Atmospheric indicators quantify baselines and trends in California's greenhouse gas emissions

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- Introduction to California GHG Emissions
- Atmospheric Indicators of Emissions: State to Local
  - Regional Enhancements: State Level Emission Estimates
  - Local Enhancements: Source Attribution and Mitigation

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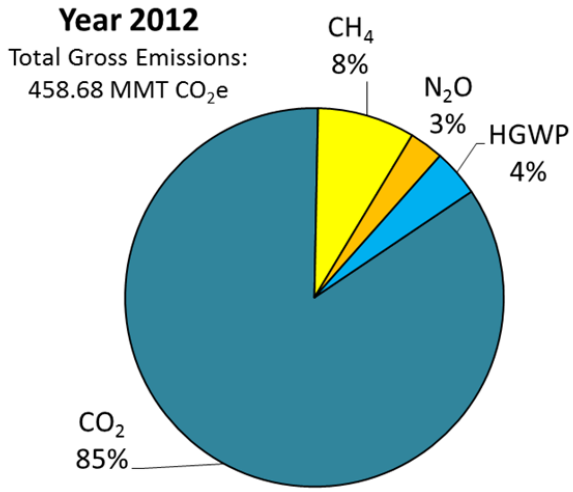
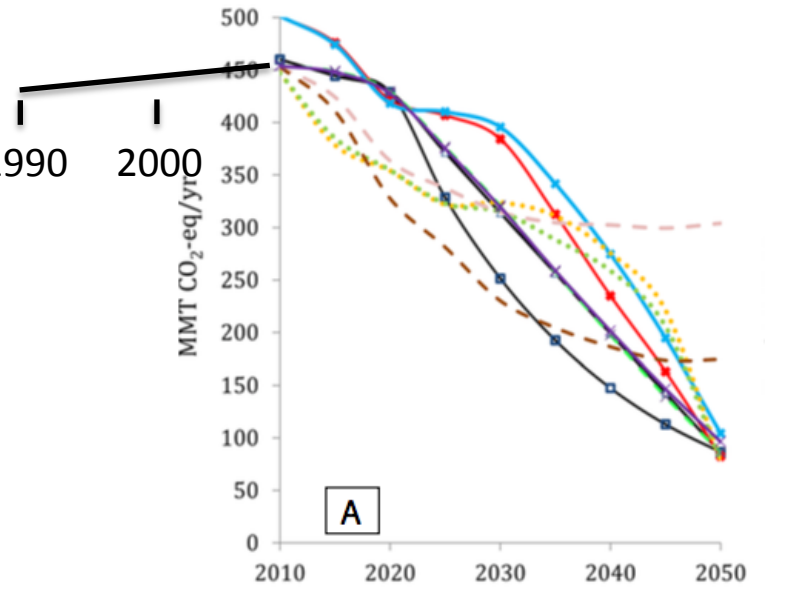
California GHG Emissions

- Current CA GHG emissions ~ 460 MMT CO2eq/yr (~ 85% fossil CO_2)
- California "Climate Solutions Act" (AB-32) mandates 1990 level (~ 430 MMTCO2eq) GHG emissions by 2020 (reduce ~ 7% from 2012 to 2020)
- Climate stabilization motivates Executive Orders: 40 and 80% reductions from 1990 by 2030 and 2050 (~ 6%/yr reductions starting in 2020 !)
- Some non-CO_2 (and biosphere carbon) emissions have large uncertainties (~ 50%)
  - Inventory verification requires regional measurements on annual timescales
  - Mitigation requires facility scale measurements



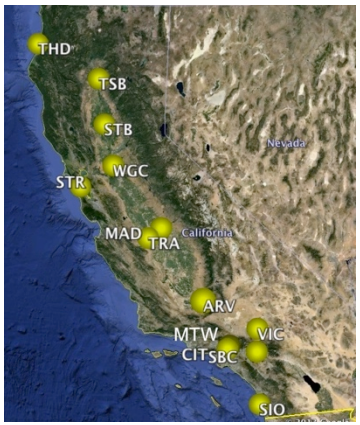
http://www.arb.ca.gov/cc/inventory/background/ghg.htm

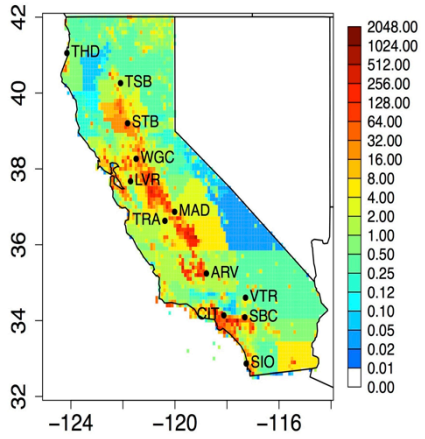


Morrison et al., 2015, Climate-Change

CA GHG Emission Studies

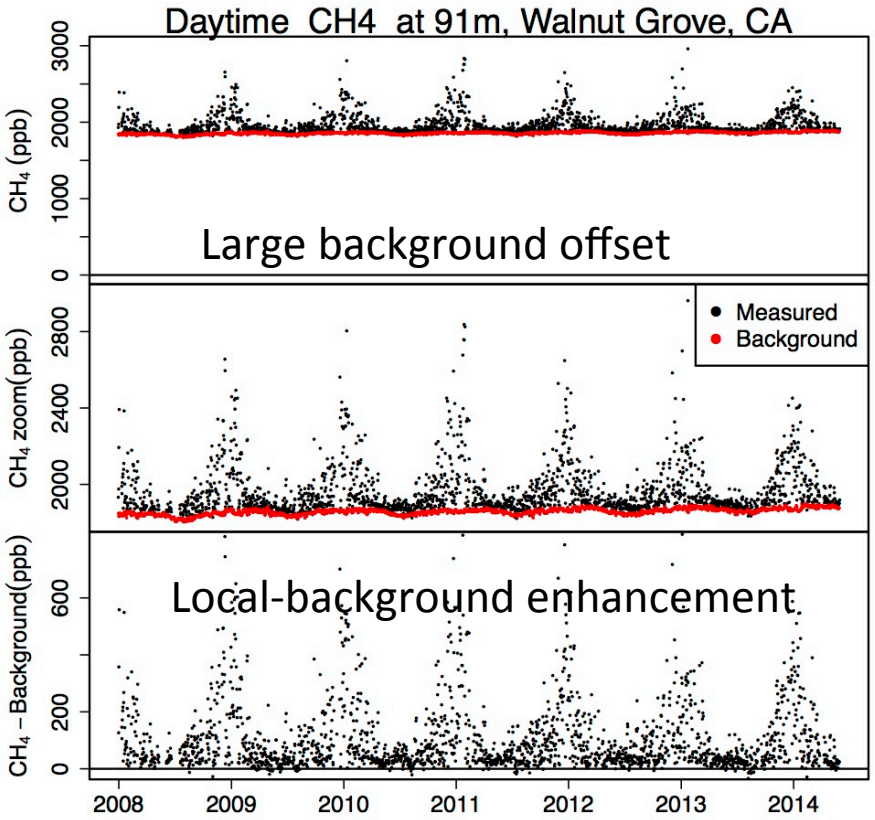
- California GHG intensively studied
- Space based observations capture CO_2 and CH_4 from globe-to-region-to-facility
  - e.g., NASA (OCO2), JAXA (GOSAT)
- Regional and urban tower networks dot most of the state w/ hourly-inter-annual coverage
  - e.g., CARB, CEC, NOAA, NIST
- Mobile techniques capture region, facility, and component level emissions episodically

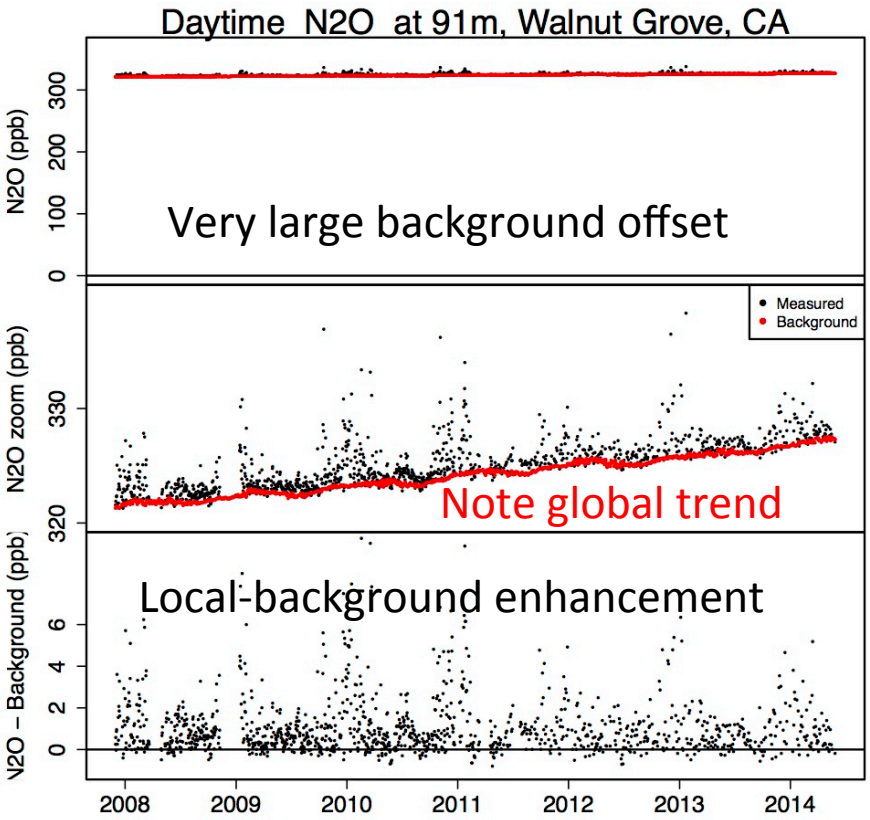




GHG as Atmospheric Indicator

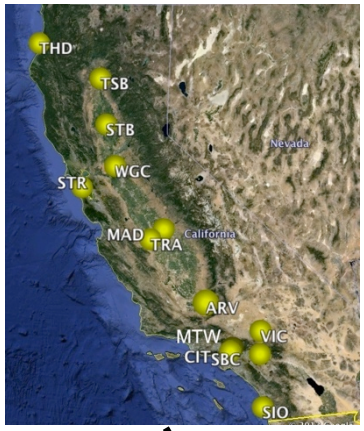
- Global GHG background inflow dominates local measurement
- Careful local & background GHG measurement essential
- California emissions estimated from local-background enhancement

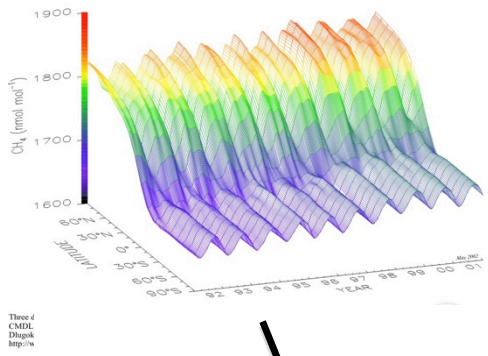




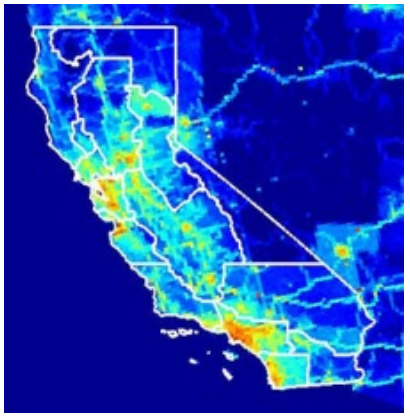
Regional Inverse Emission Estimates

California GHG and GHG Background Inflow





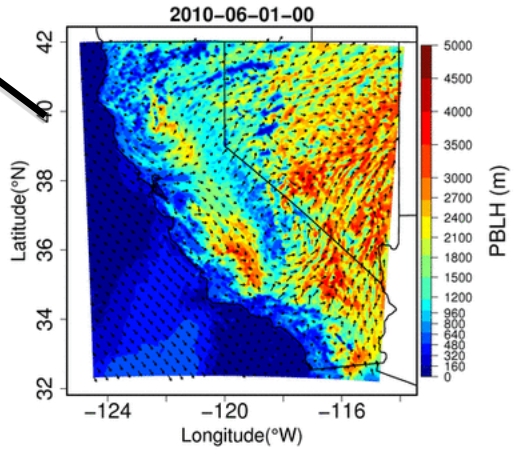
Prior Emission Model



Measured Signals and uncertainties

Predicted Signals and uncertainties

Atmospheric Transport

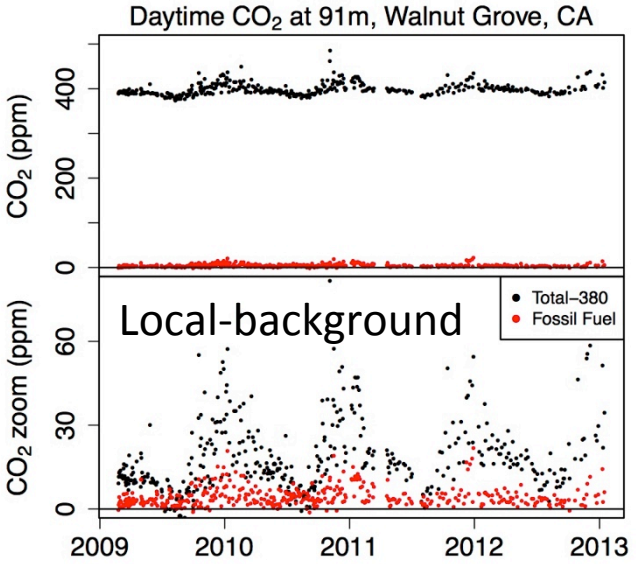


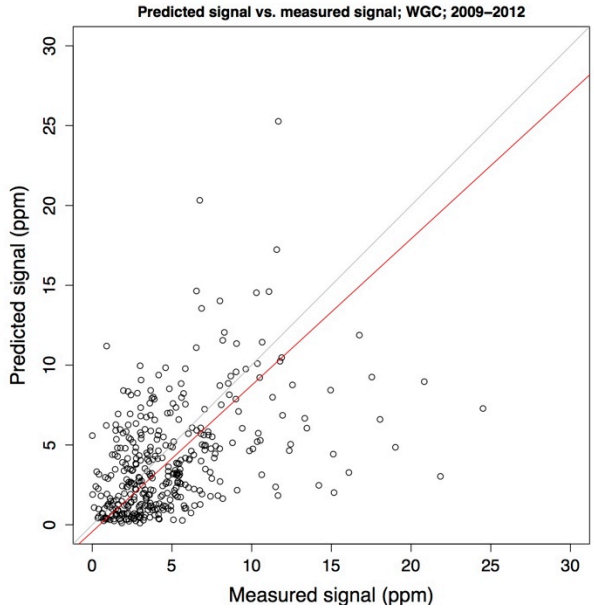
Statistical Estimator of Emissions (e.g., Bayesian)

Improved Emission Estimate

Fossil Fuel CO_2 Emissions

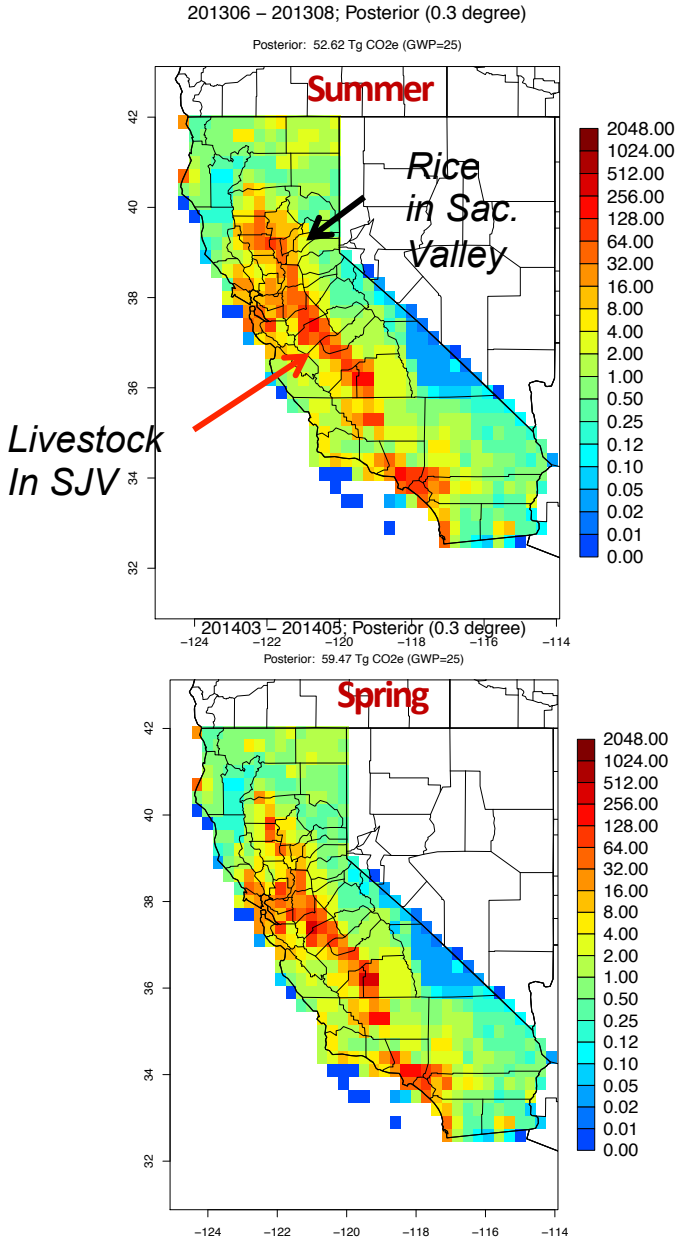
- As with other GHG local signals small compared to background
- Radiocarbon $^{14}CO_2$ provides sensitive (~ 1 ppm) measure of atmosphere fossil fuel (^{14}C free) CO_2
- Preliminary 2009-2012 model-measurement comparisons suggest emissions approximately (+/- 10%) consistent with inventory estimates
- Caltech measurements from 2010 yield similar results (Newman et. al., 2013)
- NASA project (Heather Graven, PI) underway to combine network $^{14}CO_2$ and OCO2 data for total fossil (and biosphere) CO_2 emissions across California





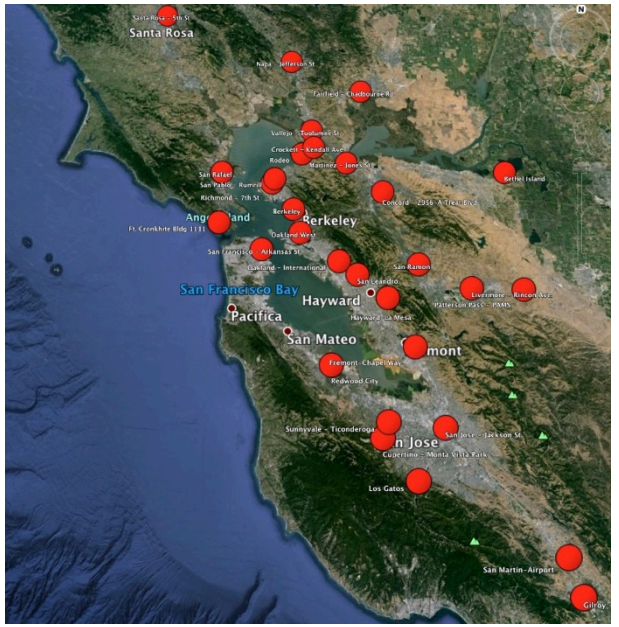
California CH_4 Emissions

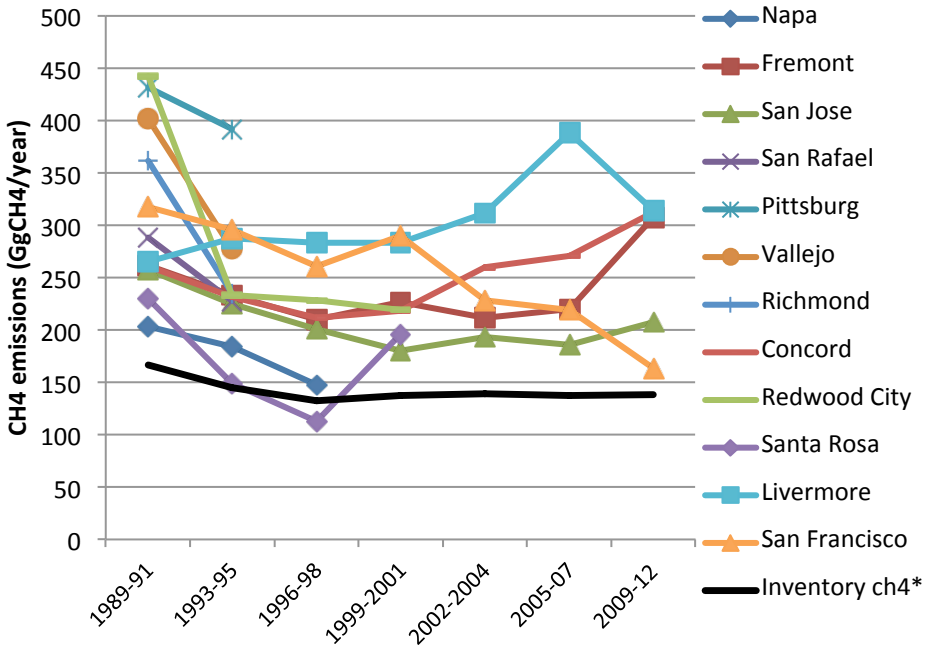
- Measurements from 10 site network over June13-May14 period
- Spatial patterns suggest livestock likely the major contributor to both valley and state total CH_4 emissions
- Preliminary annual CA emissions 2.3±0.3 Tg CH_4/yr (~ 1.5±0.2 x current inventory)
- Additional data and meteorological analysis to be completed
- N_2O being estimated using 4 sites across CA



SF Bay Area Methane

- BAAQMD: 12 site CO, CH_4 network data 1990-2012
- Estimate CH_4 emissions CH_4:CO correlations + CO emission inventory
- Regional CH_4 1.5 – 2.0 x BAAQMD Inventory
  - AQ focused sites likely biased toward CO emissions
  - Likely NG significant urban contribution
- Future: include VOC tracers to quantify NG emissions from distribution





Fairley and Fischer, Atm Env., 2015

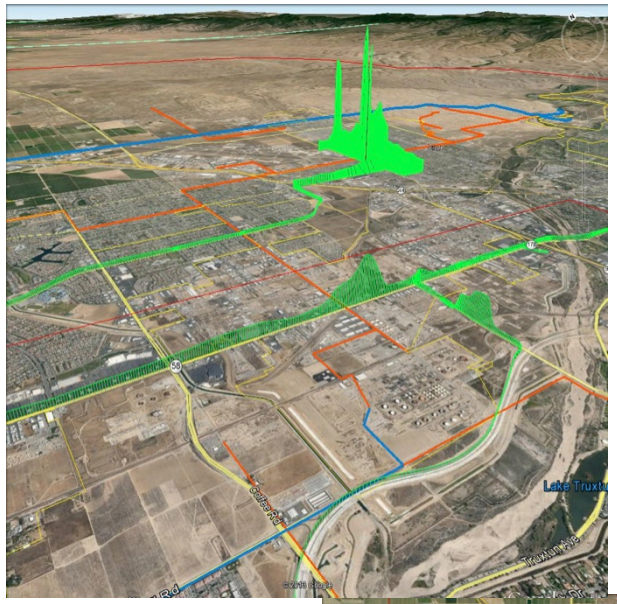
Airborne Study Quantified Point Sources of Natural Gas Methane Emission

- Captures controlled releases of natural gas to 20%
- Measurements of methane and ethane allow attribution to natural gas
- Measurements of methane emissions from oil & gas production, processing, storage, and refining

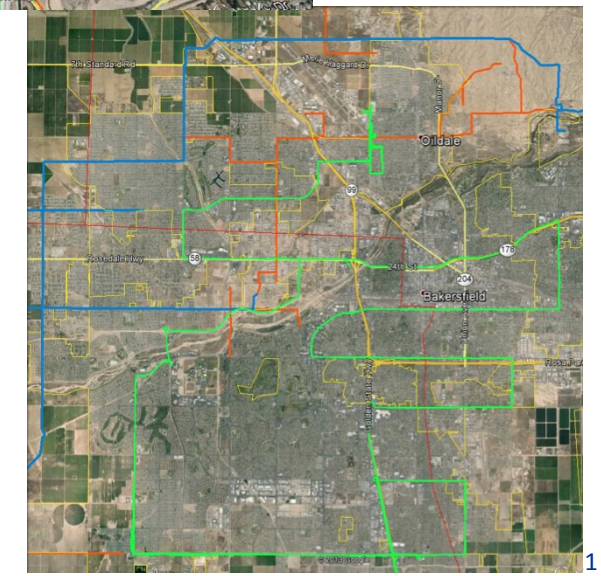
Methane Plume

Urban Road Natural Gas Emission Survey

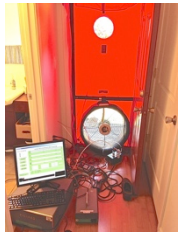
- Nov., 2013 survey 80km of Bakersfield streets
- Detect 20 large leaks above above elevated varying background
- Mobil plume integrations yield total emissions of 160 lpm
  - 40% plume emissions found within 1km of large distribution pipes
- Scaling by area suggests total emissions ~ 0.8 Gg CH_4 yr^{-1} or ~ 0.3% of consumption
- Other cities likely different

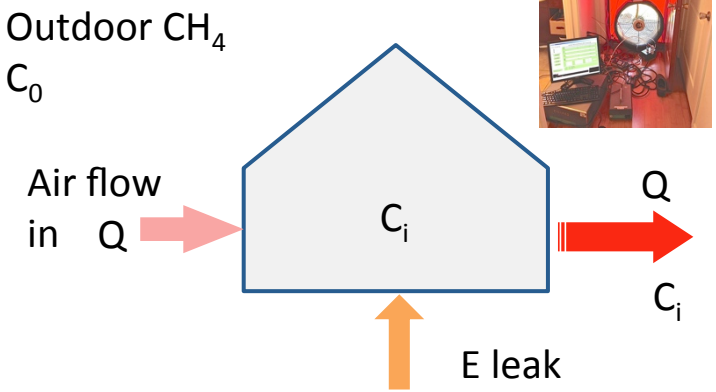


CH_4 enhancements (green), distribution (orange) and transmission (blue) pipelines



Building Scale Residential Leakage



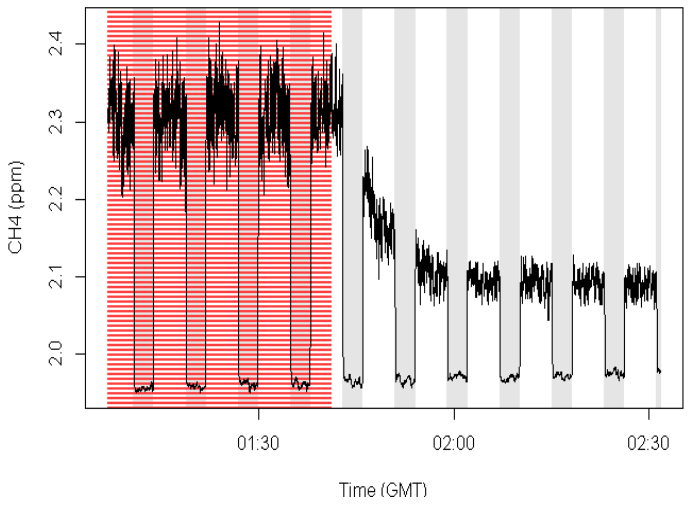


- Mass balance approach
  - Depressurize house producing controlled inflow of outdoor air
  - Measure CH_4 enhancement relative to outdoor air
- Estimate leakage in 10 SF Bay area homes
  - Average leak rate 7 +/- 2 sccm
  - ~ 0.2% of consumption
- Consistent indoor CH_4 enhancements w/ $^{13}CH_4$ NG signatures
- New CEC-ETA project underway
  - 50-75 homes across CA housing stock

$$C_0Q + E = C_i Q$$

$$E = Q\,(C_i - C_0)$$

Measured decay of indoor (white) methane toward outdoor (grey) following calibrated leak (red)



Summary

- Significant reductions in CA GHG emissions can set an example for global stewardship
- Atmospheric GHG measurements and analysis can quantify emissions at multiple scales
  - State-to-regional estimates can verify state-annual emission inventories
  - Facility estimates can verify success of mitigation activities