Updated Estimates of California's Urban and Rural Methane Emissions

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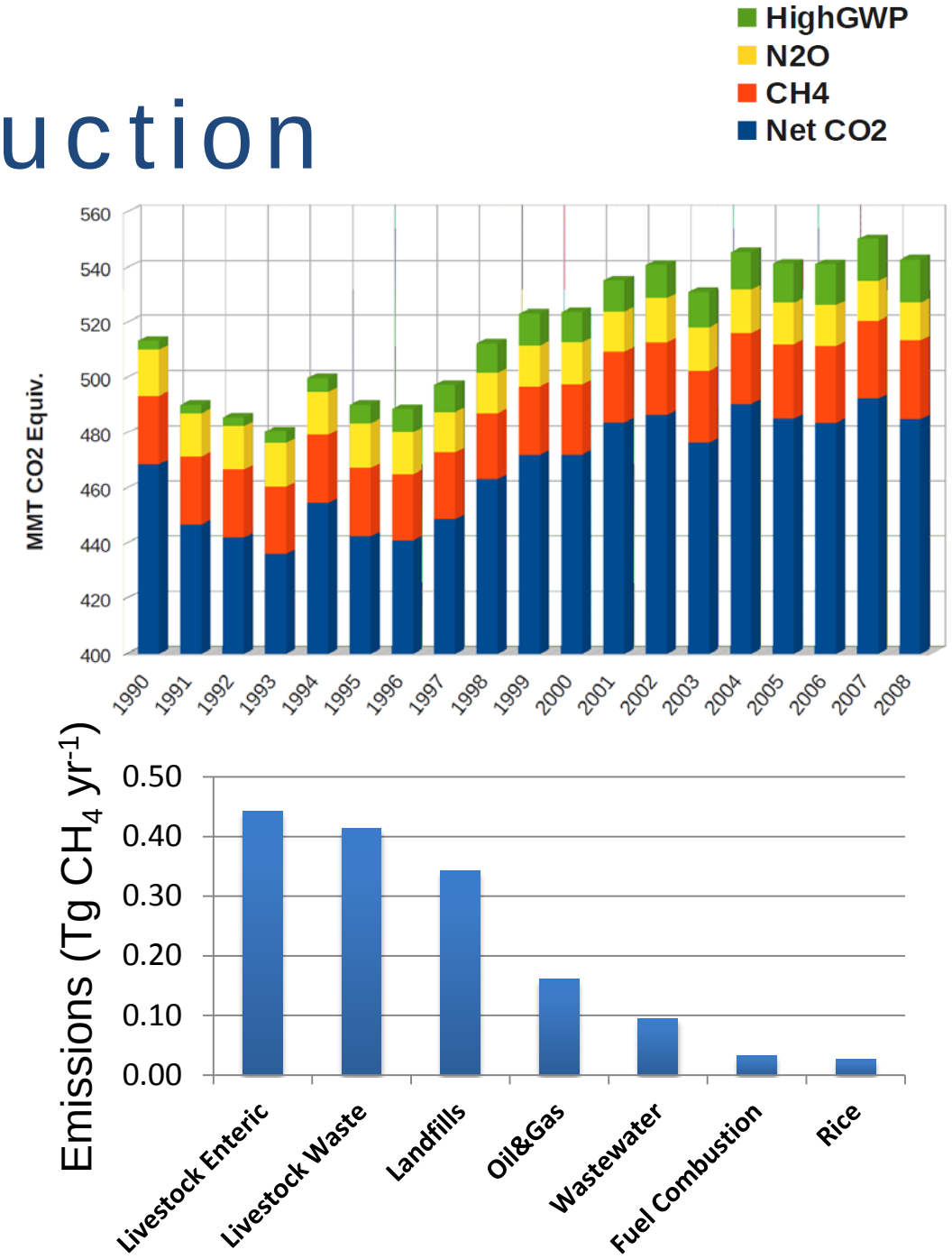
Outline

- Introduction to California Methane Emissions
- Multi-tower Inverse Model Approach
- Summer 2012 Methane Emissions
- Conclusions

Introduction

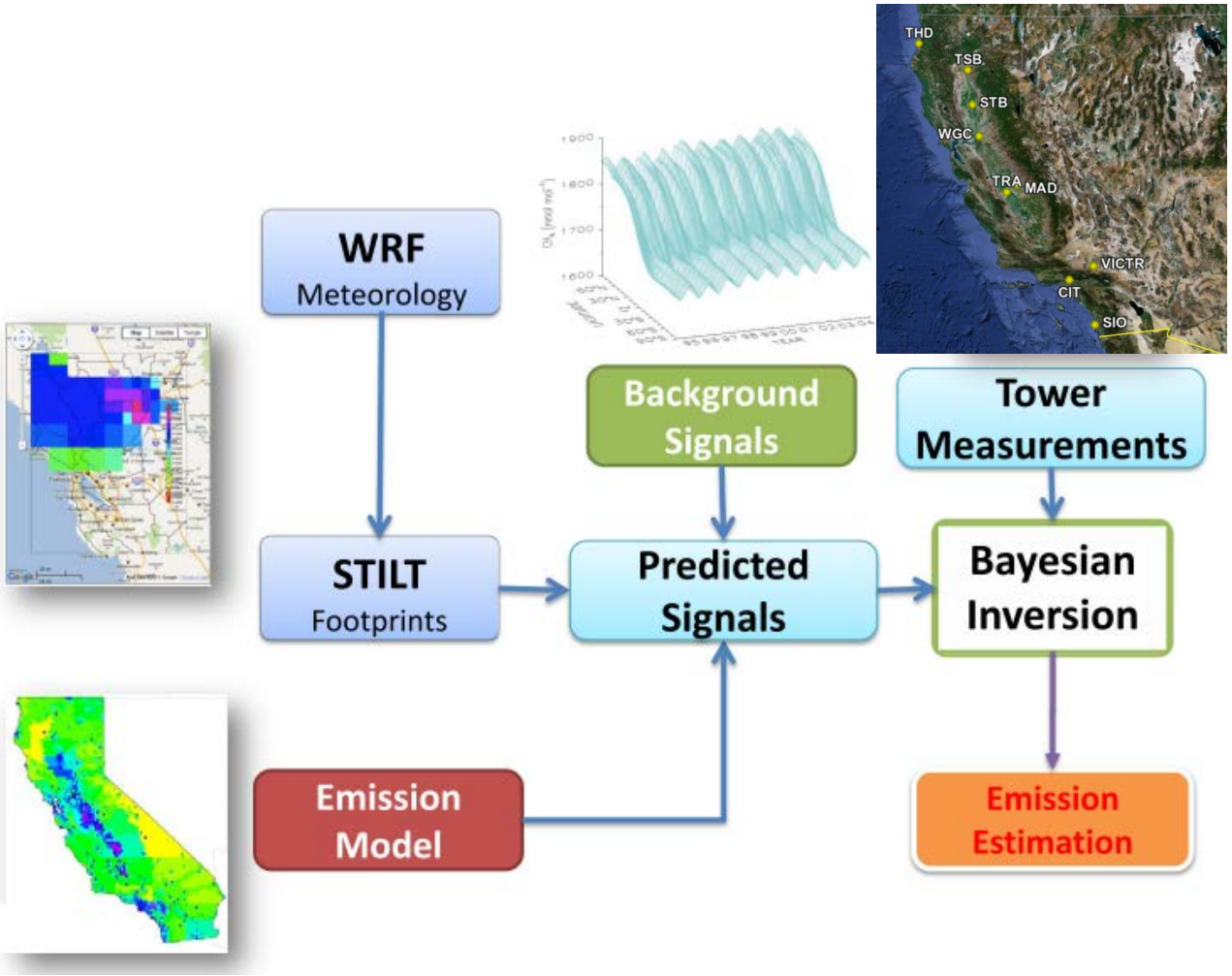
- California's greenhouse gas (GHG) control legislation (AB-32) offers a test case where current methane (CH_4) emissions are ~1.5 Tg CH_4/yr (~ 6% of total GHG)
- CH_4 inventory uncertainties are large and industrial/biological sources are not readily metered
- Atmospheric inversion provides an independent check
- We present an inverse analysis of CH_4 emissions across CA using a 9-site network of measurements during June – August, 2012



[*CARB*, 2011]

Approach

Bayesian Inverse Modeling Framework



Bayesian Inversion Schemes for surface flux, s

1. 0.1 degree Region-based Bayesian Inversion: $s = \lambda s_p$ [Jeong et al., 2012a; 2012b]

$$y = Hs_p\lambda + v$$

$$\hat{\lambda} = \left(K^T R^{-1} K + Q_\lambda^{-1}\right)^{-1} \left(K^T R^{-1} y + Q_\lambda^{-1}\lambda_p\right)$$

2. 0.3 degree Pixel-based Bayesian Inversion: [Tarantola, 1987]

$$J_s = \frac{1}{2}(y - Hs)^T R^{-1}(y - Hs) + \frac{1}{2}(s - s_p)^T Q^{-1}(s - s_p)$$

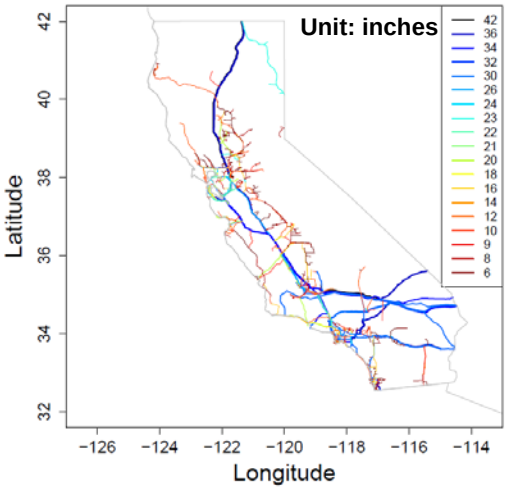
$$\hat{s} = s_p + QH^T(HQH^T + R)^{-1}(y - Hs_p)$$

y: measurement – background
H: footprint ***s_p***: prior emission
s: state vector for surface flux
λ: state vector for regions/sources ***$K=H s_p$***
R: model data mismatch covariance
Q_λ: prior covariance for λ
Q: prior covariance for ***s***
λ_p: prior for λ
v: error ~ N (0, ***R***)

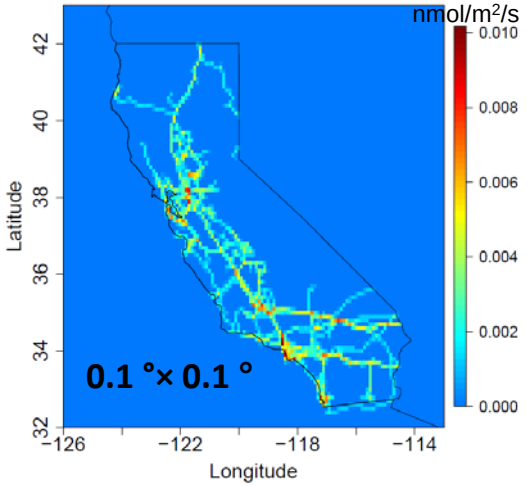
Prior CH_4 Emission Model - CALGEM

(available at calgem.lbl.gov)

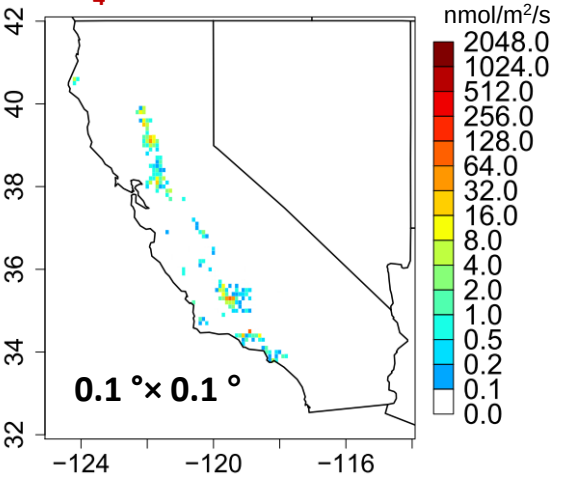
Natural Gas Pipelines in California



CH_4 from Natural Gas Pipelines

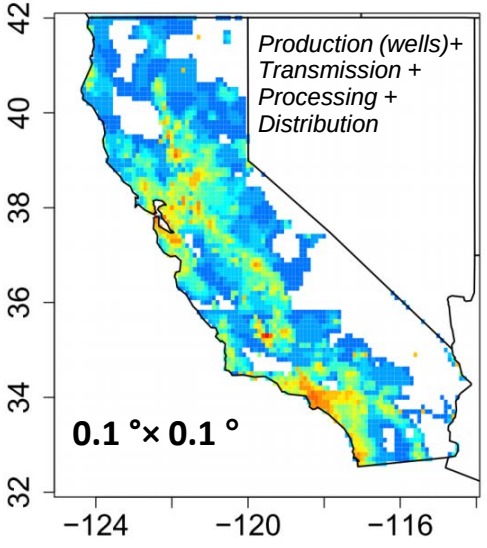


CH_4 from Natural Gas Wells

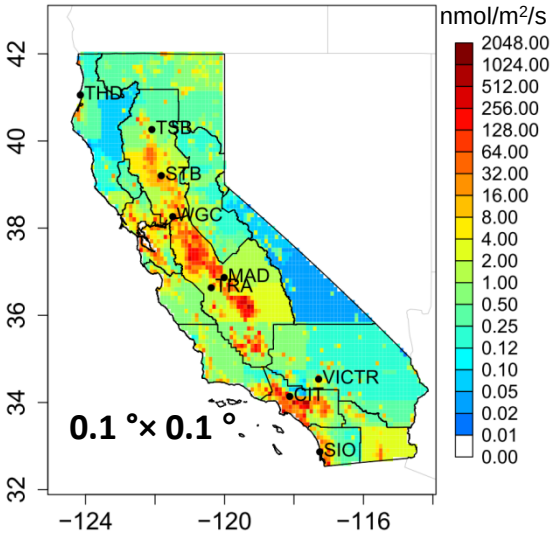


- Calibrated to CARB 2010 inventory [CARB, 2012]
- Develop new emission maps for natural gas (not scaled to CARB)
- 50% error in prior [NRC, 2010; Jeong et al. 2012a, JGR]

Total CH_4 Emissions from Natural Gas

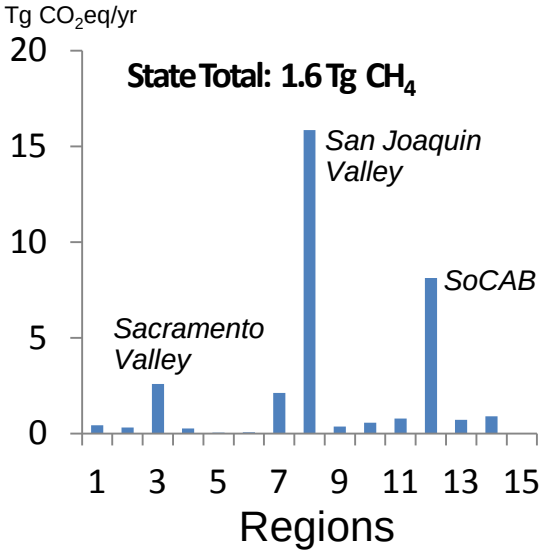


CALGEM Total CH_4 Emissions



Emission Regions for Inversion

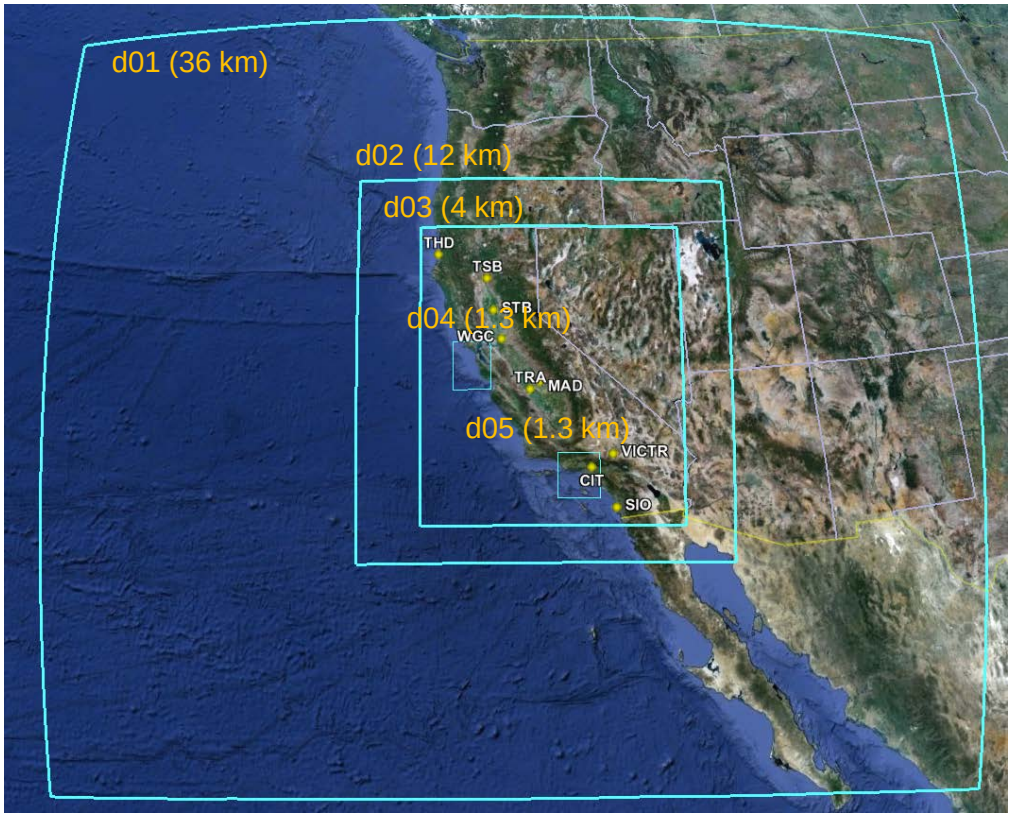
CALGEM Emissions by Region



Meteorological Model for California

- Simulate meteorology for summer 2012 using Weather Research and Forecasting (WRF) Model:
  - North American Regional Reanalysis (NARR) boundary and initial conditions
  - 6-hour spin-up [Jeong et al., 2012a, JGR]
  - Two-way nesting with four nest levels (five domains)
  - 4-km domain covers most of California
  - 5-layer thermal diffusion land surface scheme (LSM)
  - MYJ Planetary Boundary Layer (PBL) scheme

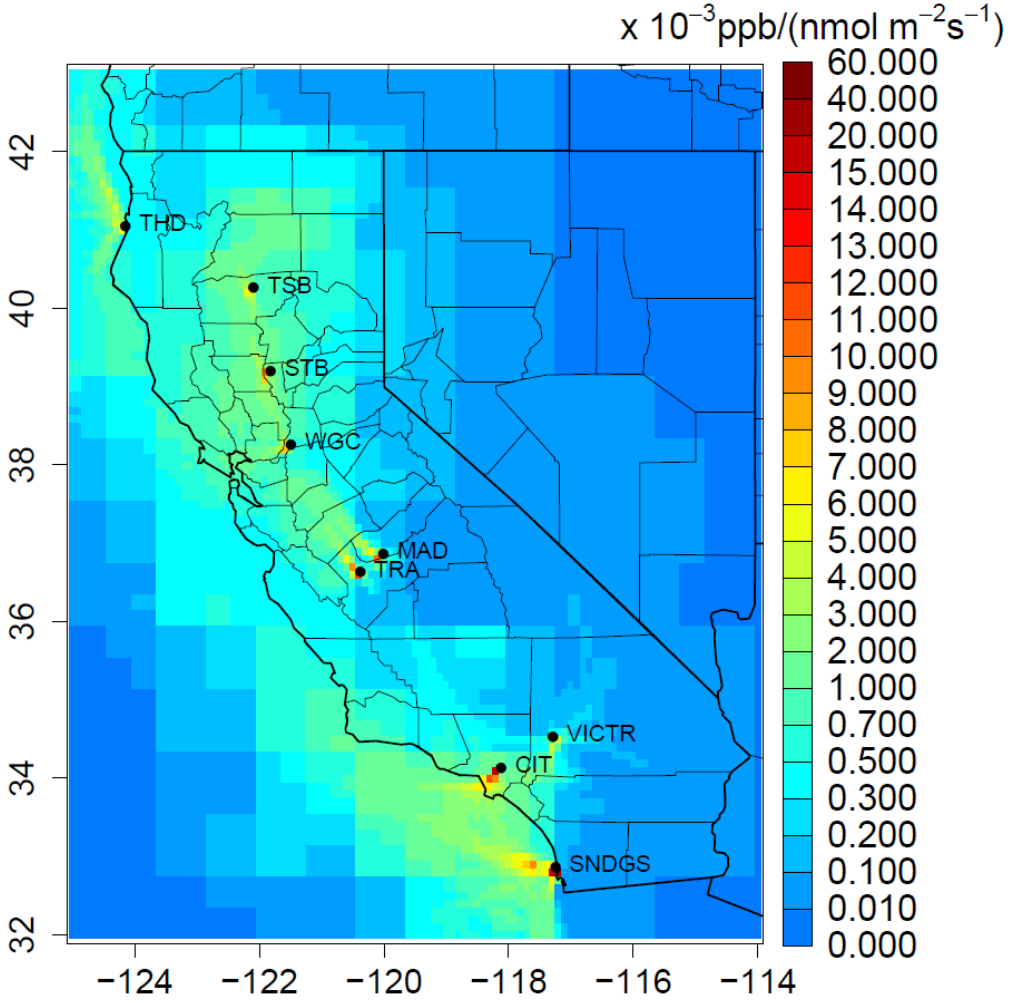
Domain Configuration for WRF



Transport Model Simulations

- Stochastic Time-Inverted Lagrangian Transport (STILT) model is used to simulate backward trajectories
  - Footprints are calculated based on 7-day backward trajectories
- Multiple towers improve sensitivity over the Central Valley and the Southern California air basin (SoCAB)
- CH_4 background values are estimated using NOAA curtain and particle trajectories (e.g. Jeong et al., 2012b)

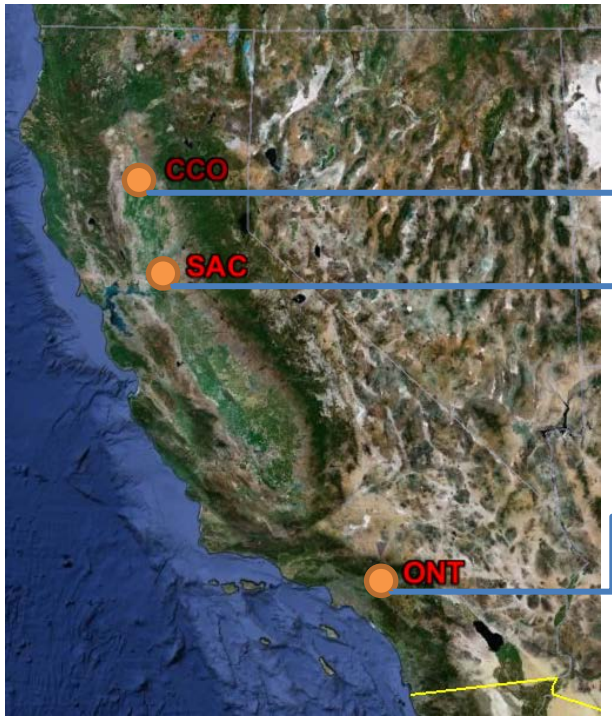
Mean Afternoon Footprints (June 2012)



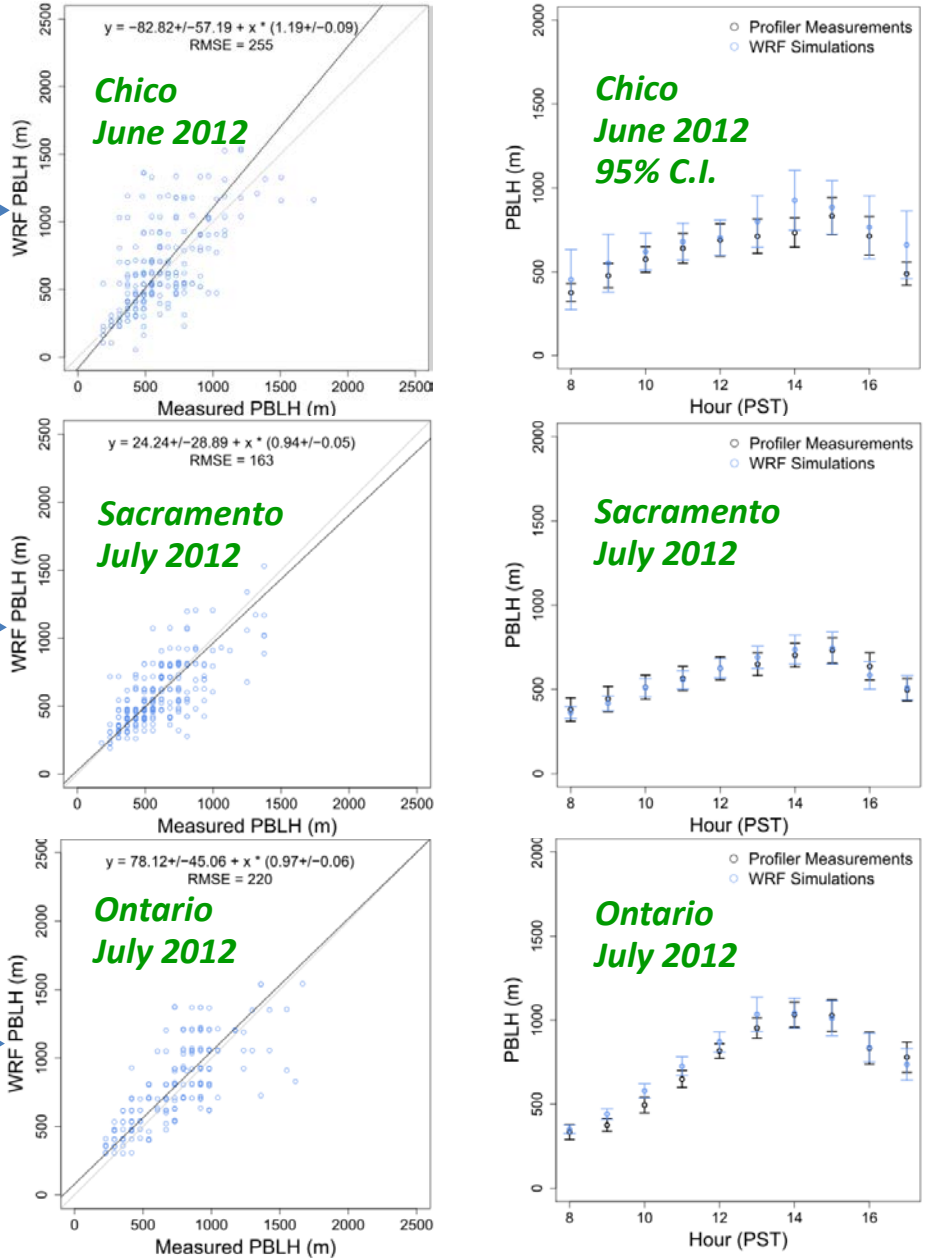
Uncertainty Analysis for Inversion

- Estimate uncertainty for each site and by error source (e.g., mixing depth, background)
- Quadrature sum of uncertainty vary by GHG measurement site: 30 - 80% of mean measured signal

Wind Profiler Measurement Sites



Comparison of Mixing Depth: WRF vs. Profiler

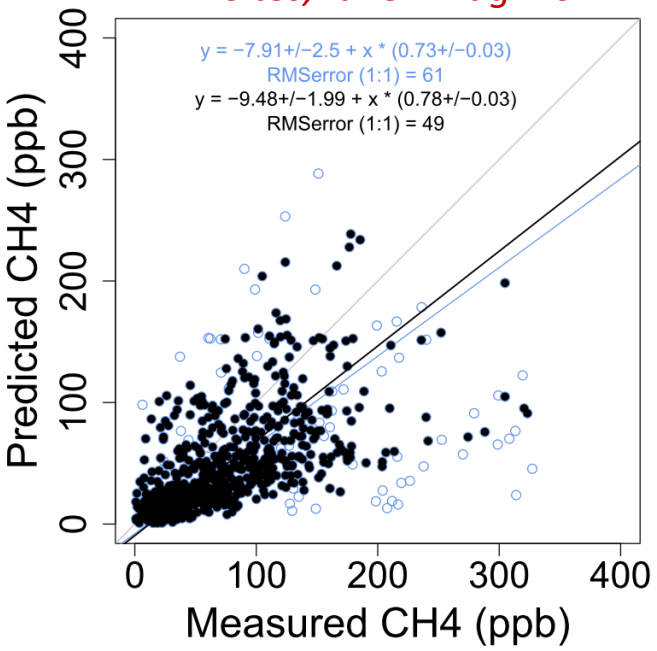


Model Measurement Comparison

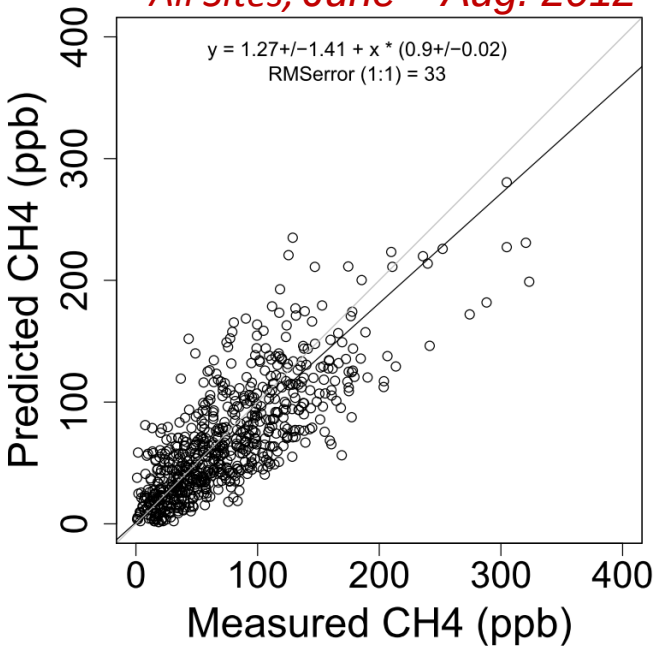
Summer 2012

- Before inversion, CALGEM predicted 3hr averaged well-mixed CH_4 ~70% of measurements before optimization
- After inversion, residual error reduced ~ 33%
- EDGAR42 prior almost certainly overestimates SoCAB CH_4 emissions

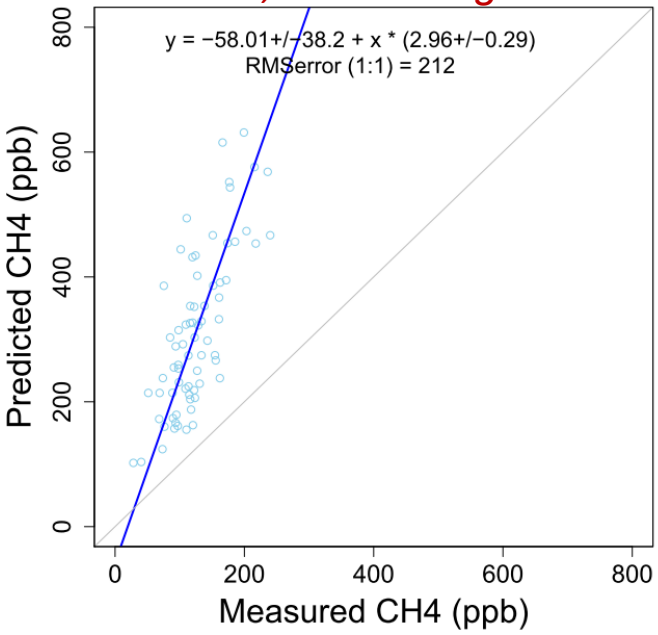
Before Inversion (CALGEM)
All Sites, June – Aug. 2012



After Inversion (CALGEM)
All Sites, June – Aug. 2012



Before Inversion (EDGAR42)
Caltech, June – Aug. 2012



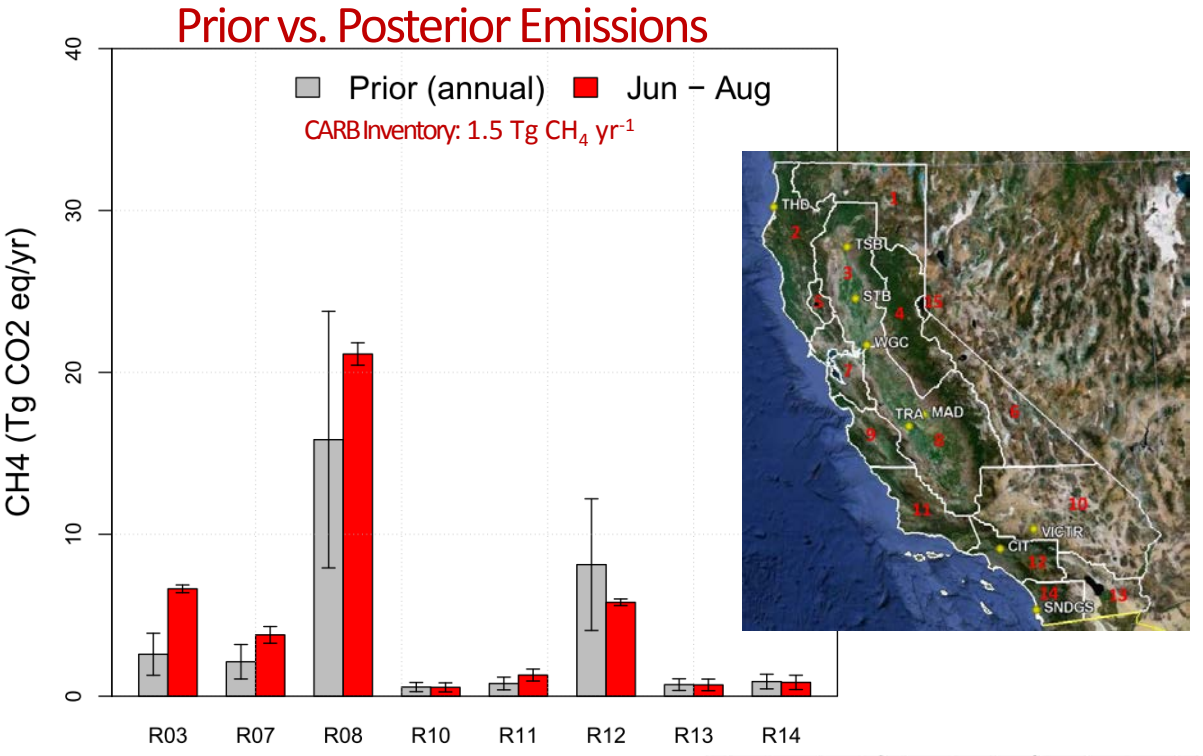
Region-based Bayesian Inversion

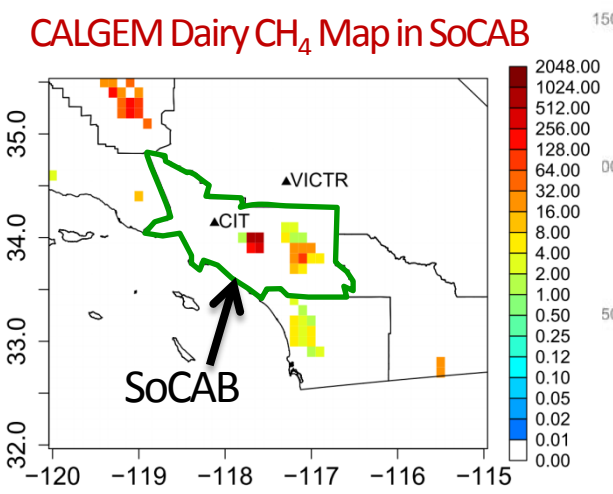
- Significant error reductions both in the Central Valley (Reg. 3 & 8) and in SoCAB (Reg. 12)

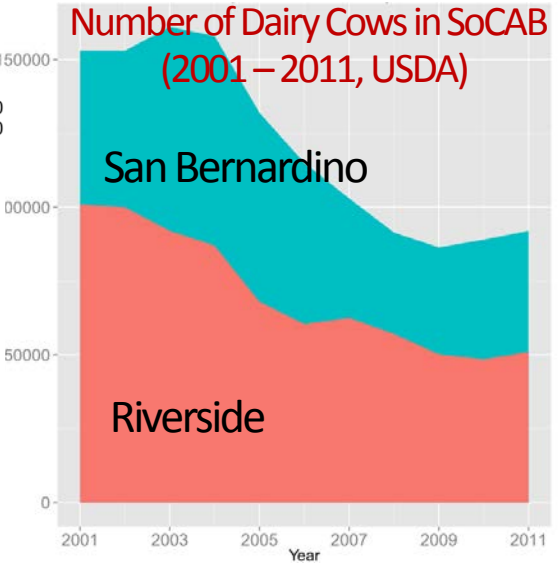
- CA total emissions (2028±91 Gg CH_4 yr^{-1} or 1.3±0.1x CARB inventory) are consistent with previous studies [Jeong et al. & Santoni et al., in review]

- Higher emissions in the Central Valley (1319±53 Gg CO_2eq) than the prior, consistent with previous studies

- Lower emissions in SoCAB partially explained by decline in dairy cows in SoCAB



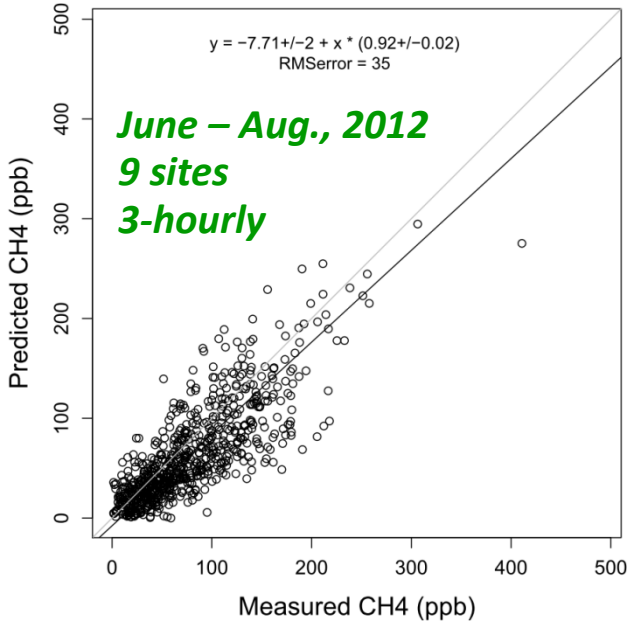




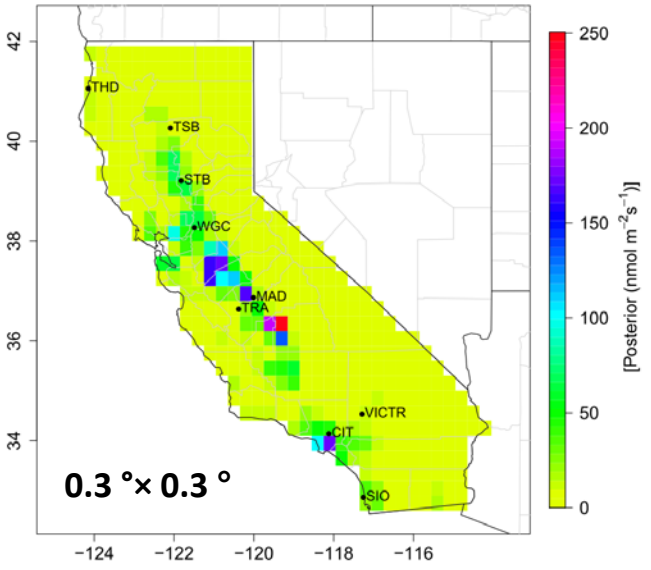
Pixel-based Bayesian Inversion

- Preliminary results show consistent emissions with region-based Bayesian analysis: CA total CH_4 = 1830±120 Gg CO_2eq/yr or 1.2±0.1 times CARB inventory
- Estimate higher emissions in the Central Valley and lower emissions in SoCAB than CALGEM prior
- Comparison with previous studies
  - CA total: consistent with Jeong et al. [in review] and Santoni et al. [in review]
  - SoCAB (270±33 Gg CH_4): consistent with Santoni et al. [in review], but lower than CO-based estimates (e.g., Wennberg et al., 2012; Peischl et al., 2013)

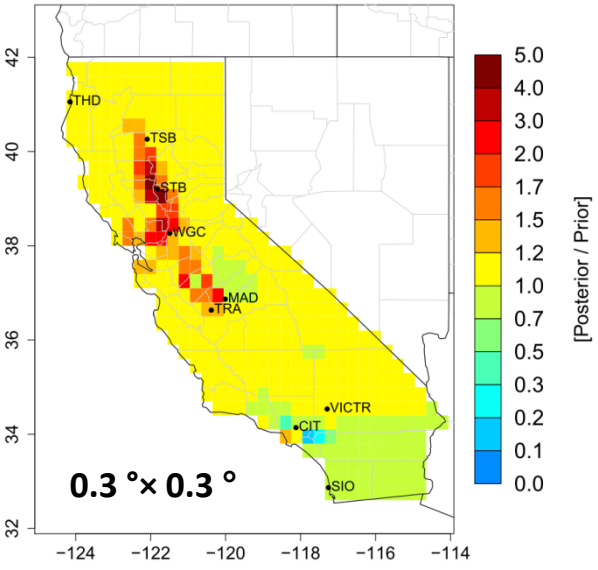
Pred. vs. Meas. After Inversion



Posterior Emissions



Posterior / Prior



Conclusions

- Bayesian Inverse modeling using a network of measurements across California constrains a significant portion of emission regions (>90% of total emissions)
- Two Bayesian inversions suggest State total emissions are 1.1-1.4 times CARB total CH_4 emissions
  - Actual CH_4 emissions are higher in the Central Valley and likely lower in SoCAB than the CALGEM prior
- A full annual analysis will make a significant process in constraining California CH_4 emissions towards AB-32
- Attribution to source sectors using additional trace gas species will improve estimate of California total emissions