Estimation of Anthropogenic CO_2 Emissions from Sparse Measurements

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Problem Statement

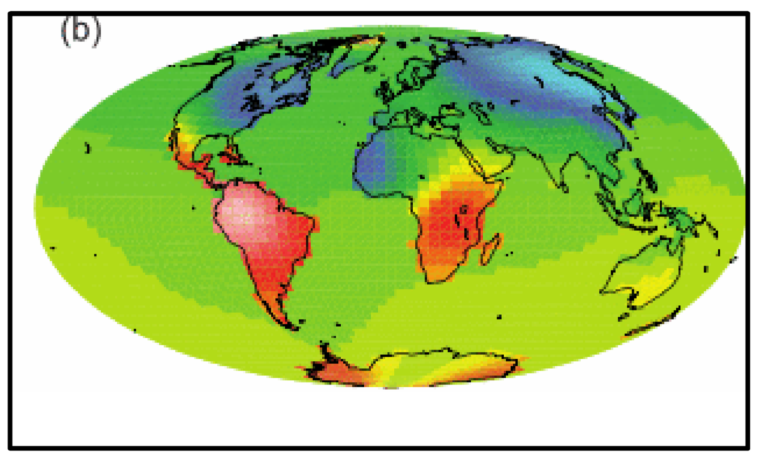
Devise a method to estimate anthropogenic (fossil-fuel) CO_2 emissions from sparse measurements

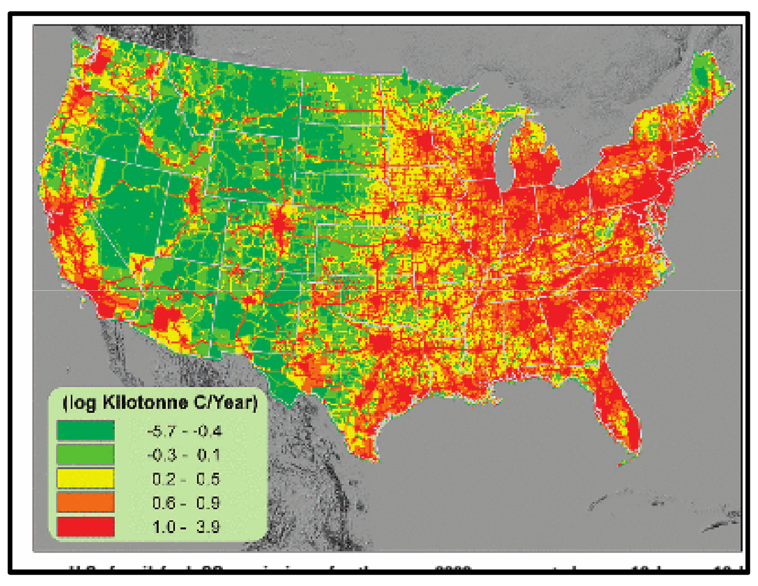
- Data: CO_2 concentrations measurements at a handful of sites

Significance

- An independent check on process-based (bottom-up) estimates of $ffCO_2$ (fossil-fuelCO$_2$) emissions
- Useful for monitoring a global CO_2 abatement treaty

Technical Challenges





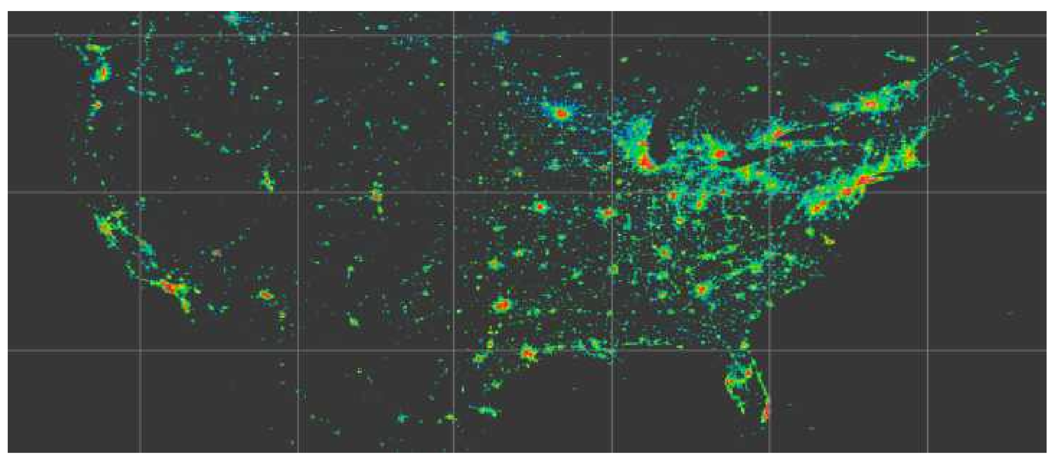
Current status

- Biospheric CO2 fluxes can be estimated from sparse measurements
- Spatial variations are smooth and can be modeled with a multivariate Gaussian
- The effective dimensionality is reduced by a good covariance model; hence the fluxes can be estimated
- No such simplification exists for $ffCO_2$ emissions
- So what's a good, low-dimensional model for $ffCO_2$ emissions?

Our Approach

Background

- Nightlight images provide an approximation to the distribution of $ffCO_2$ emissions



- The nonstationary, multiscale nature is well reproduced since they arise from the same cause – human population distribution

Spatial Modeling

- Use wavelets to model the ffCO2 distribution in space (a Multiscale Random Field Model, MsRF)
- Reduce dimensionality using the nightlight images (remove wavelet bases from "dark" areas, small scale wavelets etc.)

Inverse Modeling

- Use Weather Research and Forecasting (WRF) model to link observations (CO_2 concentrations) with $ffCO_2$ emissions, represented by the MsRF, with unknown wavelet weights
  - The MsRF is not particularly low-dimensional, even after incorporating nightlights
- Estimate wavelet weights along with sparsity-enforcement (L1 norm)
  - Algorithm (StOMP) sets all wavelet weights that are not constrained by observations to zero
  - Allows us to use high-dimensional spatial models without fear of overfitting

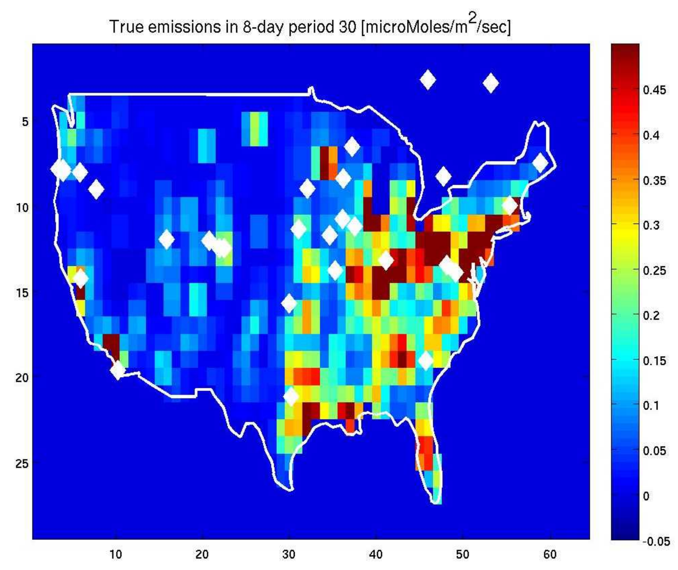
Assumption

- $C^{14}O_2$ & $C^{12}O_2$ can be measured, allowing us to estimate the $ffCO_2$ fraction in a CO_2 (observation) sample

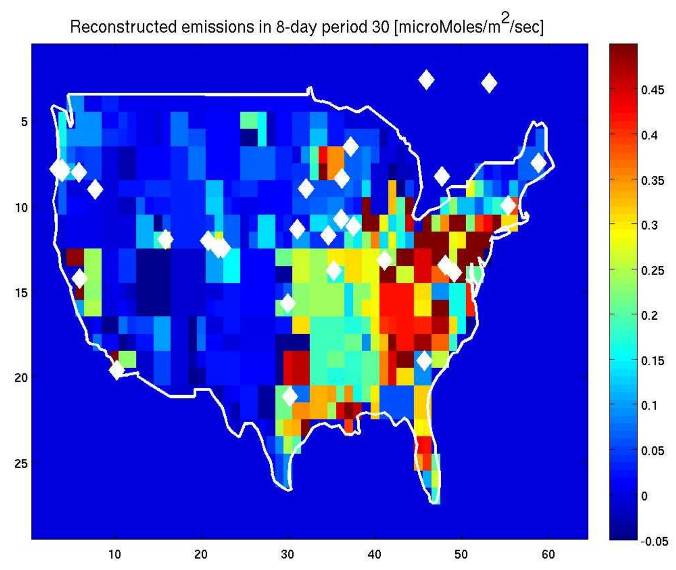
Inversion Results

Inversion Details

- Inversions with synthetic data – observations generated with emissions from the Vulcan database (US only, for 2002)
- Inversions are done for 8-day averaged $ffCO_2$ emissions, for 2002
- Spatial resolution: 1 degree
- 35 measuring towers, collecting at 3 hour intervals
- Nightlights reduced the number of wavelets from 4096 to 1035



True emissions in August 2002

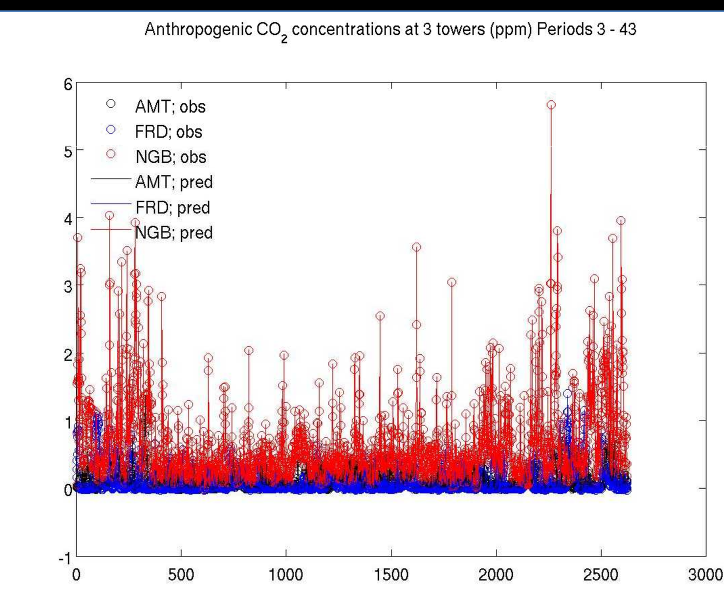


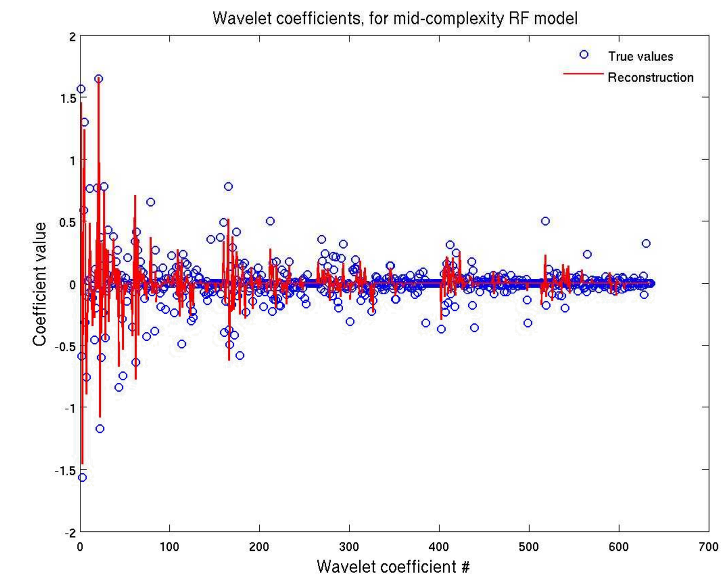
Reconstructed emissions

Numerical Performance

Posterior predictions

- The estimated emissions reproduce the observations very well
- Shown on the right for a few observation towers

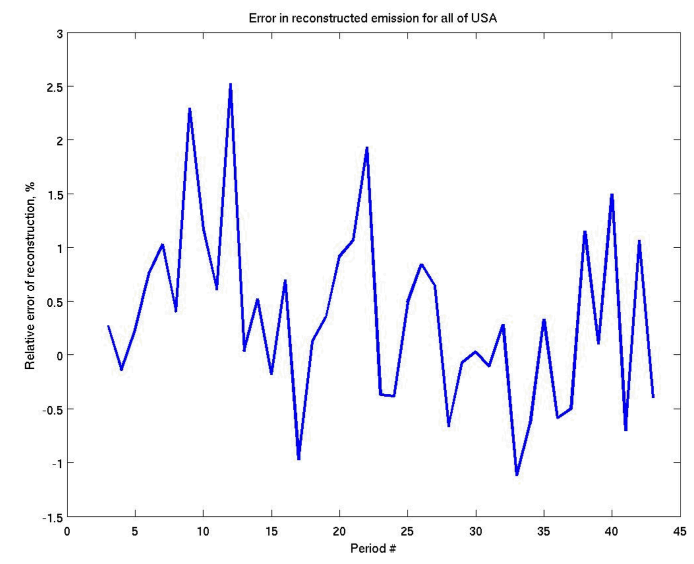


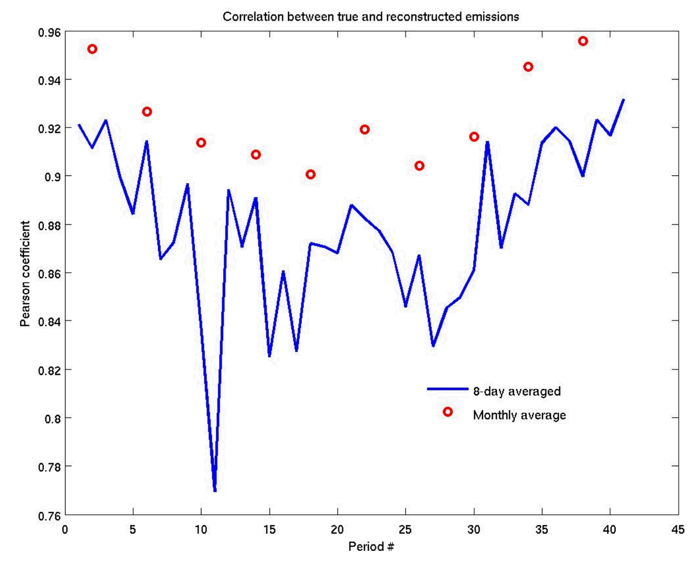


Sparsity enforcement

- The method can only estimate about half the wavelet coefficients
- The small ones are set to zero

Quality of the Inversion





- 8-day emissions can be estimated with 1-4% errors; correlation ~ 0.85
- Aggregated to the monthly level, the correlation is about 0.93
- Emissions in the North-East are best estimated from the observation

Conclusions

- Results indicate that ffCO2 emissions could be estimated
- Sources of uncertainty:
  - Source #1 : Shortcomings of the of meteorology/transport model e.g., WRF
  - Source #2 : The small number of measurement towers
- Next step: Quantify the uncertainty in the emission estimates
  - Wrap an EnKF around this procedure
  - Require algorithmic advances

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