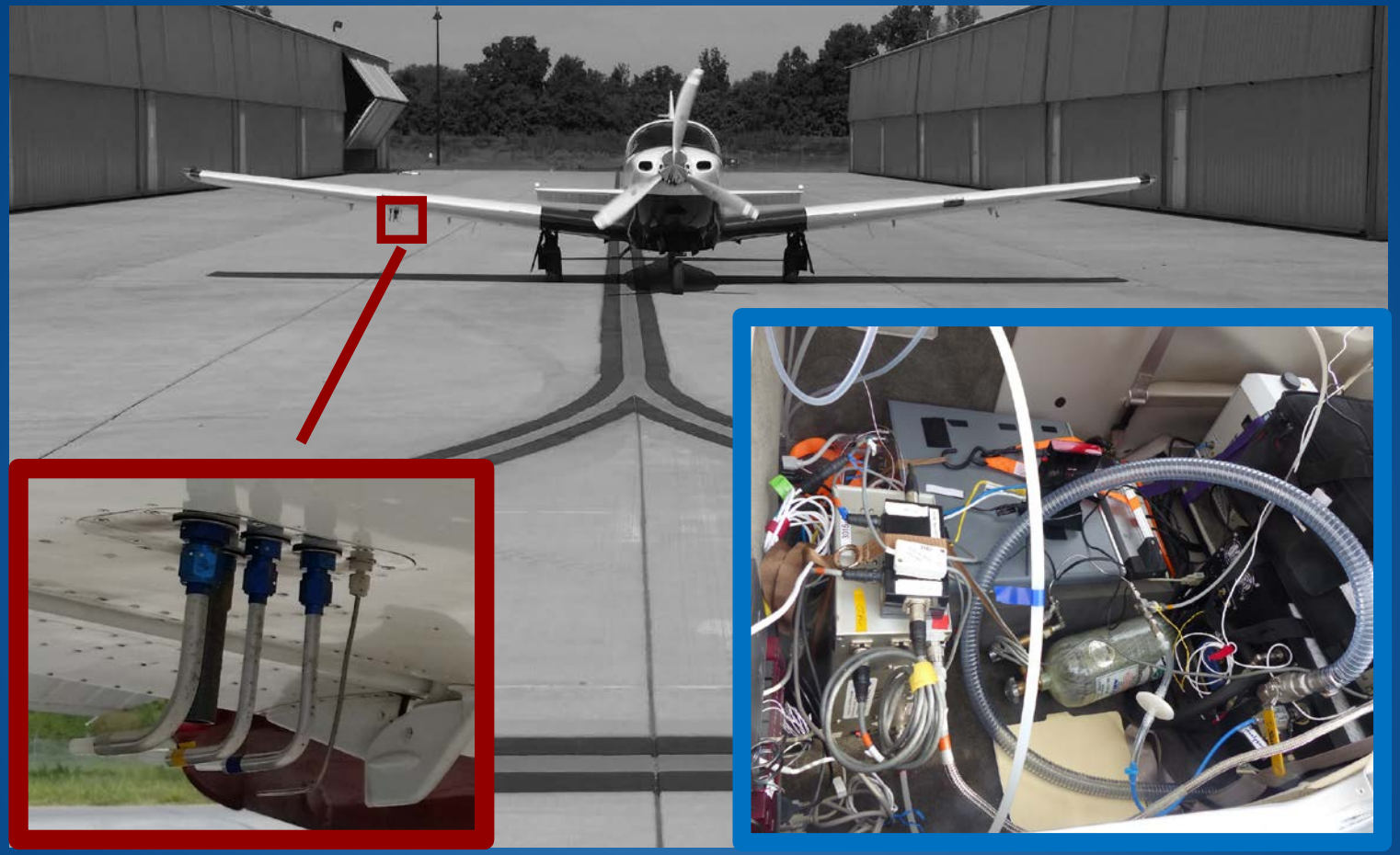
Leak Detection & Location

Source Strength Estimation

Catastrophic Failures Will Happen!

What's the best way to capture these events?

The Instrumented Aircraft



- Picarro Greenhouse gas analyzer $CO_2/CH_4/H_2O$
- Aerodyne Mini QCL Ethane TDL Analyzer
- 2B Model 205 ozone analyzer
- ECO Physics Nitric Oxide (NO)
- Whole air samples (NOAA PFP, UCI Flasks)

- Mooney Ovation & Mooney TLS
- Horizontal wind system
- Temperature & relative humidity
- 1,000 pound payload
- 900 mile single flight range

Four instrumented aircraft – anywhere in the USA in 4 hours!

Single flight range from Sacramento (SciAv), Boulder (SciAv) and Lafayette (Purdue)

How are sources quantified from the air?

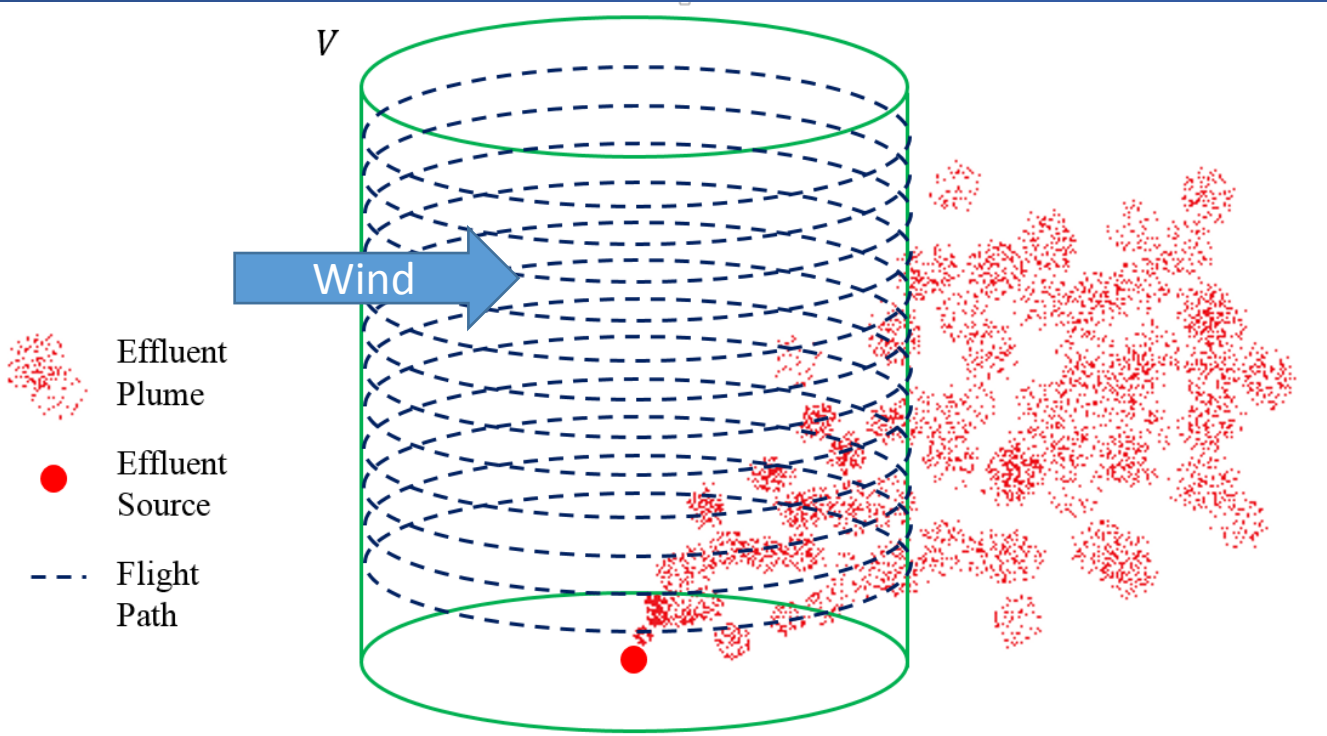


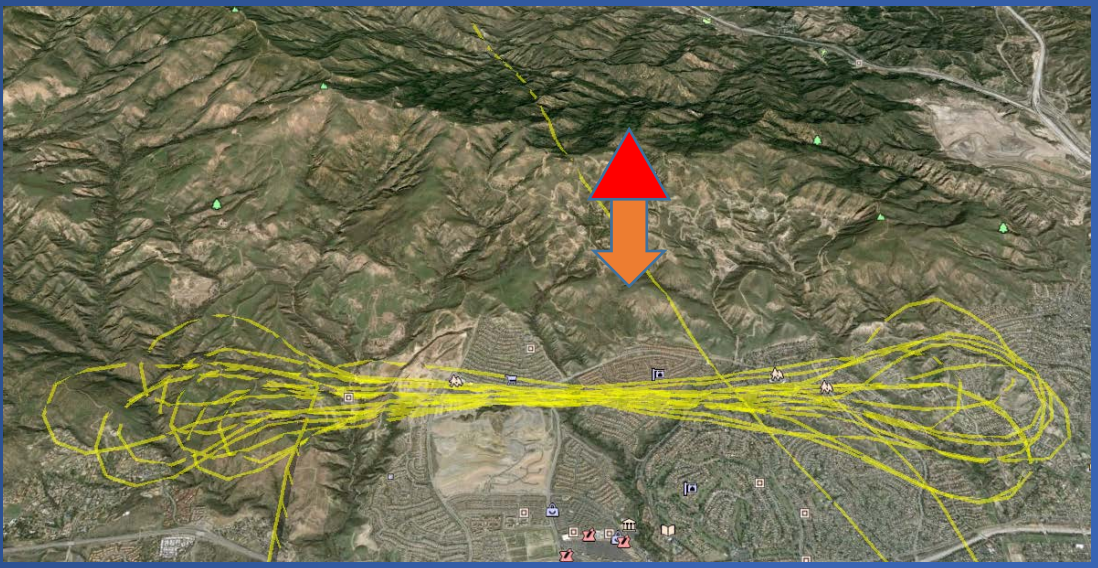
Figure 13: Sketch of flight path pattern for source leak rate estimation.

Principle of mass conservation:
Emission = Out - In

*Conley et al, in preparation

Needed: Horizontal wind & mixing ratio

Lines & Circles…



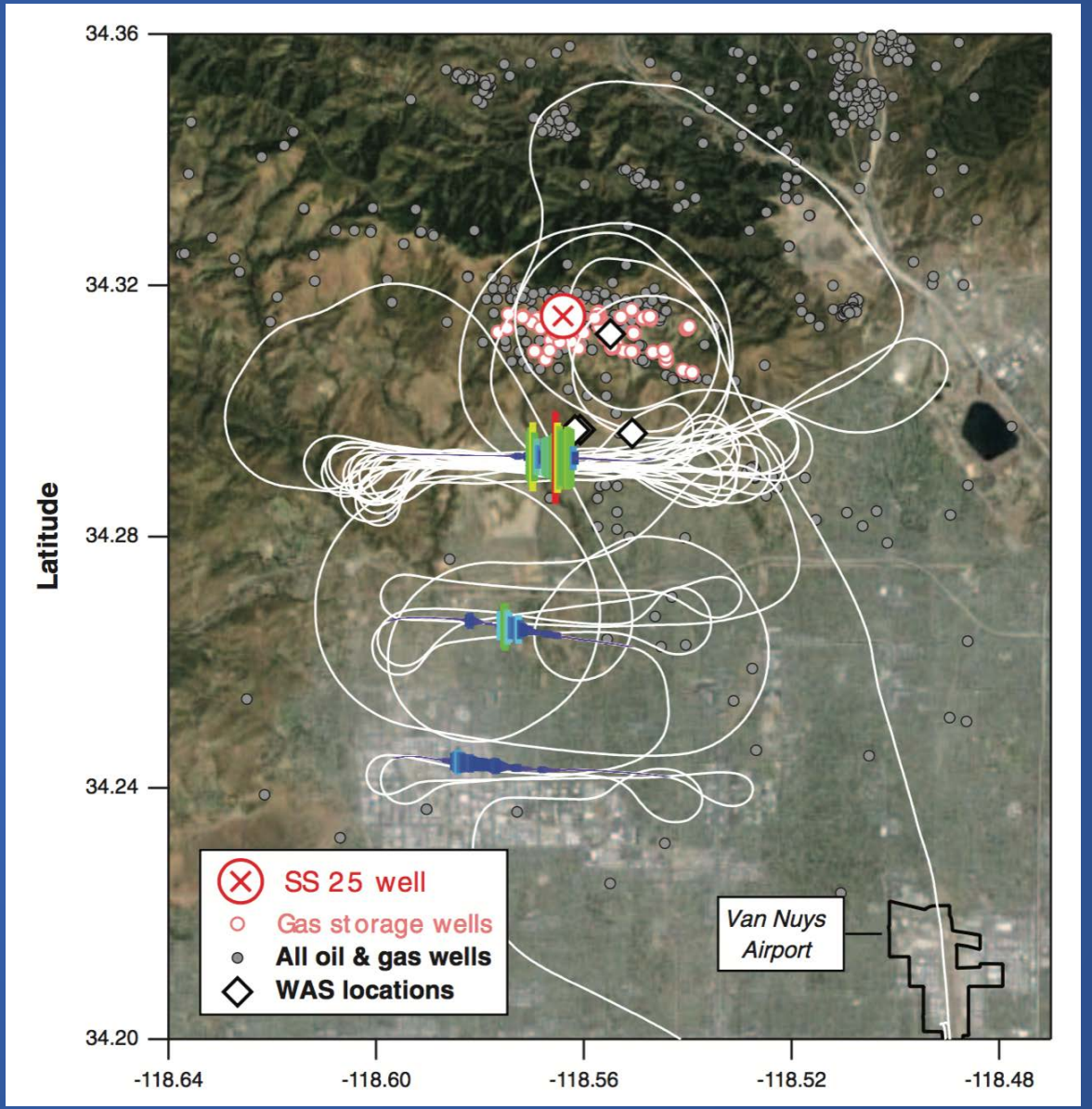
Aliso Canyon: Steep terrain to the north, no nearby sources of similar magnitude

Flat terrain, nearby sources

- Choice depends on terrain and the presence of nearby sources

Aliso Canyon Flights

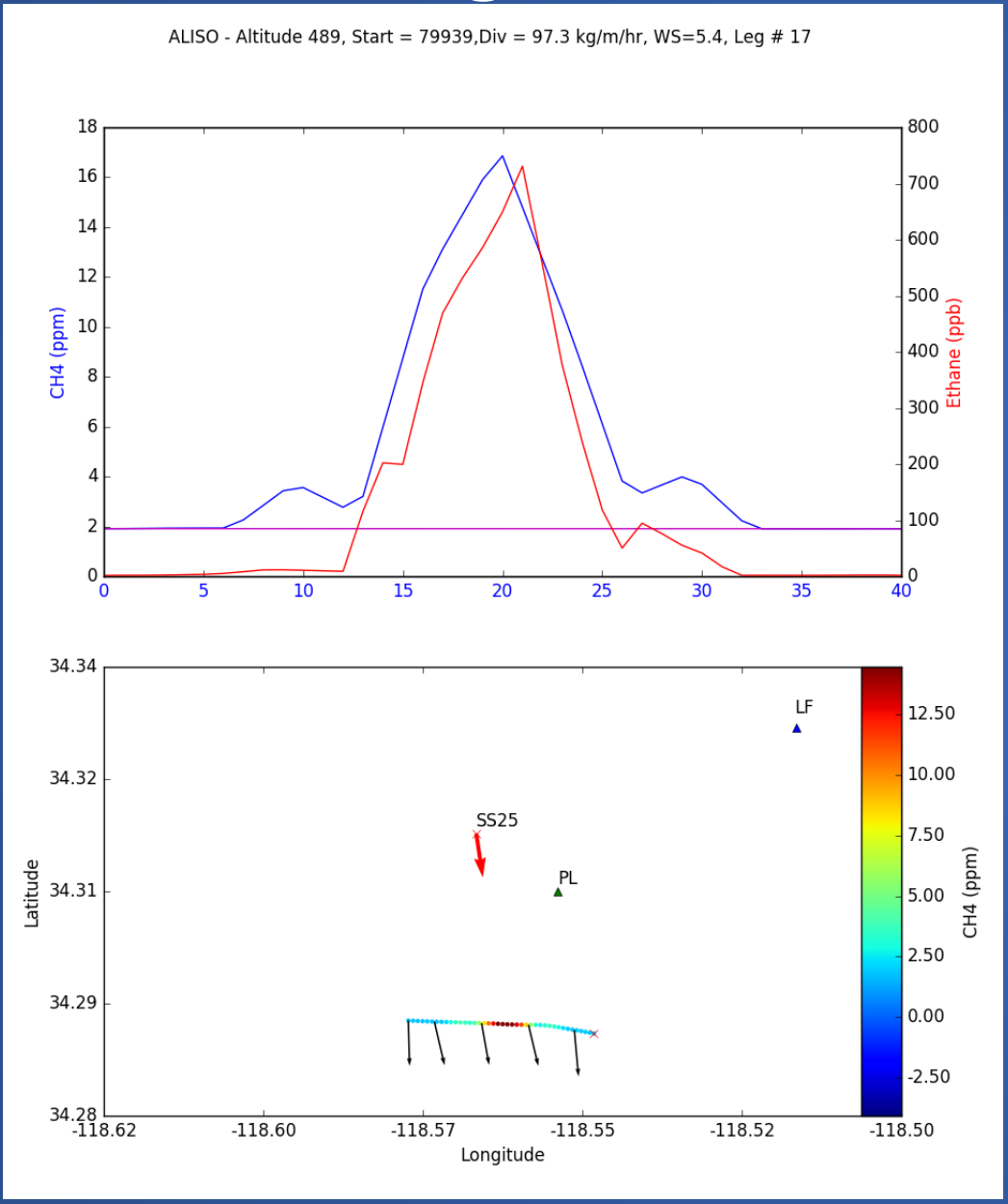
- Maximum 70 ppm 1 mile downwind (consistent with NASA Alpha Jet flight)
- Taking canister samples allows analysis of dozens of compounds
- Each measurement requires ~1 hour



*11 of 13 flights funded by SCG

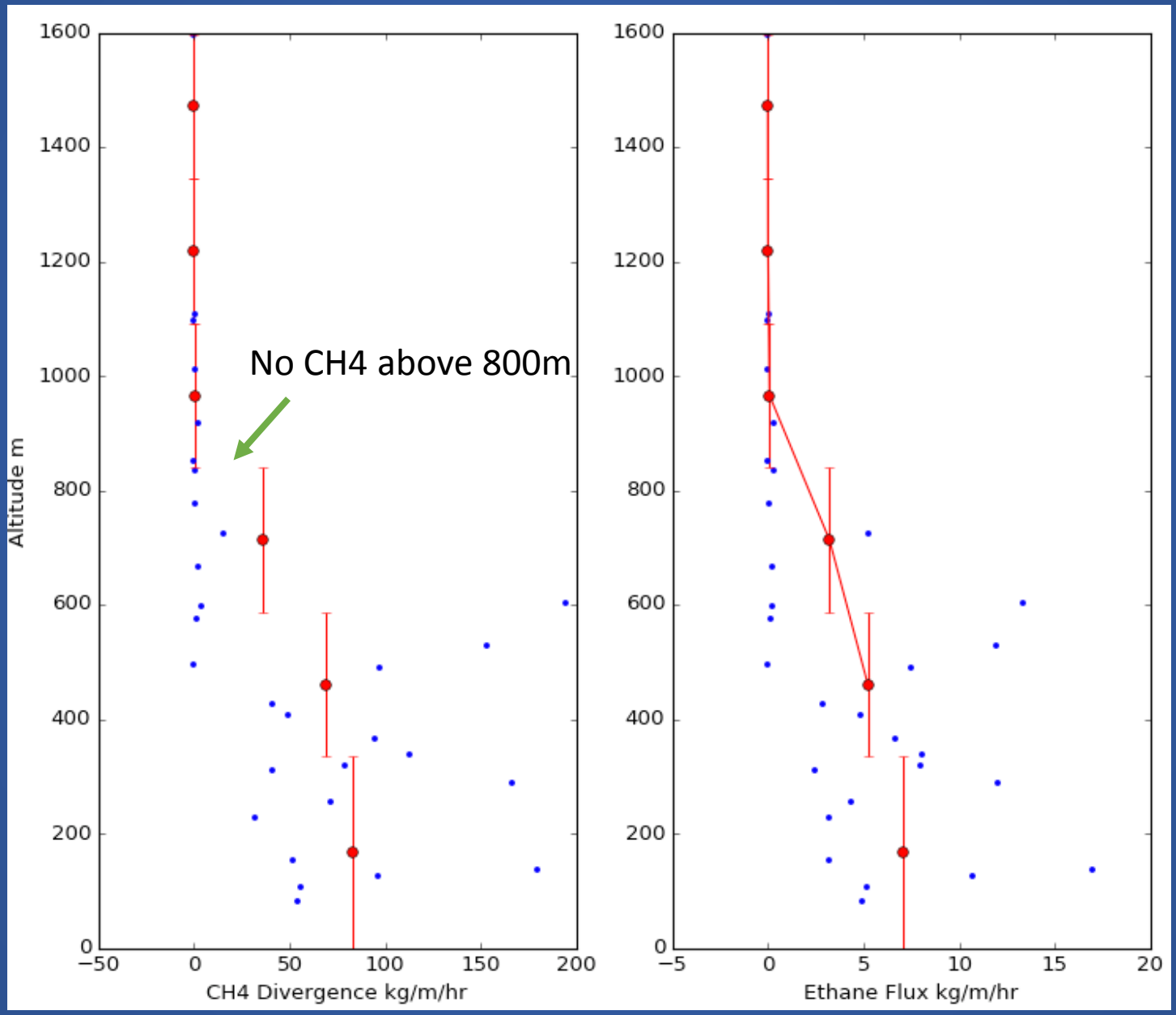
Source: Conley et al, Science 2016

Integrate the enhancement…

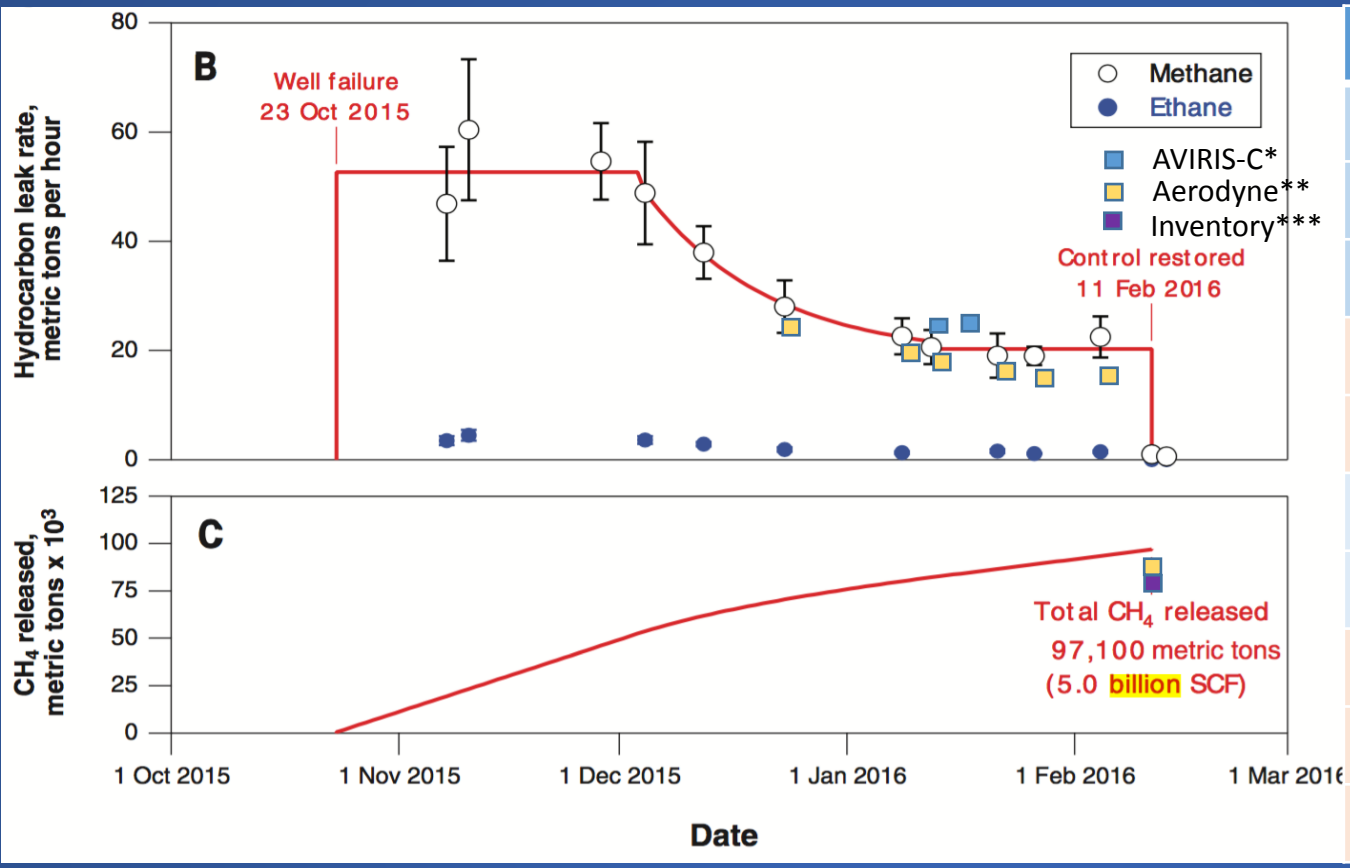


- Plume width ~18 seconds (~ 1 km)
- Enhancement observed directly downwind of SS25
- Ethane tracks methane perfectly (suggesting oil & gas source)

Add up the vertical measurements…



Comparison of Aliso Leak Estimates



Source	When	Amount
Mooney	Total	97,100
Aero	Total	86,000
SCG	Total	84,200
Mooney	Dec 23	28,100
Aero	Dec 23	25,000
Mooney	Jan 8	22,700
Aero	Jan 8	21,500
AVRIS-C	Jan 12	23,000
Mooney	Jan 12	20,700
Aero	Jan 12	20,000

- Units in table are kg-CH_4 for
- "Total" and kg-CH_4 hr^{-1} for individual dates

All methods agree to within 13%

- Thompson et al., Space-based Remote Imaging Spectroscopy of the Aliso Canyon CH4 Super-emitter, 2016
- **Herndon et al, 2016, GRL, in preparation
- *** Southern California News Release, May 26, 2016

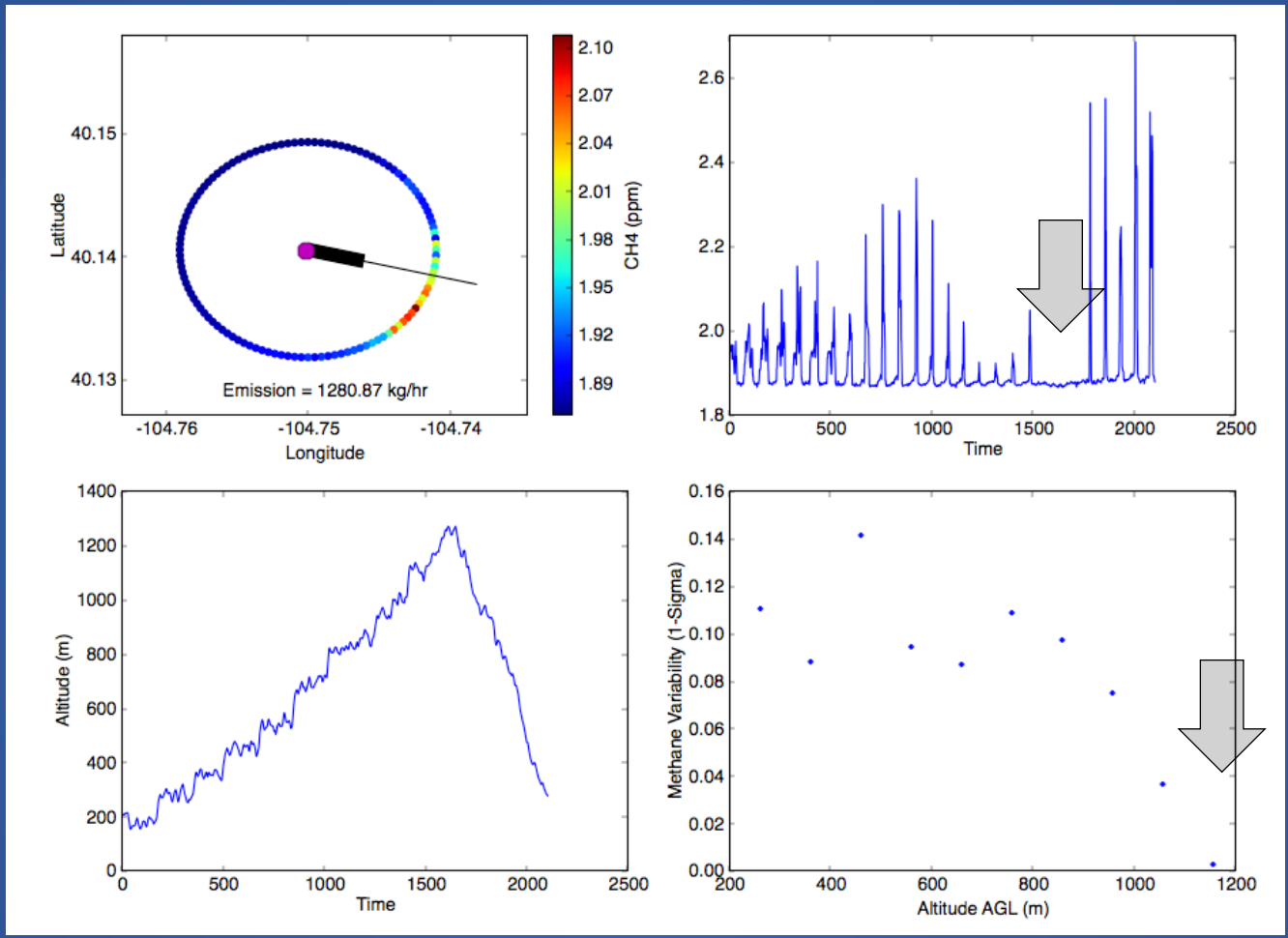
Standard circle pattern…

- Optimal radius!
- No other sites within circle
- Concentric circles
- Fly as low as possible!

Site near Denton, TX

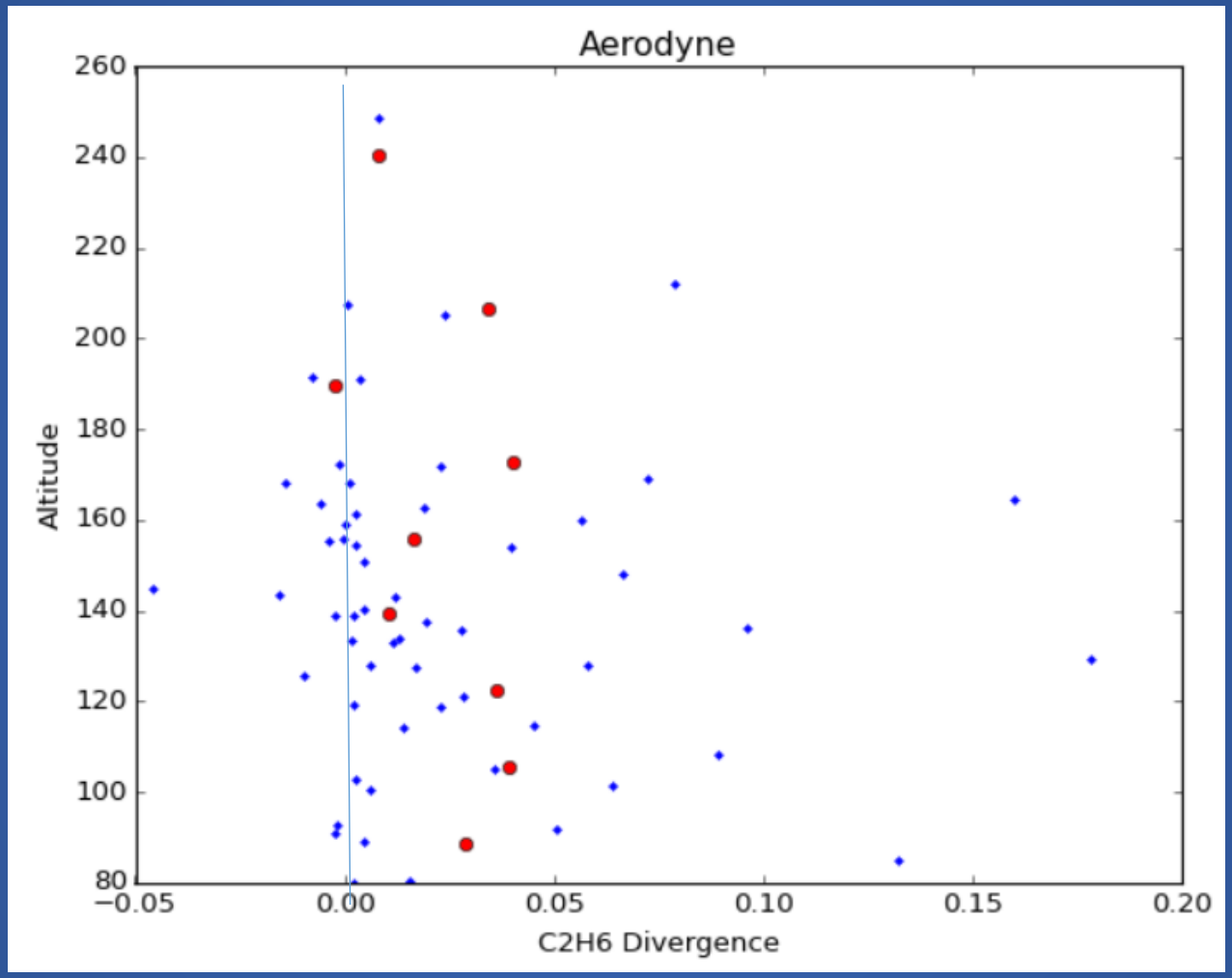
Site near Denver, CO

How can we know we got it?



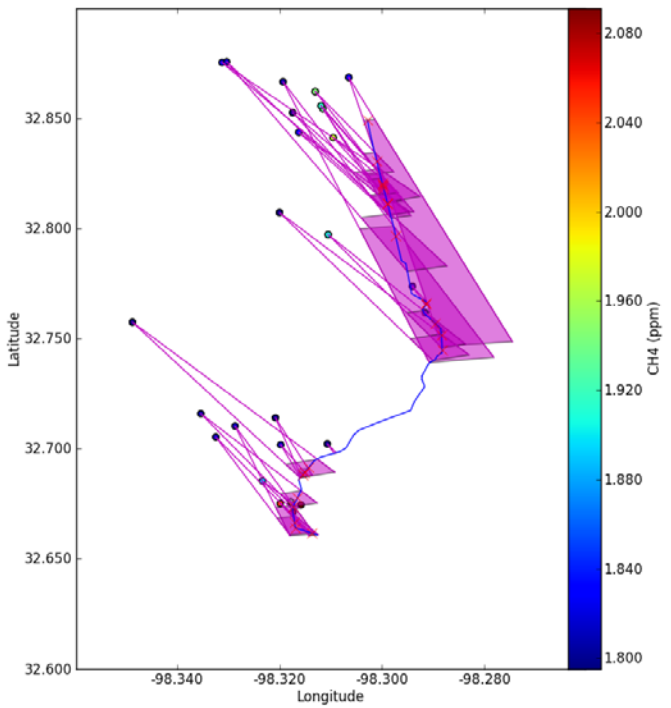
- Clear downwind signal
- Variability approaches zero at top altitudes

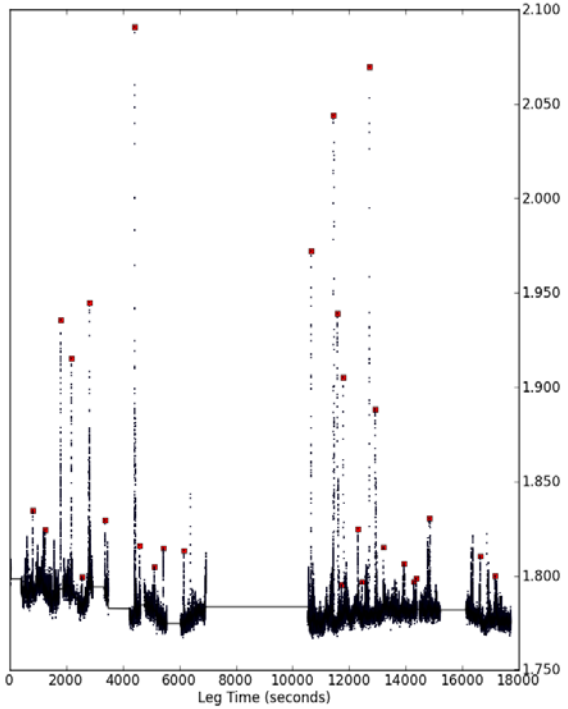
Controlled Release (Aerodyne)



- Ethane release of 5.52 kg hr^{-1}
- Method estimate of 5.5 ± 8 (?) kg hr^{-1}

Using aircraft for leak detection…





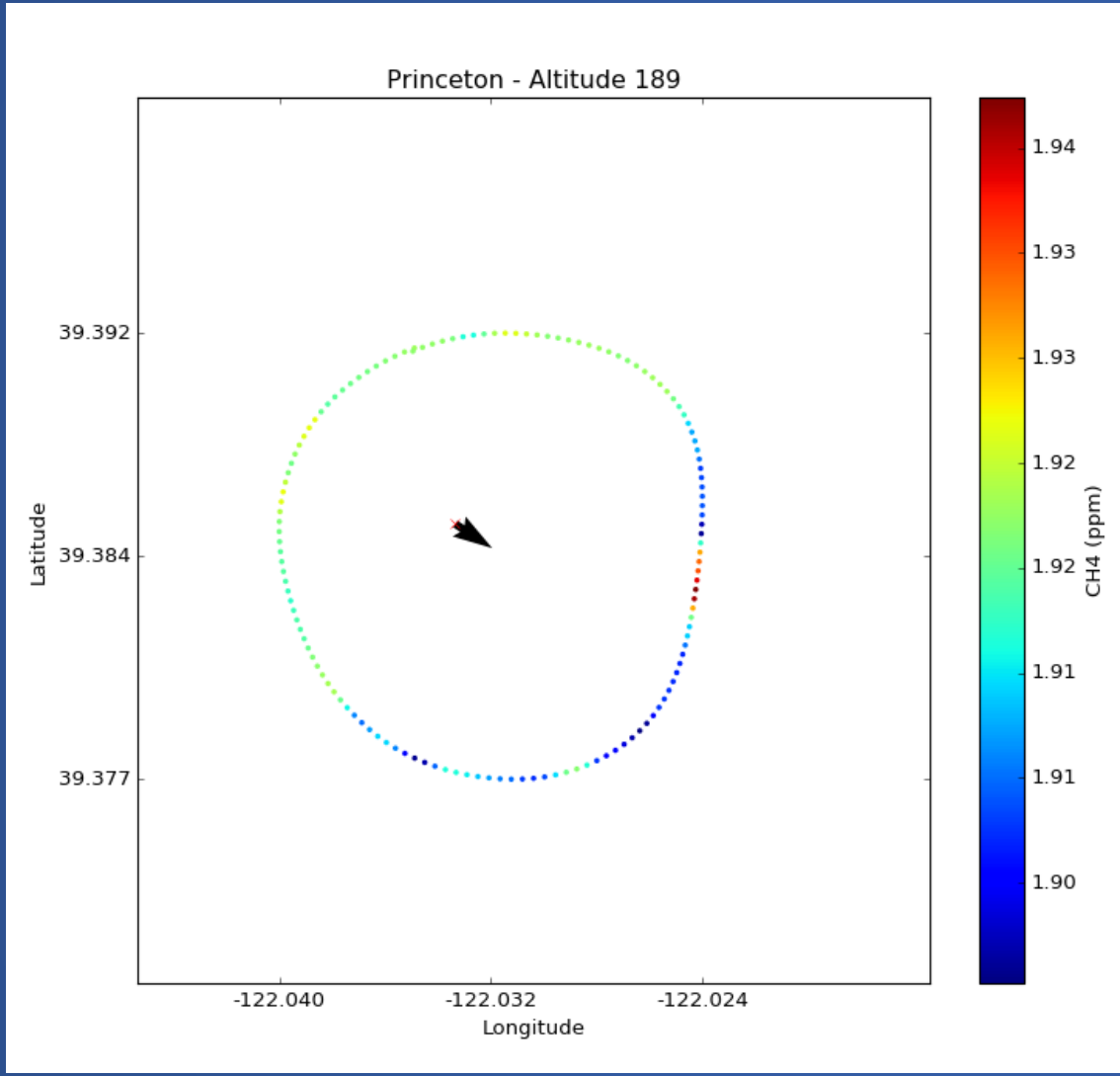
- The aircraft flies downwind of the pipeline
  - Distance based on altitude and wind speed
- Use back trajectory to estimate source location

When does No mean No?

How many passes do we need to make in order to state with 95% confidence that a negative detection actually means there isn't a leak?

We flew 112 laps around underground storage facility with modest emissions (~40 kg hr^{-1})

How many passes required?



Methane mixing ratio during a single lap around the test site. Black arrow indicates mean wind.

- The plume was seen (2σ above the lap mean) on 75 of 112 laps, suggesting a detection probability of 67% on any given lap.
- 3 passes required to say with 95% confidence that there is no leak.

3

Conclusions

- For situations requiring rapid deployment, aircraft are difficult to beat!
- Leaks can be located by flying downwind of a potential source. Three negative indications – 95% confident.
- Emissions can be accurately estimated either by flying circles around the facility or with downwind transects. Best choice dependent on terrain and neighboring emissions
- When sufficiently sampled these methods have been shown to be accurate to within ~20% - but that uncertainty is improving!