Seasonal Variations in CH_4 and N_2O Emissions from Central California

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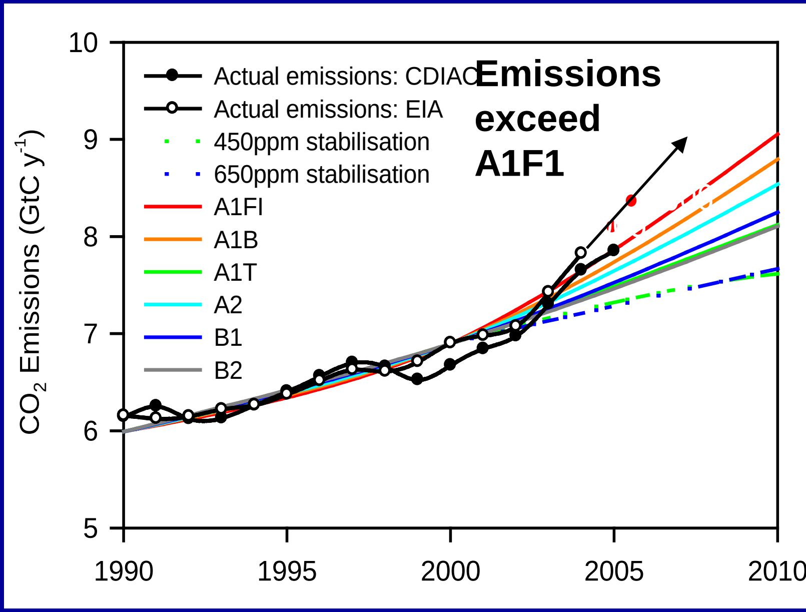
Verification is Crucial for Future Control

- **GHG emissions currently exceed even IPCC A1F1 “high growth” scenario**
- **UNFCC reporting of GHG emissions is currently optional**
- **Progress on Copenhagen emissions reductions agreements was limited, in part, by lack of verification capability. President Obama: "[verification] must, however, ensure that an accord is credible, and that we are living up to our mutual obligations.”**
- **National Academy call for progress on capability for emissions verification: “Verifying Greenhouse Gas Emissions: Methods to Support International Climate Agreements”**

Net Global Carbon Dioxide Emissions (pgC yr-1)



Global Carbon Project
Adapted from Raupach et al. 2007, PNAS

California’s legislated GHG emission controls (AB-32) will serve as an test case for verification activities

California Greenhouse Gas Emissions Measurement Project (calgem.lbl.gov) LBNL - NOAA Collaboration

Sutro Tower
(232 m agl)
Oceanic + urban

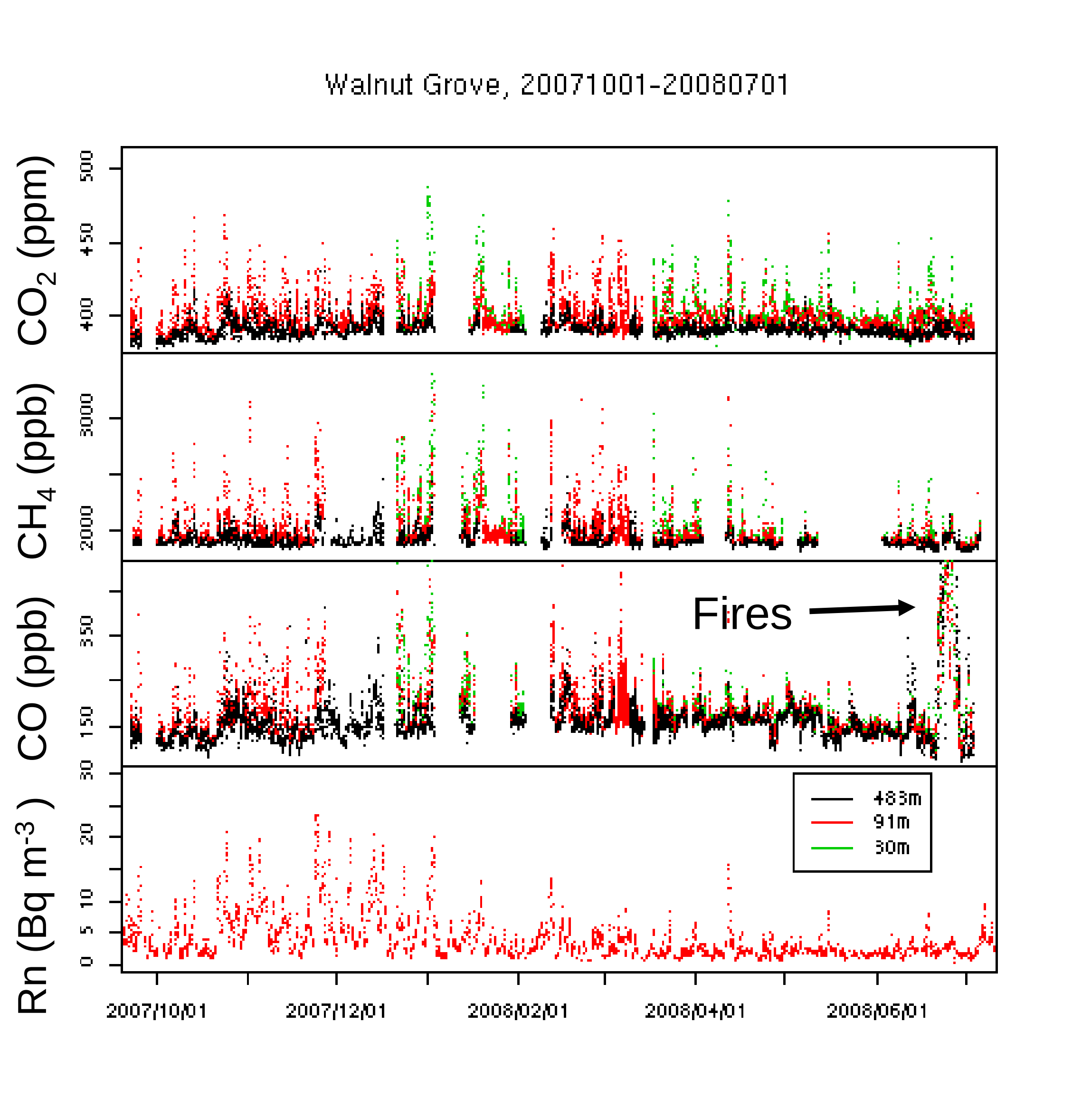
Walnut Grove
(483 m agl)
Central Valley + Bay Area

Daily (flasks):
CO2, CO, CH4, N2O
SF6, halocarb, VOC
$^{13}CO_2$, $^{13}CH_4$
Radiocarbon $^{14}CO_2$

Continuous:
CH_4, CO_2, CO, ^{222}Rn

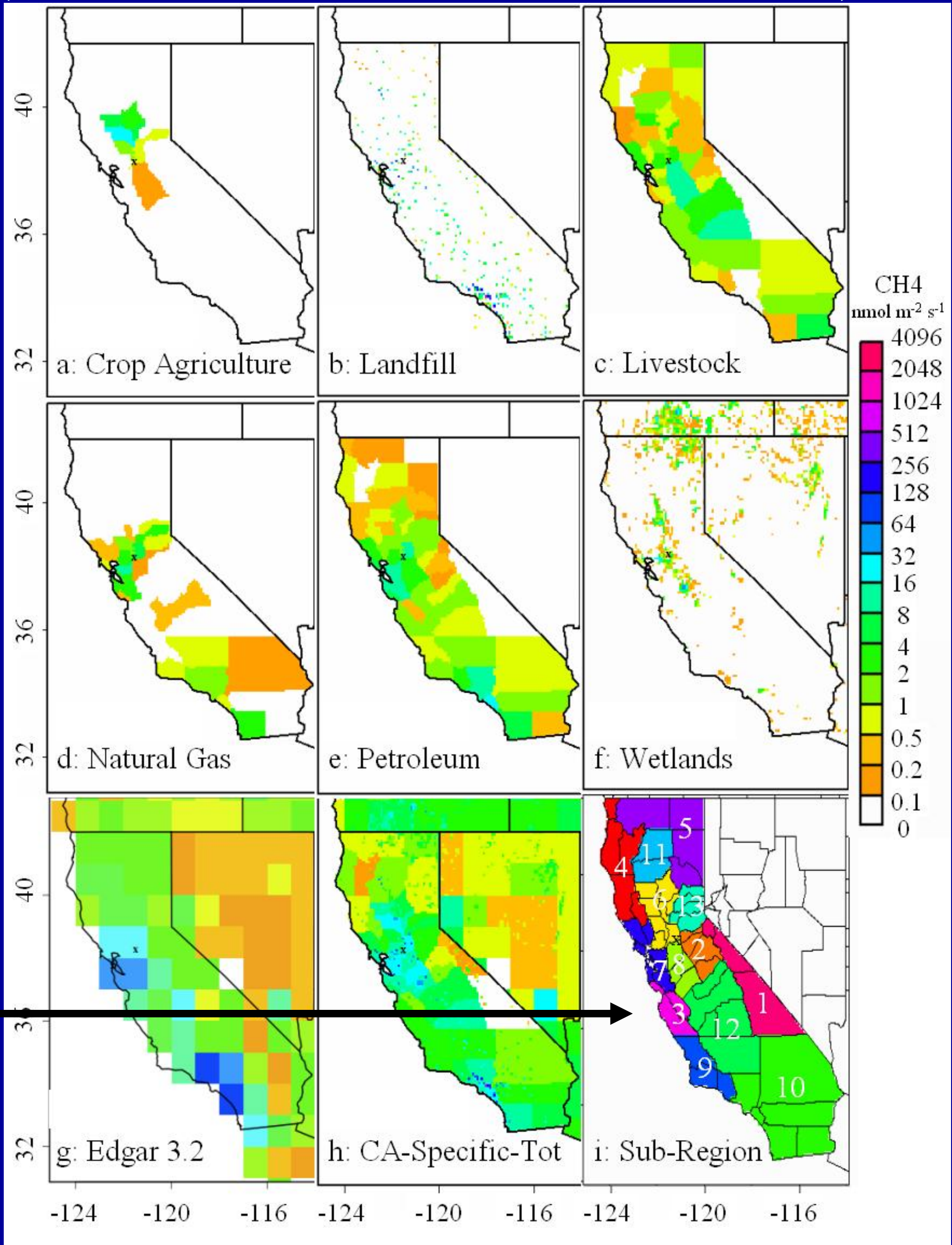
In-situ Measurements at Walnut Grove

- Elevated mixing ratios at 30, 91m indicate strong local-regional emissions
- Synoptic variations offer opportunity to extract emissions information
- 483 m mixing ratios generally near background levels at night (decouple from surface influence)



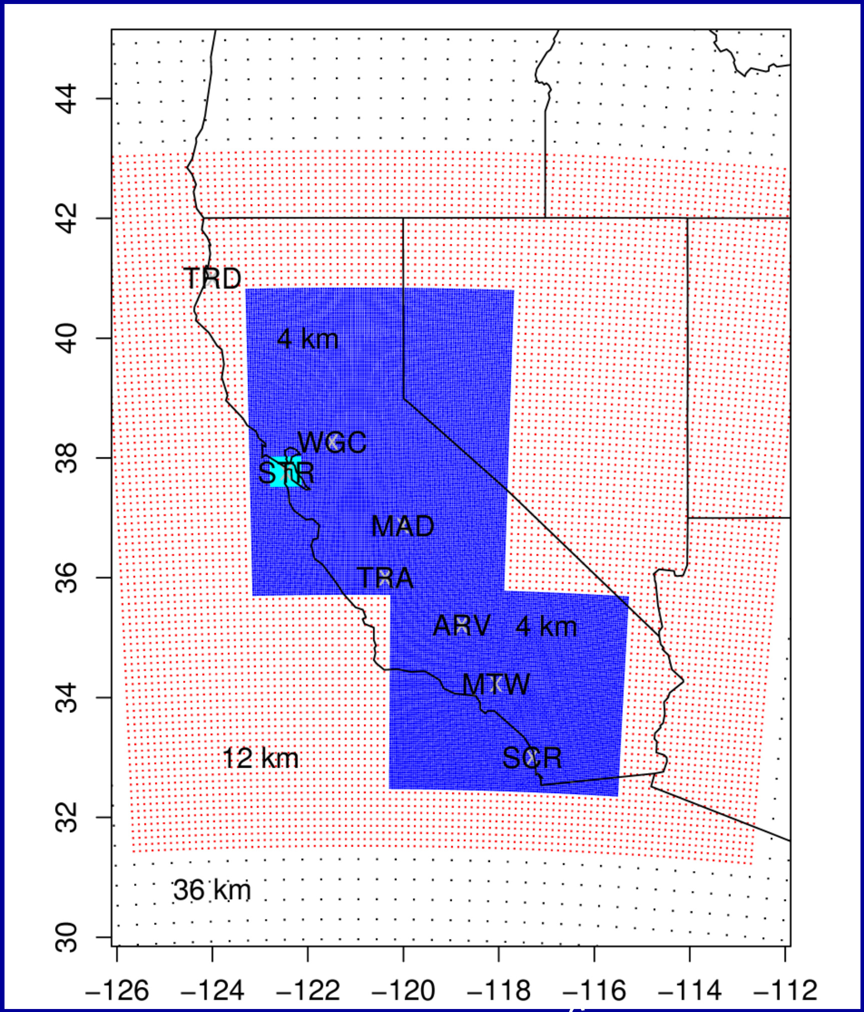
a priori CH_4 Emissions (henceforth assumed static)

- Crop Agriculture (Salas)
- Landfill (point sources)
- Livestock (USDA)
- Natural gas dist./use
- Petroleum refining and use
- Wetlands (Potter et al.)
- Above sum to CA-specific
- EDGAR3.2 (1x1degree)
  - Landfills and petroleum extraction and refining ~ 2 x CA estimates
- Also: regional subdivision for spatial analysis



Meteorological Model for CA Domain

- Weather Research Forecast Model (WRF)
  - Nested domains
    - 36 km (W. US), 12 km (CA)
    - 4 km (Central Valley)
    - 1.3 km (Sutro, Mt Wilson)
  - NARR boundary forcing and internal nudging
  - Daily runs, hourly output

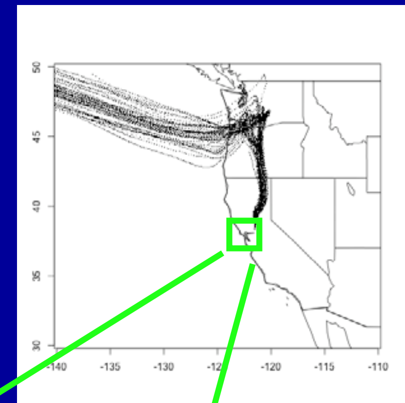


WRF-STILT Footprints for WGC Tower

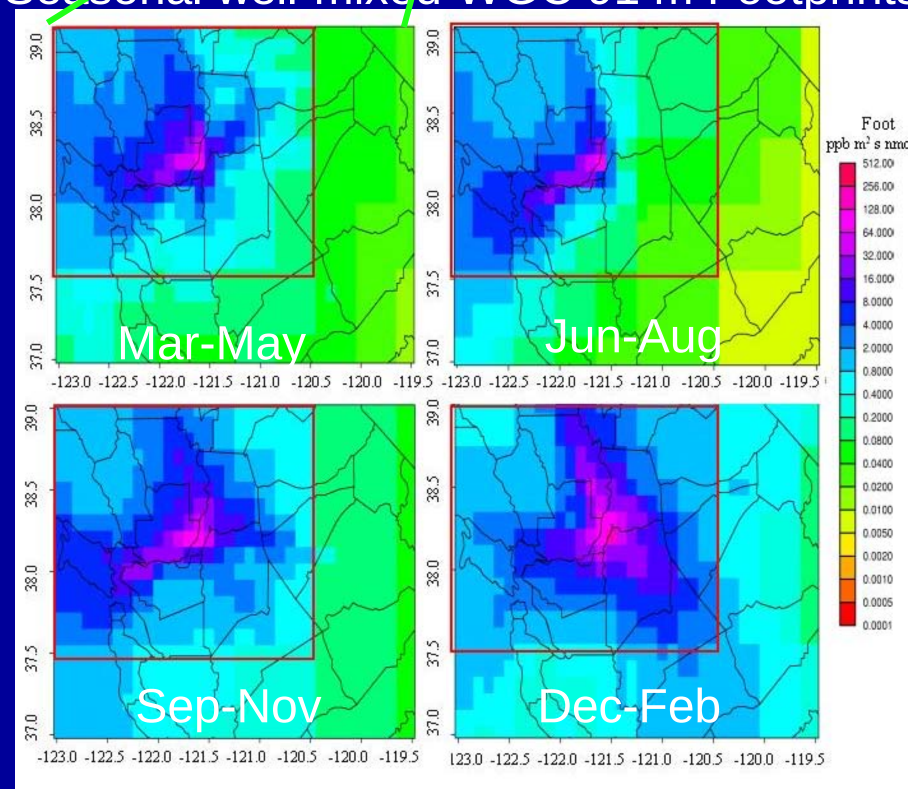
- Footprint from ensemble of particle trajectories, p

$$f(\underline{X}_r,t_r|x_i,y_j,t_m) \propto \sum_{p=1..N} \left(\frac{\Delta t}{Zi}\right) \Big\| i,j,m,p$$

- Seasonally averaged footprints:
  - largest surface influences (purple) for Bay Area and Central Valley
  - Summer channeling of flow through Golden Gate to tower reduces valley influence



Seasonal well-mixed WGC 91 m Footprints

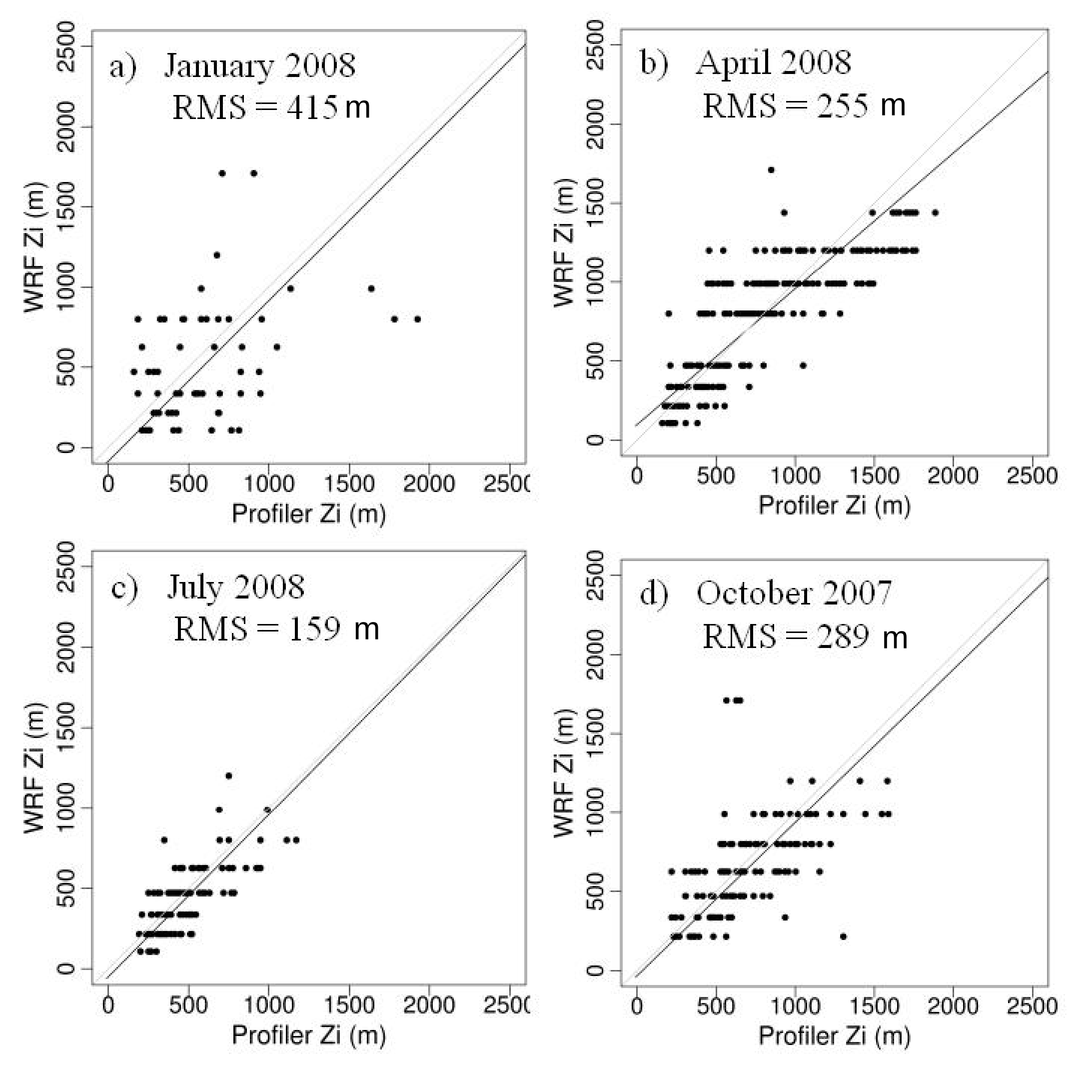


Uncertainty Estimation

- Quantify errors sources
- Propagate errors through modeling system to provide quantitative uncertainties
  - Boundary layer ~ 25 %
  - Wind Velocity ~ 10%
  - GHG background ~ 15 %
  - Inventory resolution ~ 8 %
  - Other ~ 8%
- Quadrature sum ~ 32%

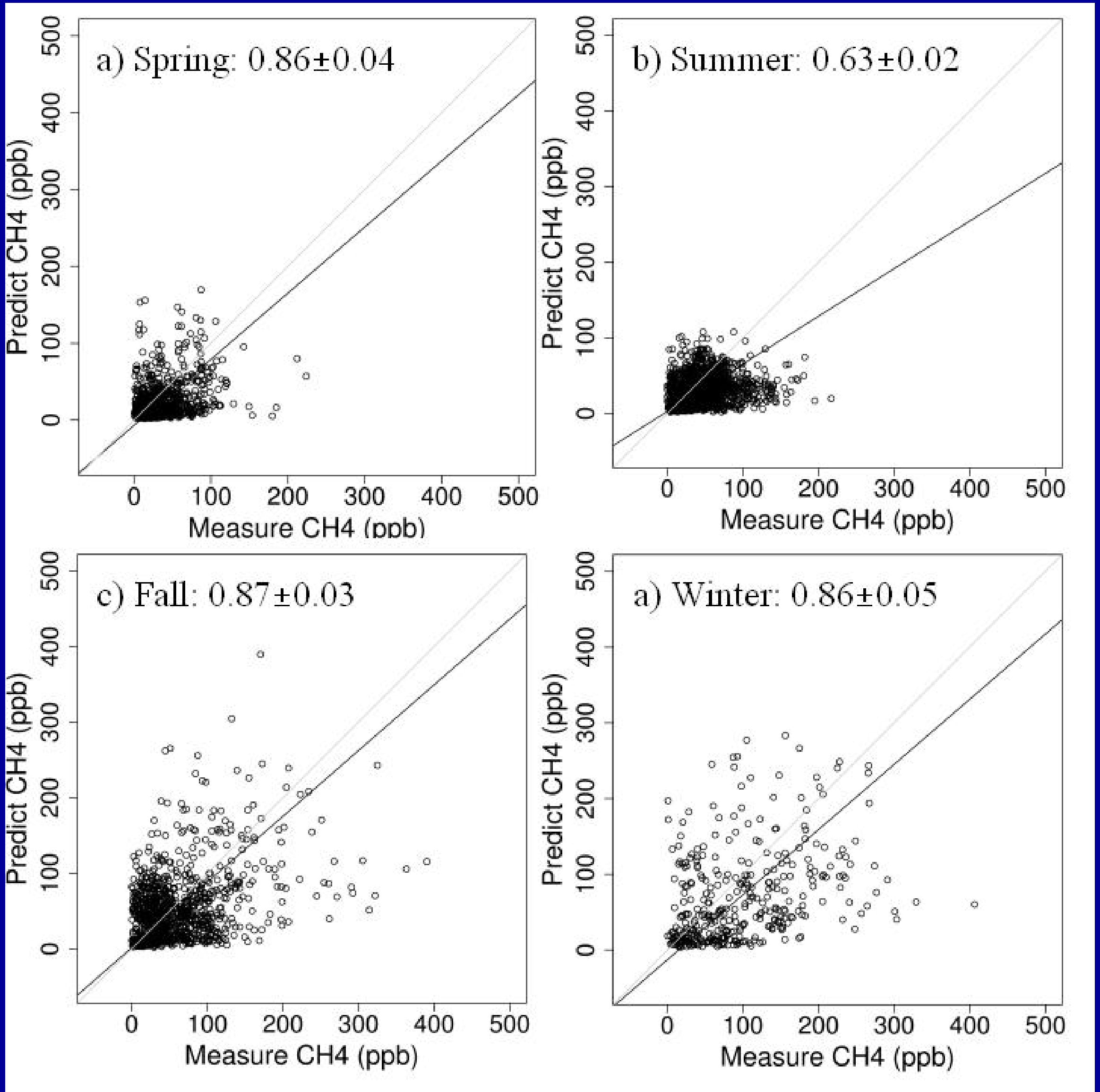
of signal for individual time points

WRF-STILT versus Profiler PBL Depth



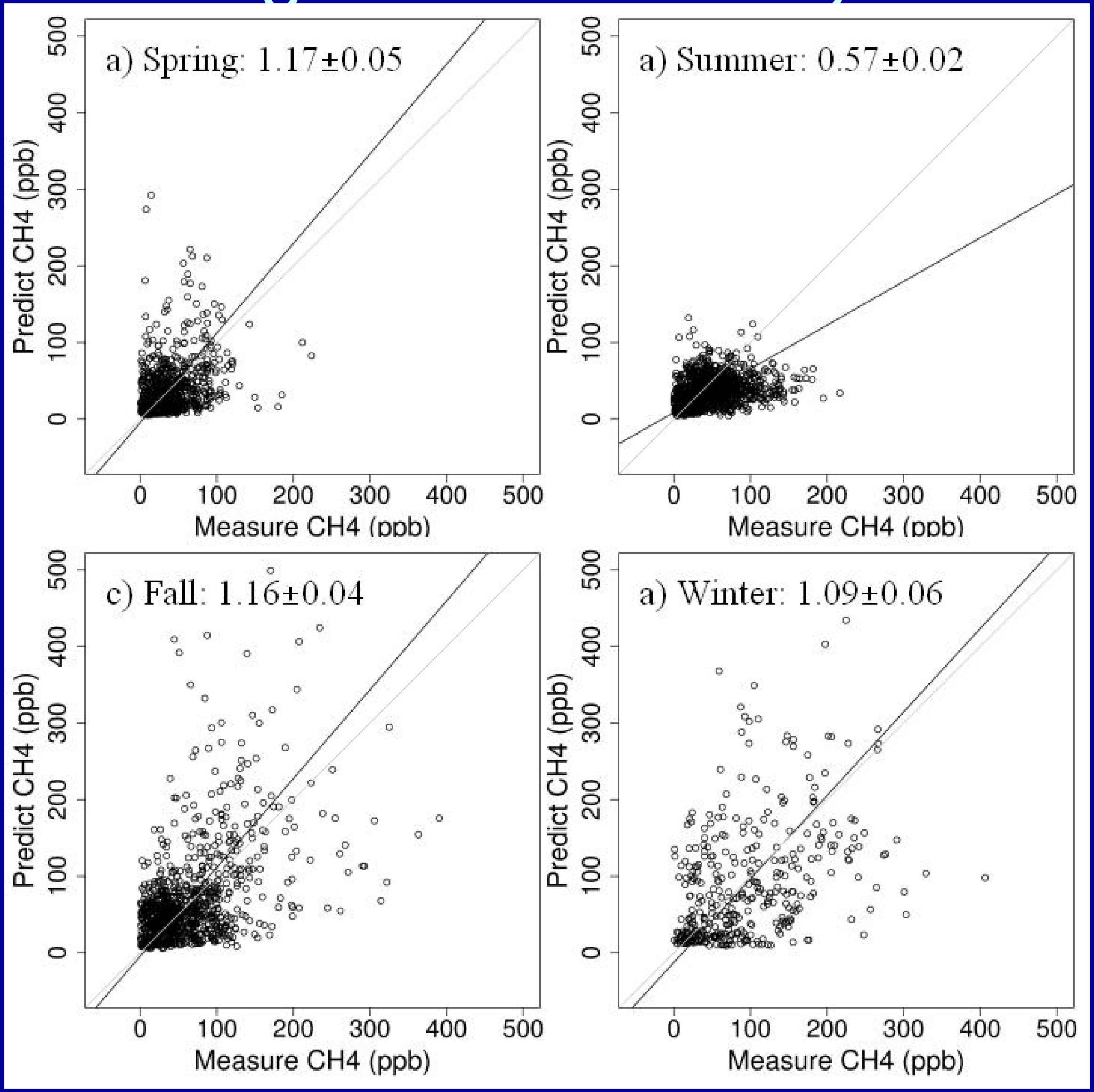
Compare Measured and Predicted CH_4 by Season for CA Specific Inventory

- Data screened for well-mixed CH_4 and consistency in ^{222}Rn
- Scatter approximately consistent with estimated uncertainties
- CH_4 emissions appear under-estimated (~ 15%) in CA inventory for most periods
- Summer emissions may be significantly under-estimated but transport uncertainty may be at issue



Compare Measured and Predicted CH_4 by Season for Edgar 3.2 Inventory

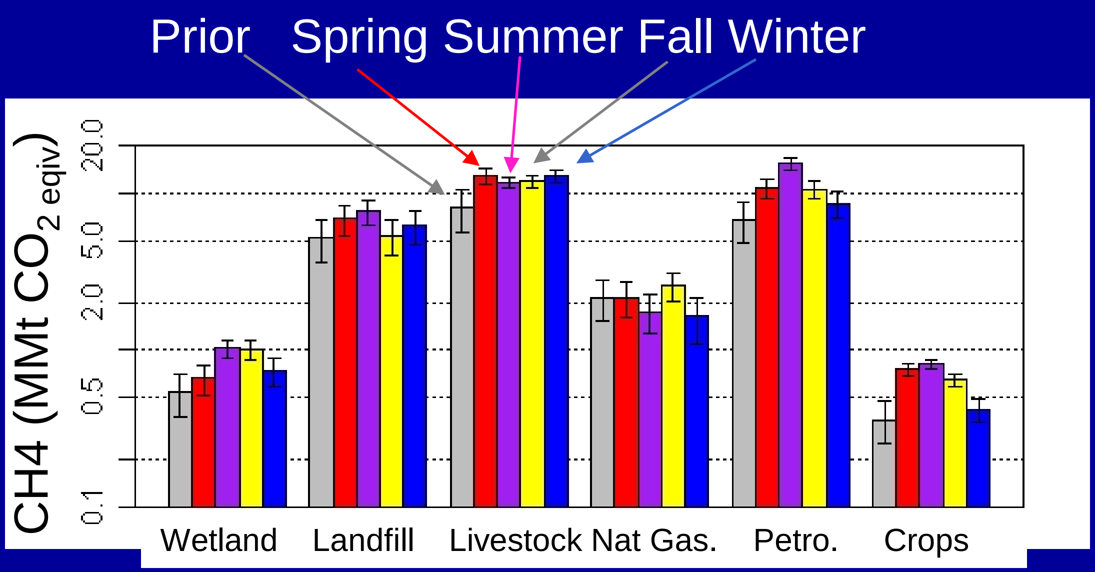
- Scatter approximately consistent with estimated uncertainties
- Edgar CH_4 emissions appear slightly over-estimated in CA except in summer



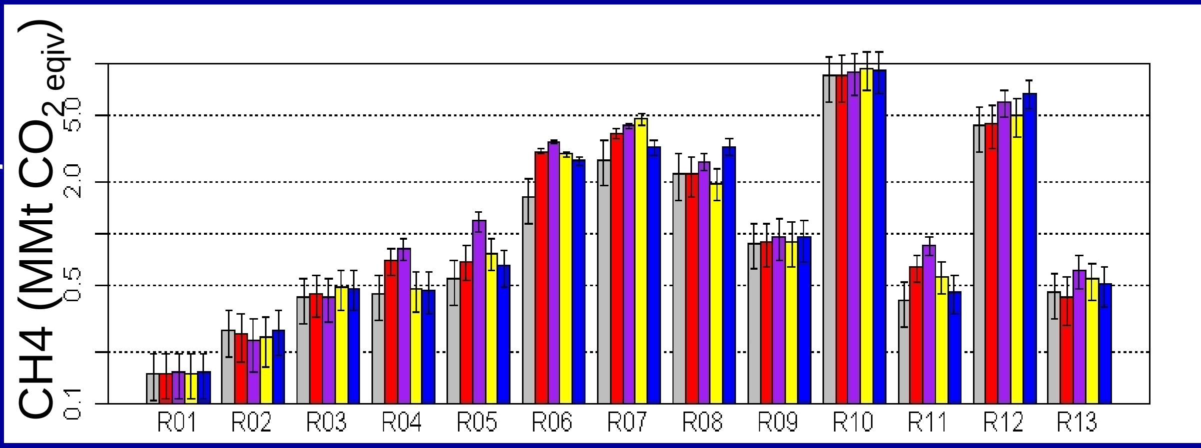
Seasonality in CH_4 emissions

- Several sources show higher emissions in summer
  - Partially consistent with biogeochemical models
  - However: imperfect spatial distributions of sources may bias attribution
- Region analysis
  - Data reduce emissions uncertainty for regions near tower
  - Partially captures seasonality in spatial distribution

Source Sector Analysis by Season

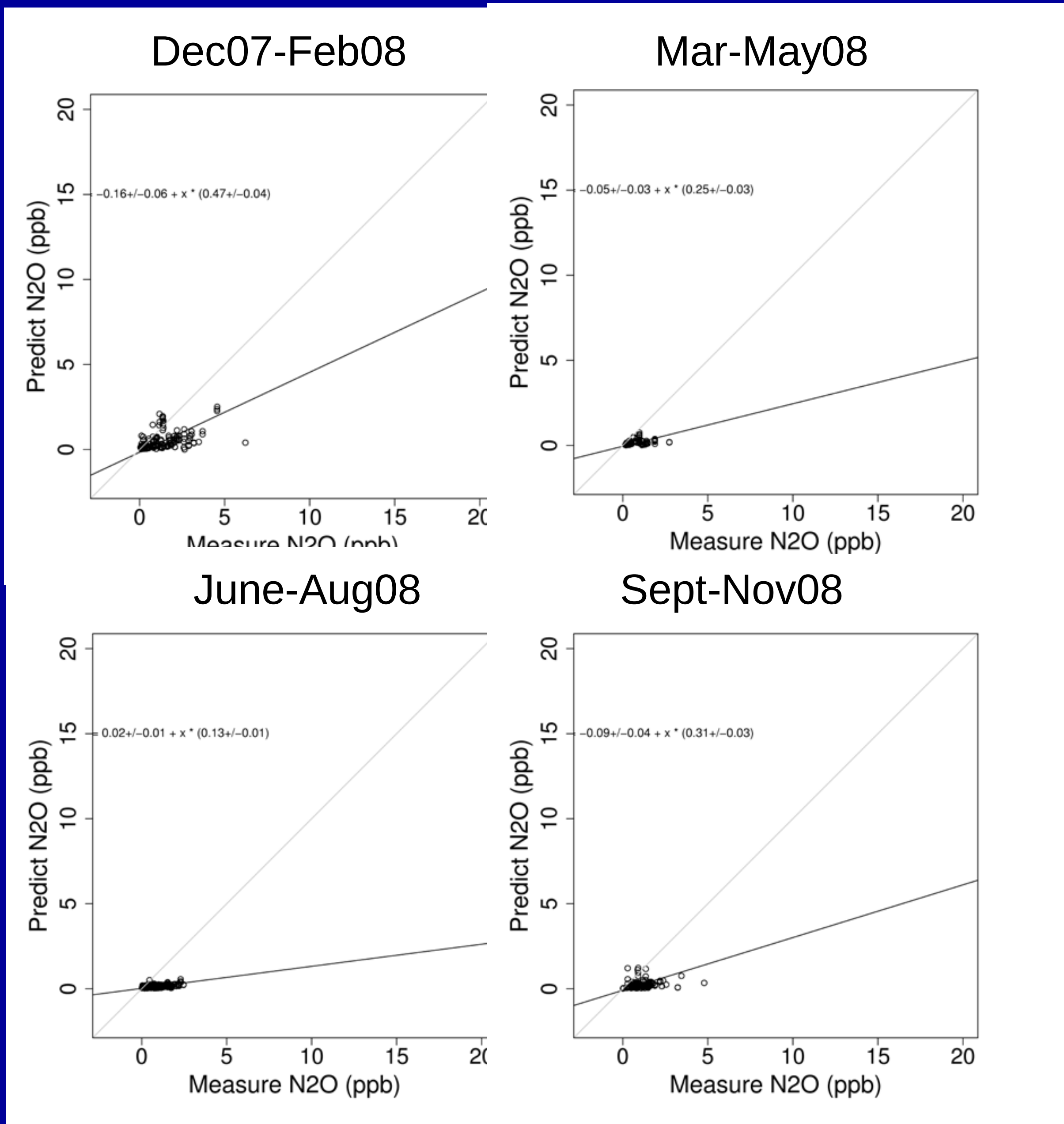


Region Analysis by Season



Preliminary N_2O Comparison

- Compare measured and predicted N_2O using Edgar 3.2 emission inventory
- N_2O flask data is sparse compared to *in situ* CH_4
- Slopes suggest actual emissions 2-8 x higher than inventory
- Coarse (1º) spatial resolution of Edgar inventory likely adds uncertainty



Conclusions

- Careful attention to uncertainties essential for quantitative emission inventory assessment
  - Tower-based measurement errors are now small compared to other sources of uncertainty
  - Meteorological uncertainty appears dominant, requiring multiple measurements and methods (e.g., wind profilers, tracer gases)
- Initial inverse estimates of Central California emissions:
  - CA specific CH_4 ~ 20% low; Edgar ~ 20% high (summer?)
  - Edgar 3.2 N_2O emissions appear 2-8 x low
- Tall-tower measurements in valley appear to constrain ~ 100-200km region surrounding tower
  - Network of towers required to capture regional emissions from California
  - Satellite sensors will dramatically increase data density but uncertainty (particularly biases) require careful treatment

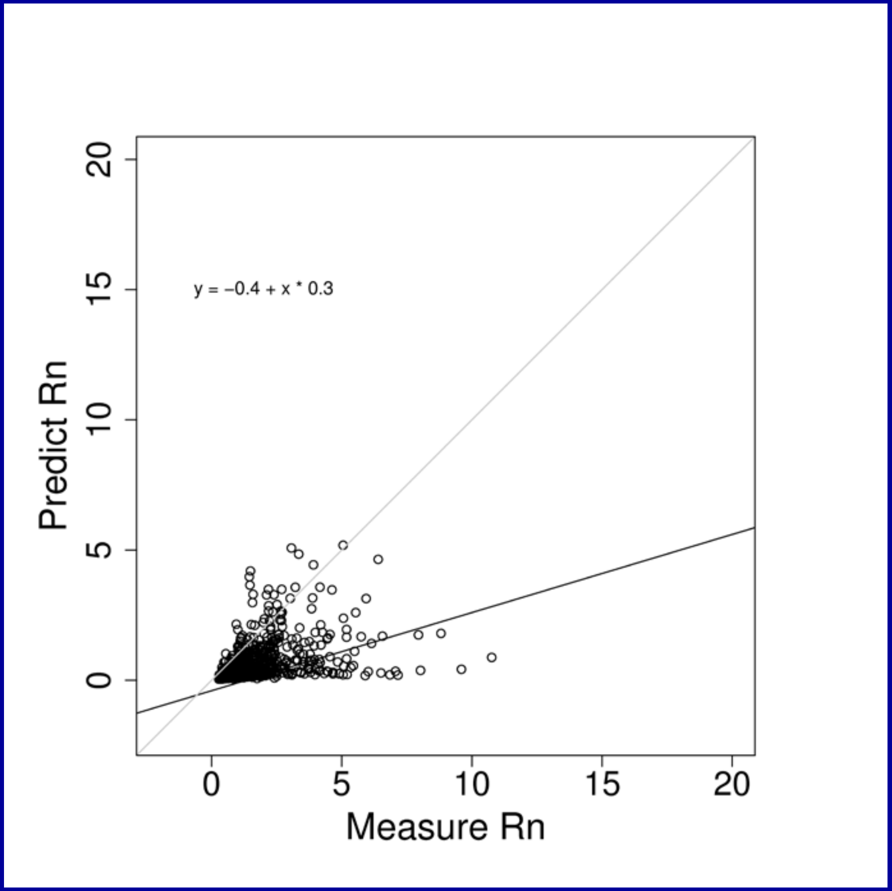

Thank You

Outline

- Need for GHG emissions verification
- Focus on California's GHG emissions
- The California Greenhouse Gas Emission Measurement Project (CALGEM)
- Estimates of seasonal CH_4 & N_2O emissions
- Conclusions

^{222}Radon Discriminant of Transport Failure

- Compute predicted ^{222}Rn signal using two emission maps
  - Uniform 1 atom cm^{-2} s^{-1}
  - ^{222}Rn emissions scaled from soil ^{238}U maps
- Compare measured and predicted ^{222}Rn
- Exclude time points with low predicted:measured ratio
  - 6% data removed in 2008

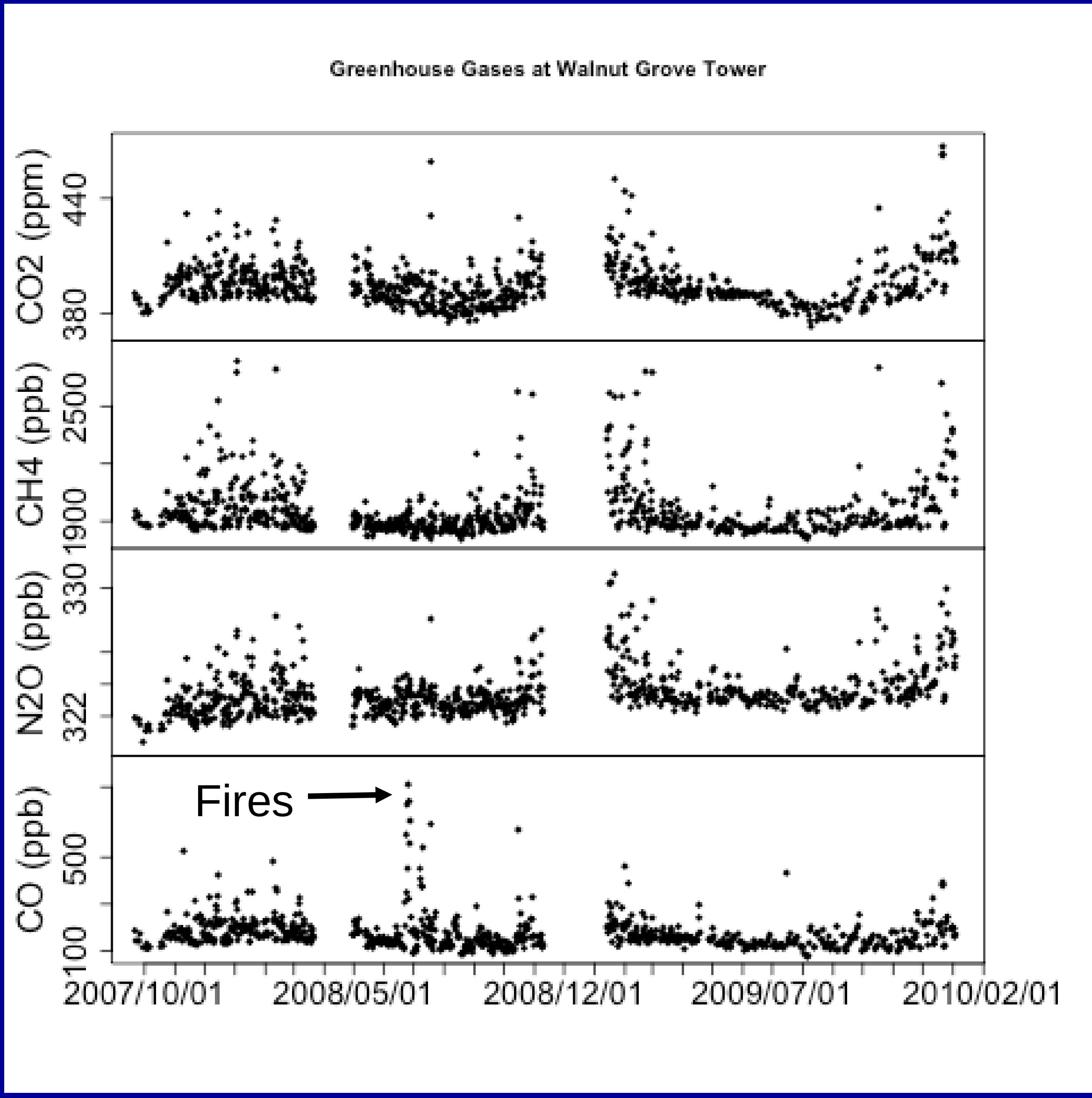


GHG Emissions Verification

- Supports Policy Needs
  - Timely decision-making & mitigation/adaptation assessment
  - Distinguish anthropogenic from natural emissions
  - Separate flows to/from terrestrial biosphere & ocean
  - Provide information on geo-political spatio-temporal scales
- Transparent & Objective
  - Traceable publicly availability data, models, & products
  - Attention to bias/errors (regular calibration & validation)
- Global, Sustained, Flexible, & Scalable
  - Continue operation over decades
  - Progress from CO_2 to all GHG species
  - Combine operational and research aspects

Flask Measurements at Walnut Grove

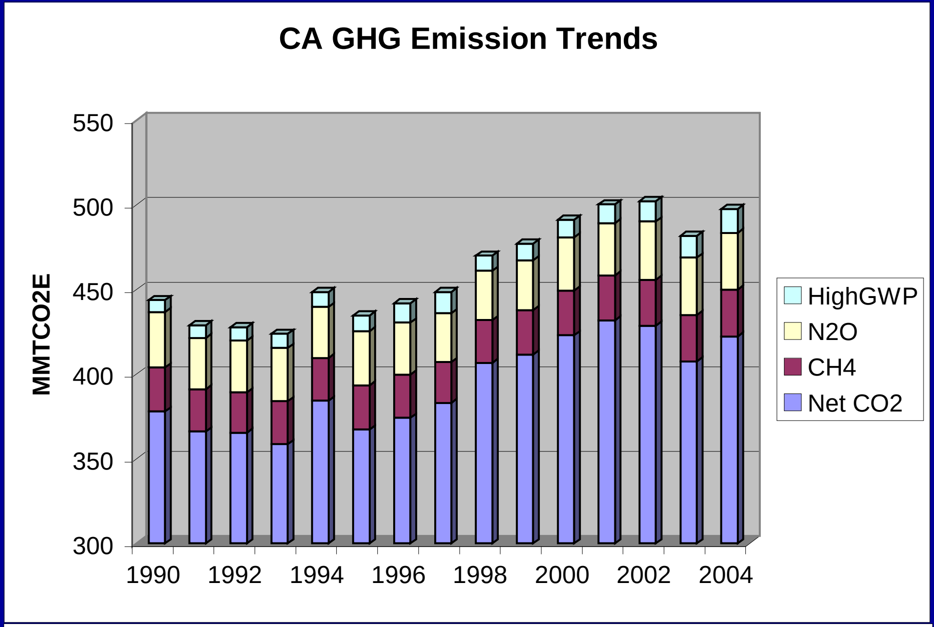
- Even twice daily flasks capture significant variability
- Impact of regional emissions present in measured data
- Strong diurnal variations due to boundary layer
- Seasonal cycles due to varied emissions, winds, and boundary layer depth

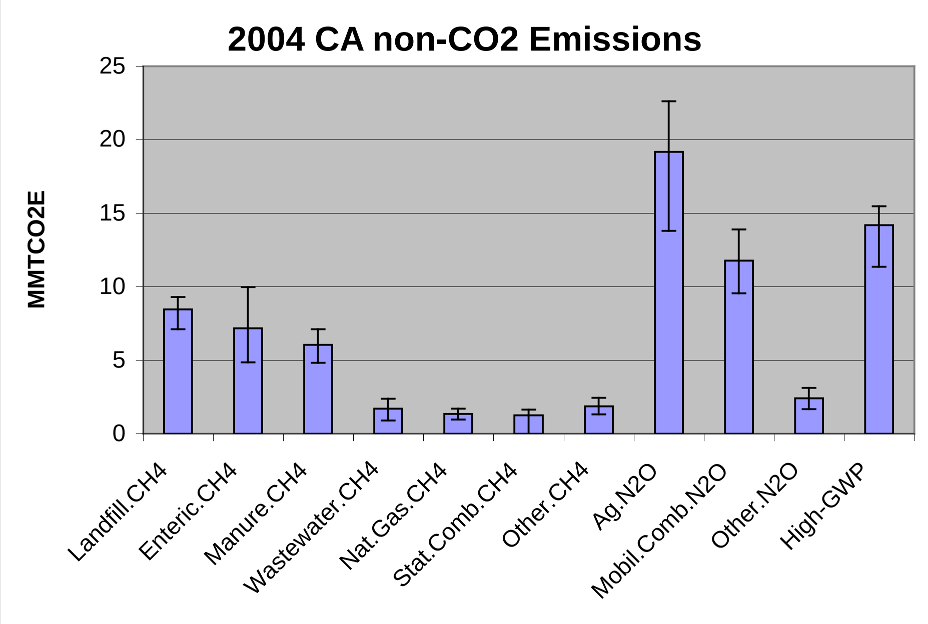


California GHG Emissions

- 2007, California becomes first state in US to legislate GHG controls
  - AB-32: 1990 levels in 2020
  - The Stick: Quantitative verification of emissions reductions required to assess success of AB-32
  - The Carrot: Verified GHG emission reduction has economic value to drive behavior & innovation
- Non-CO_2 GHG emissions comparable to CO_2 but…
  - Biological sources are not readily metered
  - Uncertainties in inventories are large (even using US average fractional error estimates)
- Atmospheric inverse method provides independent check

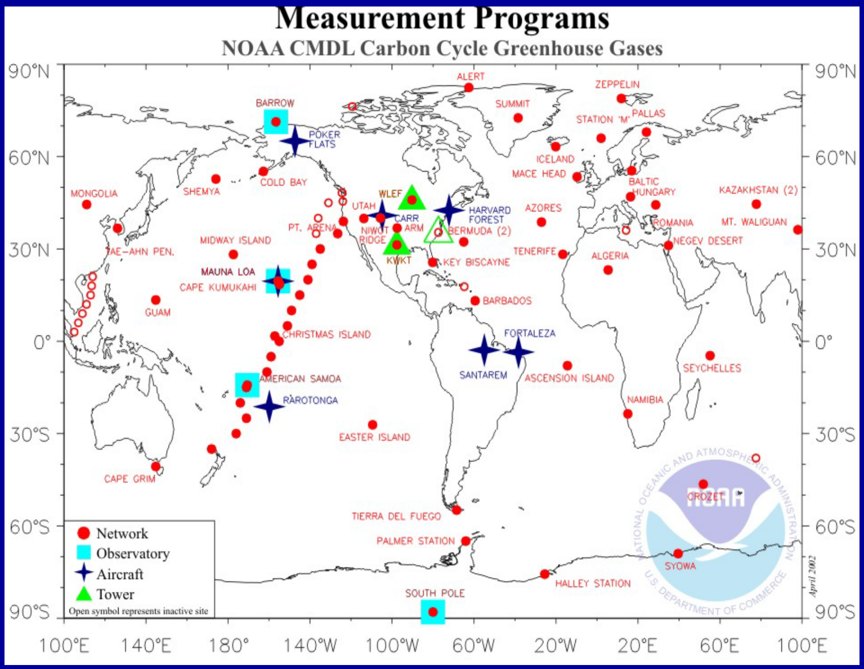
CEC, 2006 ; USEPA, 2007

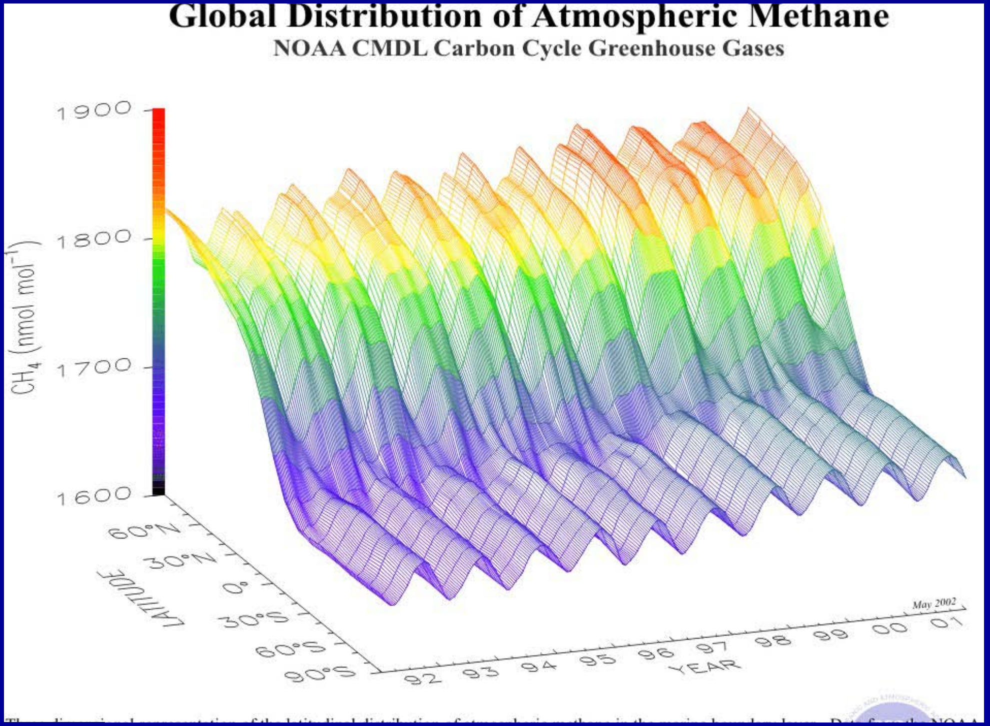




Global CH_4 Background

- Global monitoring provides data for emissions estimates
- CH_4 exhibits latitudinal gradient due to northern hemisphere sources





(NOAA-ESRL Global Monitoring)