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Attribution of Methane Emissions in the Arctic and Continental US

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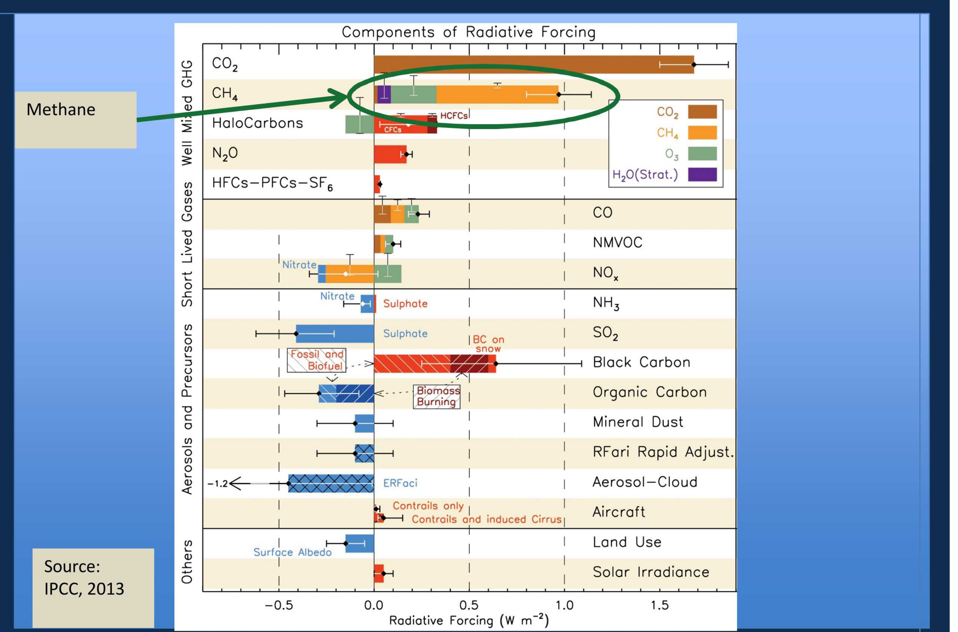
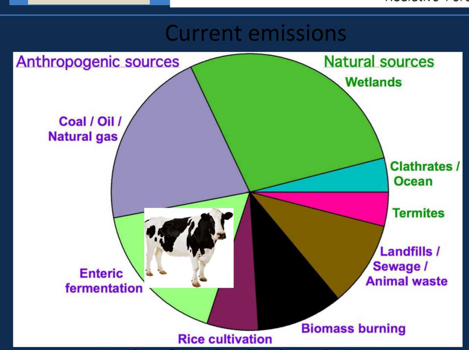
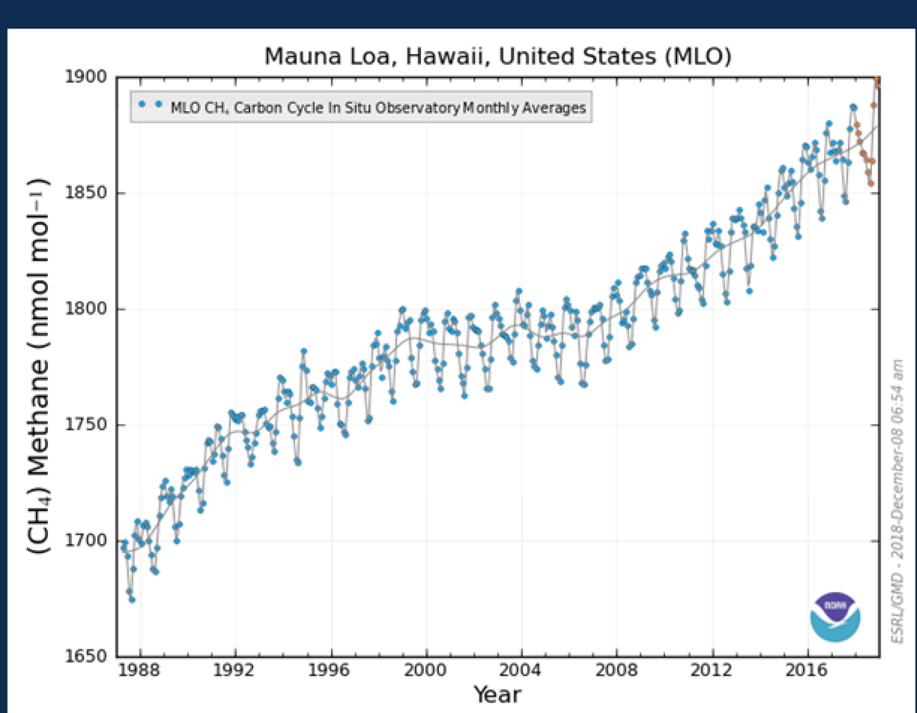




Methane is a potent GHG

- Anthropogenic sources are ~70% of current total
- Wetlands account for ~25% of total emissions
- Coal/Oil/Natural gas are ~30% of Anthropogenic
- Short atmospheric lifetime: ~12 yrs (>1000 years for CO_2)



- Methane continues to follow historical growth trend
- Causes of 2000-2008 pause are under debate

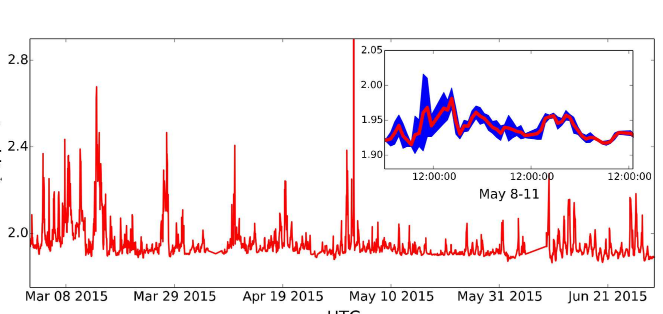
Introduction

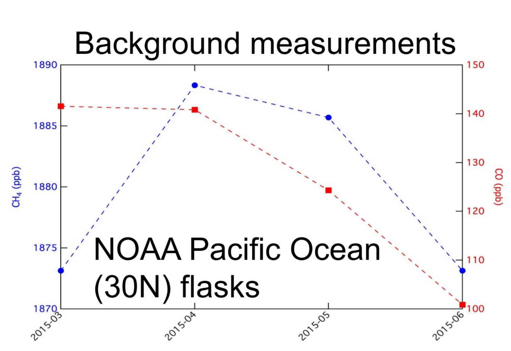
- 2015 Paris Climate Change Conference (COP21) signatories set goals: keep global temperature increase well below 2 °C above pre-industrial levels.
- U.S. cannot exit the Paris Agreement prior to November 2020 and continues to participate.
- 2018 IPCC report reiterated necessity for control of non-CO_2 emissions to meet goals
- 2018 Katowice (COP24) signatories, including the U.S. and China, agreed to methods for measuring an reporting emissions.
- Strong need exists for verifying emissions.
- Uncertainty in emissions is lowest at national scale, highest at the regional scale where corrective actions are administered.
- We demonstrate improved methodology for verifying inventories, potentially improving municipal-scale estimates.

Measurements

- Location: Livermore, CA, ~150 m above sea level, 64 km south-east of San Francisco
- Prevailing westerly winds provide frequent Pacific Ocean background
- Inlet height: 27 m above ground level
- Calibrated hourly measurements of CH4, CO2, H2O

Example time series in Livermore





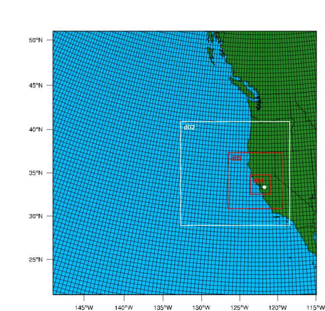
Transport Modeling

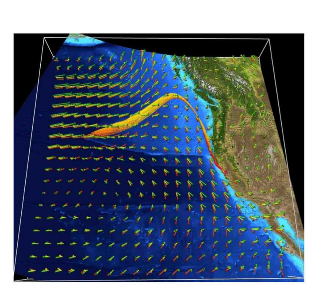
Forward transport model (WRF)

- WRF v3.9 with 36, 12, 4, 1.3km domains, 50 vertical layers.
- NCEP NARR BC/IC, outer domain nudging

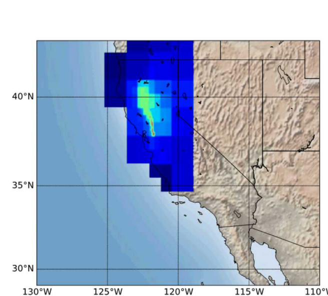
Inverse Lagrangian model (STILT)

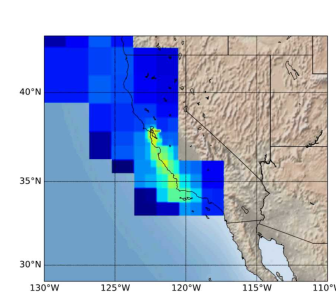
- Release point: Livermore (-121.71°, 37.67°)
- 500 particles, hourly UTC 1900 - 0300 hrs
- Simulation period 7 days backward in time





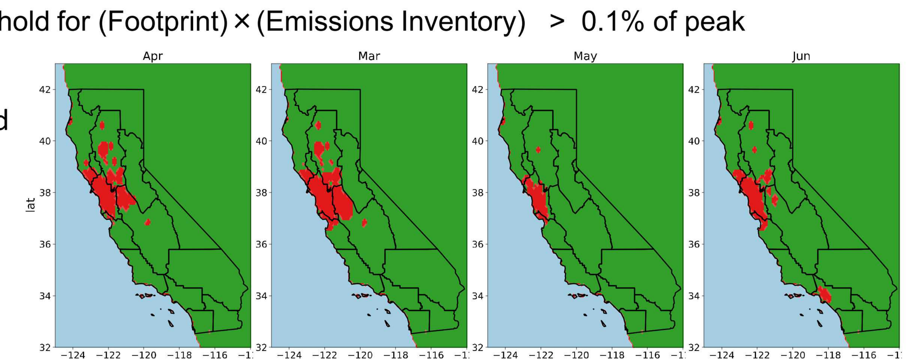
Trace emissions for 7 days prior using Lagrangian model



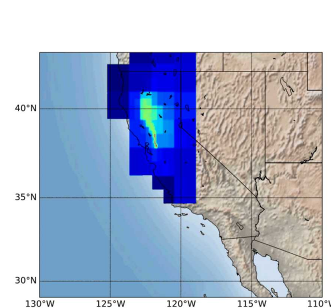


Regions of influence (ROI) given a threshold for (Footprint) × (Emissions Inventory) > 0.1% of peak

- Red indicate land influence > threshold
- Regional air district border shown
- Infer fluxes for single influence region

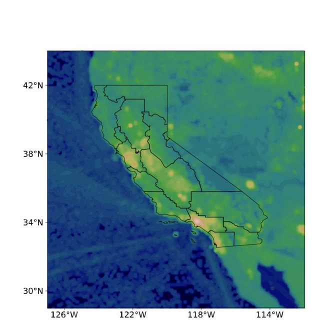


- **Generate model of concentrations at the receptor site**



Integrated 7 day influence (for a single measurement hour)

×



EDGAR v4.3.2, (0.1° × 0.1°)

2012 anthropogenic methane

=

Uncalibrated Model

Prior Model for observations:

$X_{CH4}(t)$

Predicted mixing ratio at our measurement location (before bias correction)

Reconciling Emissions Estimates

$$X(t) = b(t) + F(t)\cdot(\lambda E_i + E_p + E_o) + \epsilon_d$$

Simulated measurement; Background; Footprint; Multiplicative Bias; Emissions inside ROI; Emissions outside ROI; Additive discrepancy

- Compare modeled concentrations to measurements
- Used Bayes formula to generate probability densities of parameters given the measurements

$$p(\lambda,\sigma_m,\mu_\lambda,\sigma_\lambda,\delta_b,\tau_c|y) \sim p(y|\lambda,\delta_b,\sigma_m,\tau_c)p(\lambda|\mu_\lambda,\sigma_\lambda)p(\mu_\lambda)p(\sigma_\lambda)p(\tau_c)p(\sigma_m)p(\delta_b)$$

- Multiplicative bias and additive discrepancy have previously been treated as time invariant to simplify analysis and exhibit large variance and often poor fit to measurements

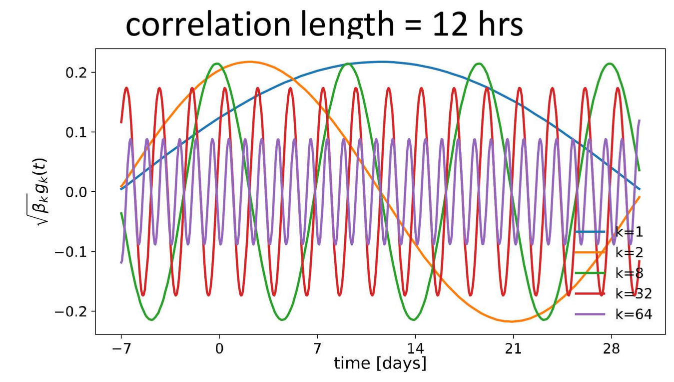
Modeling Innovations

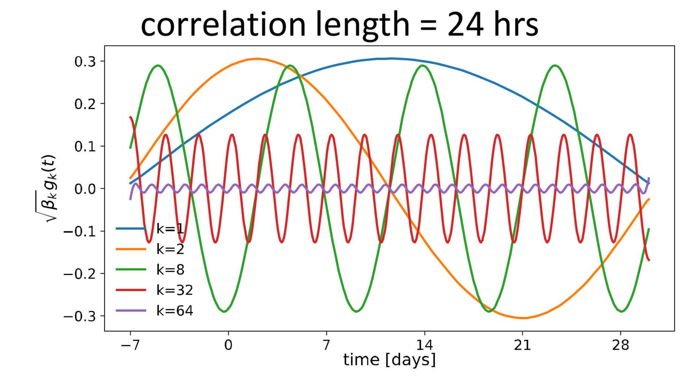
- Consider the factor λ to be a function of time
- Represent λ(t) as a Karhunen-Loève expansion

$$X(t) = b(t) + \sum_{i=-(N_t-1)}^{0}\left(\lambda_0 + \sum_k c_k \frac{1}{\delta t}\int_{t_{i-1}}^{t_i}\sqrt{\beta_k}g_k(t)d\tau\right)\sum_j F_{t,i}(x_j)E(x_j)$$

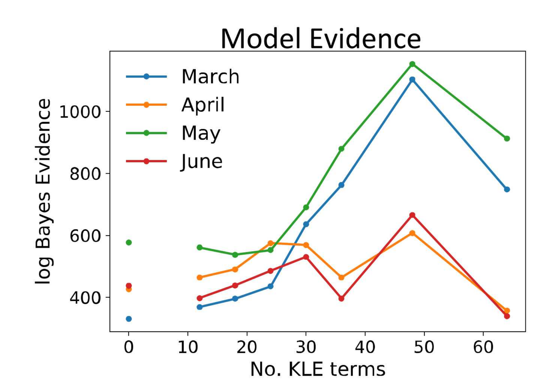
where β_k and $g_k(t)$ are the Karhunen-Loève Expansion eigenvalues and eigenfunctions of the covariance matrix for λ, respectively , and c_k are the coefficients to be inferred

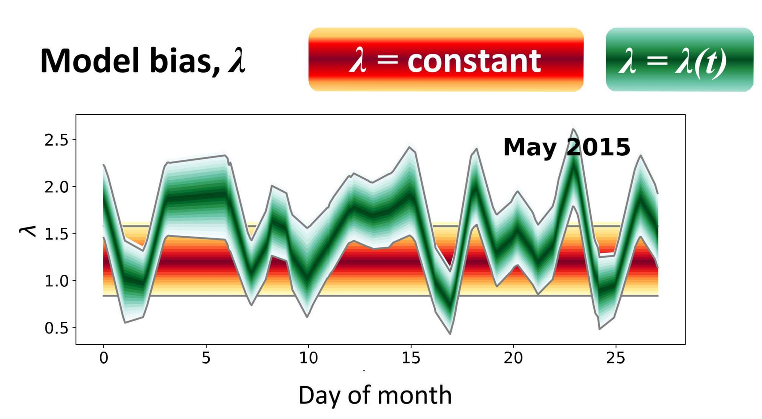
Example KLE basis sets for λ, assuming square-exponential correlation function :

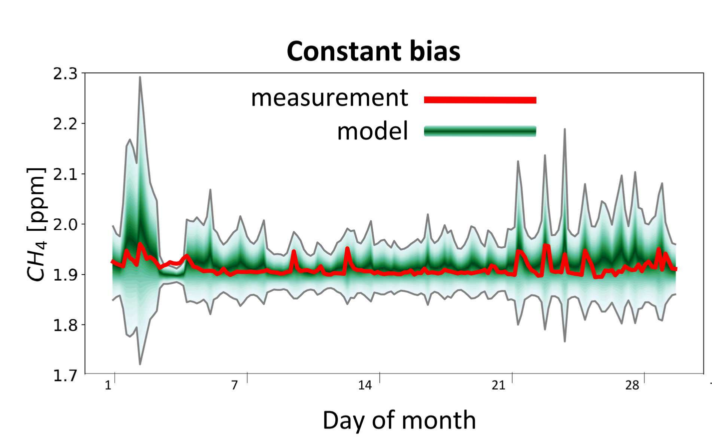


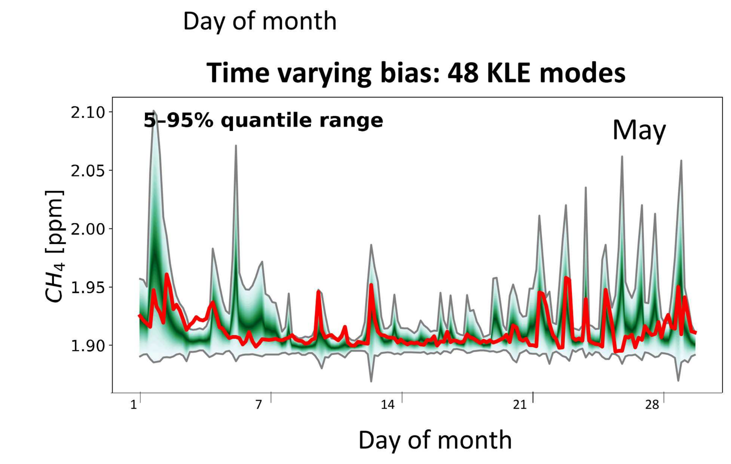


- Compare model evidence (probability of data given the model) to determine the "optimal" model









Conclusion and Outlook

- Employing a temporally varying bias improves representation of the posterior predictive model, according to model evidence
- Variability between months requires further investigation
- Temporal and spatial structure will be further analyzed
- Potential to reveal deficiencies in emissions inventory
- Alternative emissions inventories to EDGAR will be analyzed
- Additional tracers will be included

References

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