Predicting Atmospheric Methane Signals from Regional Scale Emissions in California: Toward Inverse Model Analysis

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BACKGROUND

The State of California has made control of GHG emissions a priority. In California, methane and other non-CO_2 GHGs are estimated to be a significant fraction (~ 15%) of total GHG forcing, with CH_4 contributing a large share.

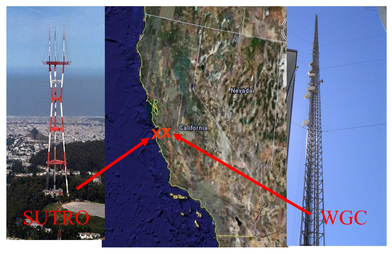
However, current inventory and model-based estimates of non-CO_2 GHG emissions are extremely uncertain, because many of the factors controlling emissions are poorly quantified. The California Energy Commission is supporting the design and implementation of initial measurements to estimate regional emissions of non-CO_2 GHGs using inverse techniques.

APPROACH

CH_4 concentration "signals" are simulated for specific measurement sites using ***a priori* emission maps** and **surface footprints** that are calculated from an atmospheric Lagrangian transport model driven by **mesoscale meteorological** model simulations. The simulated signals have noise added to them to reflect instrument uncertainty and errors due in the meteorological model. Then an **inverse model** is used to reconstruct the best estimate of resulting ***a posteriori* surface emissions and uncertainties**, given the model inputs.

MEASUREMENT SITES

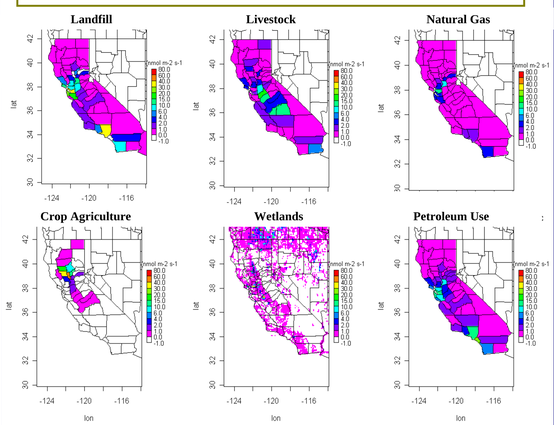
Two tall towers were chosen as observation sites for the simulations described in this work. The towers are located above San Francisco (SUTRO) and in the Sacramento delta near Walnut Grove, CA (WGC).



A PRIORI CH_4 EMISSION MAPS

- Landfills (LF): computed with loading and composition data
- Natural gas (NG): Gas usage from the California Air Resources Board (CARB)
- Petroleum related (PL): non-reactive VOC emissions (CARB)
- Livestock (LS) CH_4: Emissions factor analysis (CARB)
- Wetlands (WL): NASA-CASA model (Potter et. al., 2006)
- Agricultural soils (DNDC): DNDC model (Salas, 2006)

A PRIORI CH_4 EMISSION MAPS



TRANSPORT MODELS

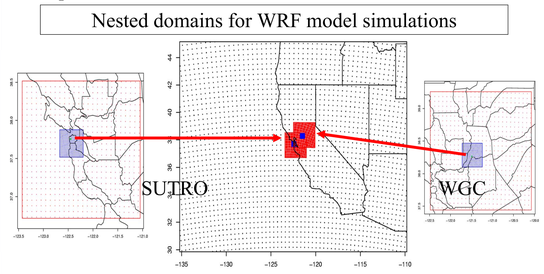
Concentration Influence Functions

Atmospheric signals were calculated for specific heights at each site by multiplying surface CH_4 emissions with influence functions, herein described as "footprints", calculated with the Stochastic Time-Inverted Lagrangian Transport (STILT) model (Lin, Gerbig et al., 2003). For each time point, the STILT model was configured to release 100 particles from the measurement location and then transport the particles backward in time 120 hr (5 days).

Meterological Models

Two sets of predicted meteorology were used to drive STILT. The first set was calculated previously using a version (Medvigy et al., 2005) of the RAMS model. The RAMS simulations were calculated at 45 km resolution for continental North America, and are henceforth labled BRAMS. The second set was calculated using a modified version of the WRF model (Skamarock, 2005), with ouput variables optimized for use with STILT (Nehrkorn et al., 2007). The WRF simulations were calculated on the nested grids at 40 (black), 8 (red), and 1.6 (blue) km resolutions for the domains shown below. Only the simulations at WGC are described in this poster .

Nested domains for WRF model simulations



Inversion

Predicted CH_4 concentrations, C, are calculated from the product of the STILT footprint, f, surface CH_4 emissions F, and a background CH_4 signal as:

$$\underline{C} = \underline{\underline{f}}\,\underline{F} + \underline{\underline{I}}\,\underline{C}_0$$

I is influence function for background CH_4 concentrations C_0. In the following work, we solve for multiplicative scaling factors for the relative strength of the emissions sources such that:

$$\underline{F} = \underline{\underline{\phi}}\,\underline{\lambda}$$

$$\underline{C} - \underline{\underline{I}}\,\underline{C}_0 = \underline{\underline{f}}\,\underline{\underline{\phi}}\,\underline{\lambda} + \varepsilon$$

where Φ is *a priori* CH_4 emission map, and λ is the scaling factor, and ε is an error term. In these simulations, C_0 was assumed to be zero. Following standard Baysian estimation methods for a linear system, the *a posteriori* estimate of λ and error covariance S_λ, are given by:

$$\hat{\underline{\lambda}} = (\underline{\underline{K}}^T \underline{\underline{S}}_\varepsilon^{-1} \underline{\underline{K}} + \underline{\underline{S}}_{prior}^{-1})^{-1} (\underline{\underline{K}}^T \underline{\underline{S}}^{-1} \underline{y} + \underline{\underline{S}}_{prior}^{-1} \underline{\lambda}_{prior})$$

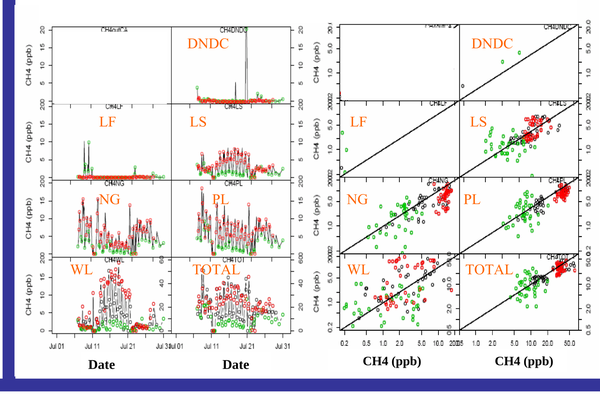
$$\hat{\underline{\underline{S}}}_\lambda = (\underline{\underline{K}}^T \underline{\underline{S}}_\varepsilon^{-1} \underline{\underline{K}} + \underline{\underline{S}}_{prior}^{-1})^{-1}$$

where y is the measured CH_4 signal, $K = \underline{\underline{f}}\,\underline{\underline{\phi}}$, and S_ε and S_{prior} are the measurement and *a priori* and *a posteriori* error covariance matrices respectively (Lin et al. 2004). In the following work, we set $\lambda_{prior} = 1$, $S_{prior} = 0.09$, assuming emissions were known to 30%. Sε was estimated from a quadratic sum of instrument noise (assumed to be 1 ppb) and "transport error" estimated from the difference between the simulated WRF and BRAMS CH_4 signals

RESULTS

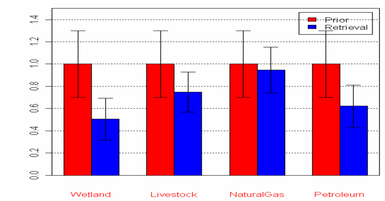
CH_4 Concentrations Predicted by STILT

Atmospheric CH_4 concentrations predicted for the WGC tower at 100 m agl in July, 2004, are shown below. The left figure shows CH_4 time series from WRF-STILT. At right, is the comparison of CH_4 concentration from WRF-STILT and BRAMS-STILT (time series not shown). WRF-STILT CH_4 concentrations agree reasonably well with BRAMS for all sources, particularly wetland (WL), livestock (LS), natural gas (NG), and petroleum use (PL), which dominate the contribution to total CH_4 signal in this simulation. The simulations show a strong diurnal cycle with lower daytime (green) and higher nighttime (red) CH_4 concentrations.



Inversion Results (WGC 100m)

Using the WRF signals as 'measurements', y, and BRAMS as the 'model', fϕ, we find that 1) the *a posteriori* uncertainties are reduced relative to the *a prior* uncertainty and 2) the λ values are < 1.0, consistent with the CH_4 signals simulated by WRF being smaller than those from BRAMS, particularly at night (see scatter plots).



CONCLUSIONS

- Simulated CH_4 signals obtained with BRAMS and WRF both show strong diurnal variations, and relatively consistent daytime concentrations, though nighttime concentrations differ.
- The inversion technique successfully retrieves the *a priori* emissions and improves on the *a priori* uncertainty in the existing emission inventory maps.

FURTHER WORK

- Estimate errors in WRF transport using surface and upper air measurements and incorporate into Sε.
- Investigate effects variable CH_4 background on inverse model retrieval.
- Compare tower measurements from SUTRO and WGC with WRF-STILT predictions and retrieve CA estimates of CH_4 emission from California.
- Incorporate additional tracers (e.g., CO, and CH_4 isotopes) to improve source attribution.

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