Use of Inverse Modeling to Evaluate Emissions Inventories

Stephen M. Ogle
Natural Resources Ecology Laboratory
Colorado State University

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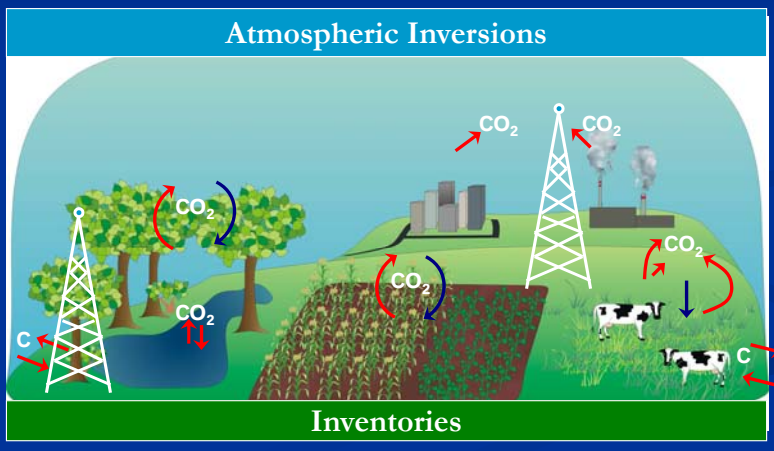
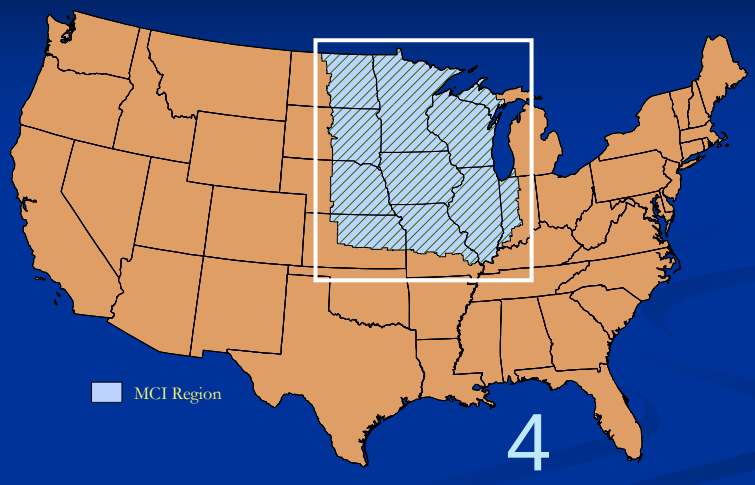
National Aeronautics and Space Administration

US Mid-Continent Intensive Study

- Compare and reconcile CO_2 fluxes from inventories and atmospheric inversions



MCI Study Region



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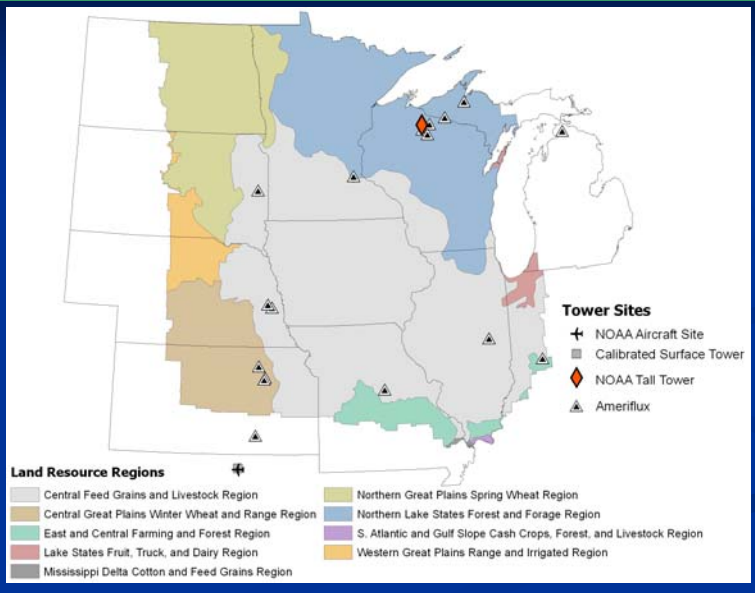
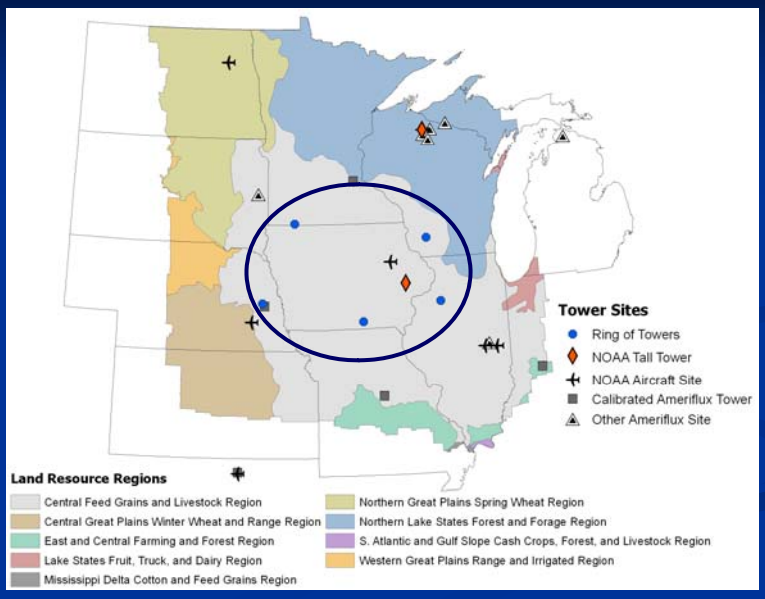
MCI Pre-Campaign Observations



MCI Campaign Region



Inventory

- Emissions = Activity Data * Emission Factor
  - Emission factor may be based measurements and/or modeling
- Strength
  - Ground-based activity data used to estimate sources and sinks of CO_2
  - Can be used to determine anthropogenic impact on greenhouse gas emissions
- Weakness
  - Does not provide the total CO_2 flux
    - As implemented in national GHG inventories, i.e., only anthropogenic sources
    - Estimates may not be consistent with total CO_2 flux in a region

CO_2 Sources

Included in National GHG Inventory

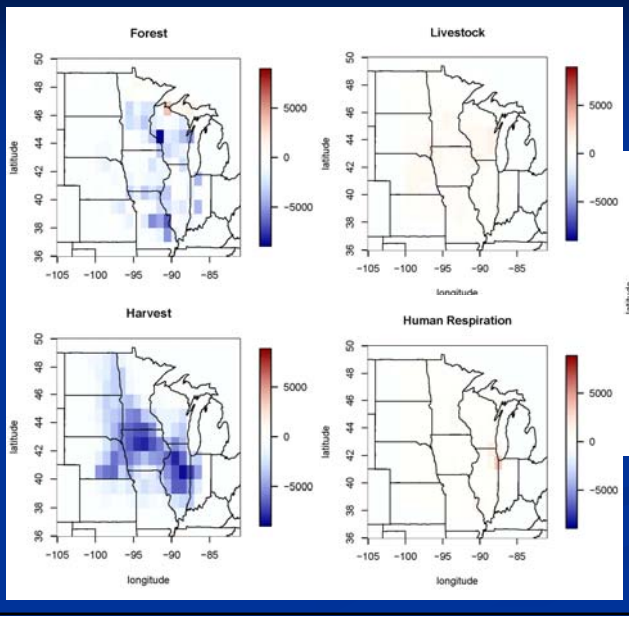
- Fossil emission of CO_2
- Biomass, dead biomass and soil C stock change
  - Forestland, Cropland, Settlements and Grassland
- Harvested woody product C
- Inorganic CO_2 (including liming)

CO_2 Sources

Typically Not Included in National GHG Inventory

- Harvested Crop Grain C
  - Lateral transport of carbon fixed during photosynthesis which is harvested and a portion exported from the region
- Livestock and Human Respiration of CO_2
  - Mass balance of CO_2 flux with uptake in crops, including lateral transport into region
- Biofuel CO_2 Emission from Combustion
  - Mass balance of CO_2 flux with uptake during photosynthesis in biofuel feedstock crop production
- Wetland CO_2 Emissions
  - Generally considered non-anthropogenic
- Landfill Emissions of CO_2
  - Biogenic and therefore not estimated

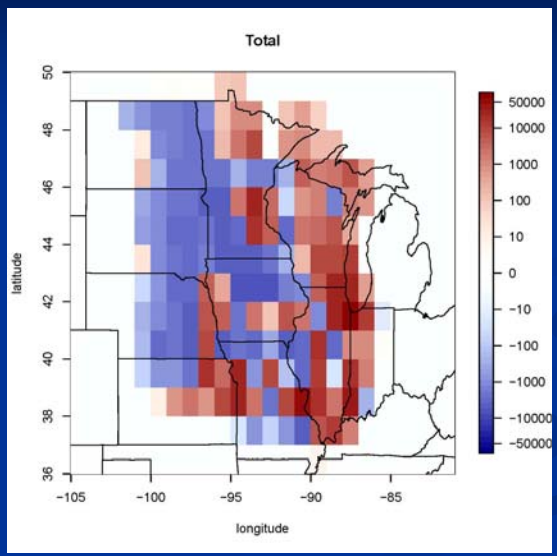
Comparing Sources (Gigagrams CO_2)



Other sources are not visible on this scale.

West et al., JGR, in review

Inventory Results (Gigagrams CO_2)

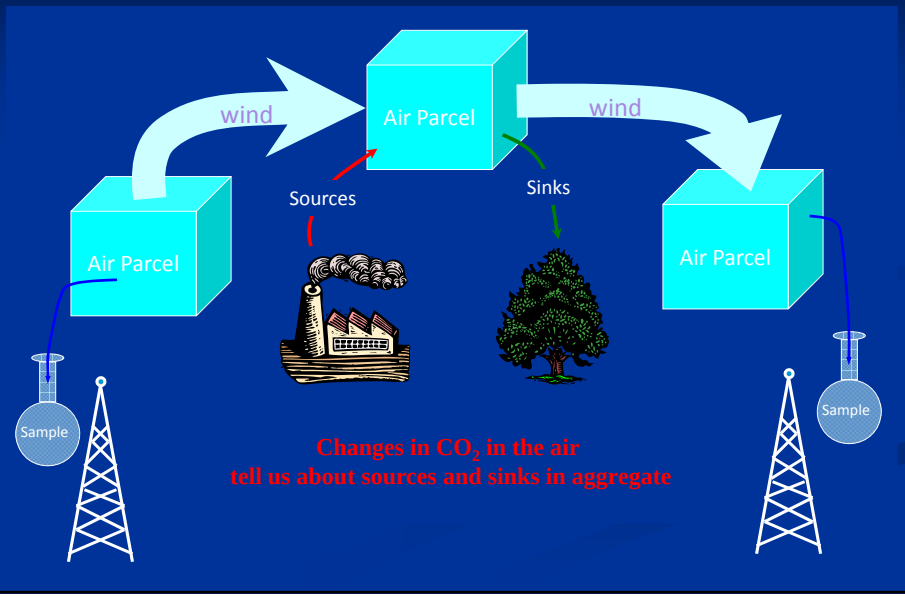


West et al., JGR, in review

Inversion

- Can be used to estimate CO_2 flux based on prior information about flux, atmospheric CO_2 concentration data, and transport modeling
- Strength
  - Atmospheric CO_2 measurement constraint
    - Consistent with total flux for region (mass balance)
- Weakness
  - Does not typically disaggregate to source
    - No direct inference on the anthropogenic effect of emissions
  - Cannot capture point sources at current measurement density
    - e.g., power plant emissions are excluded from current inversion analyses

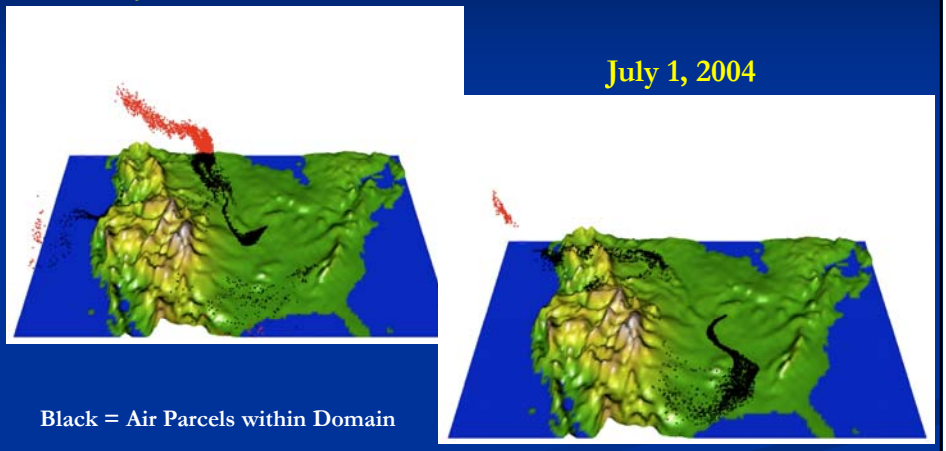
Basis for Inverse Modeling of CO_2



Transport of Air Parcels

June 15, 2004

July 1, 2004



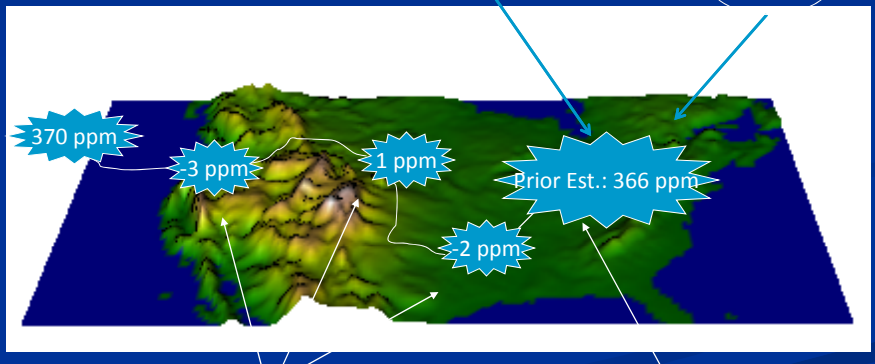
Black = Air Parcels within Domain

Red = Air Parcels outside of Domain (Boundary Conditions)

Transport Model: Conceptualizing

"Observed" **at 2PM on 7/7/2004: 368 ppm**

"Calculated" for 2PM on 7/7/2004: 370 ppm - 3 ppm + 1 ppm - 2 ppm = *366 ppm*



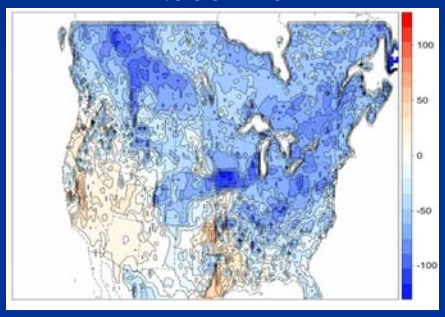
Carbon drawdown in upwind areas must be too strong since the observed CO_2 at the tower is higher than what we predict

WLEF Tower

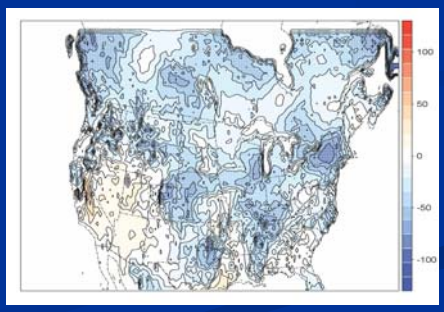
Atmospheric CO_2 Inversion Results

June 15 - July 15, without Fossil Fuel Emissions (g C m^{-2})

Inversion Prior



Inversion Result

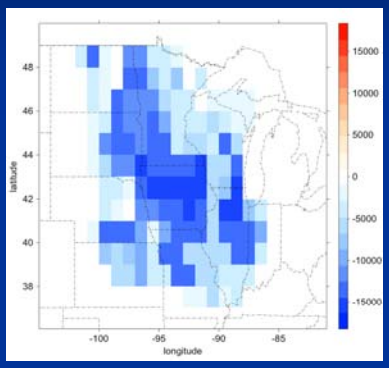


Schuh et al., Biogeosciences Disc. 6:10195-10241

Global Inversion vs. Inventory (Gigagrams CO_2)

Without CO_2 Tower Observations in the MCI

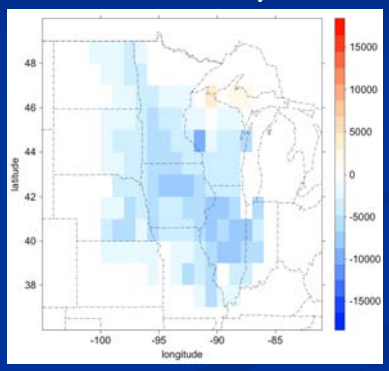
2007 CarbonTracker Inversion



Carbon Sink: 1166 Tg CO_2

Excludes Fossil Fuel CO_2 Emissions

2007 Inventory



Carbon Sink: 477 Tg CO_2

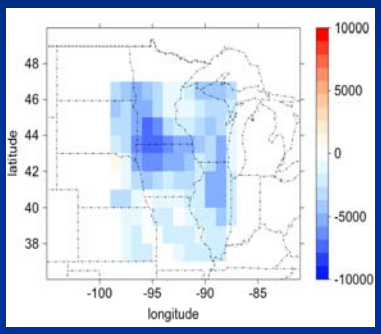
Difference between inversion and inventory = 689 Tg CO_2

CarbonTracker: Peters et al., PNAS 104:18925-18930

Meso-Scale Inversion vs. Inventory (Gg CO_2)

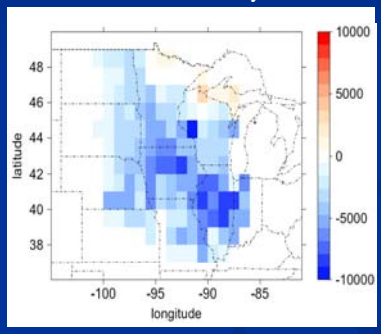
With Additional CO_2 Tower Observations in the MCI

2007 PSU Meso-Scale Inversion



Excludes Fossil Fuel CO_2 Emissions

2007 Inventory



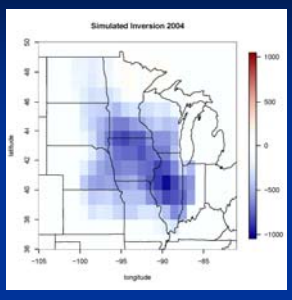
Carbon Sink: 325 Tg CO_2

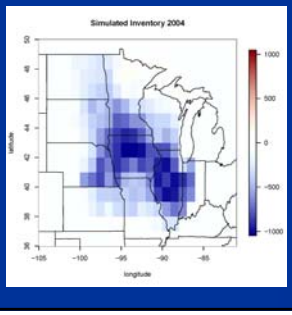
Carbon Sink: 406 Tg CO_2

Difference between inversion and inventory = 81 Tg CO_2

PSU Meso-Scale: Thomas et al., Preliminary Results

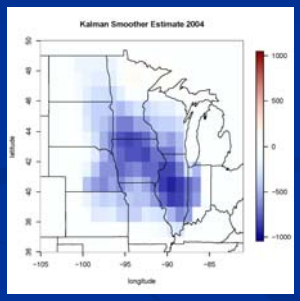
Mathematically Reconciling





Kalman Smoother

Example with simulated data



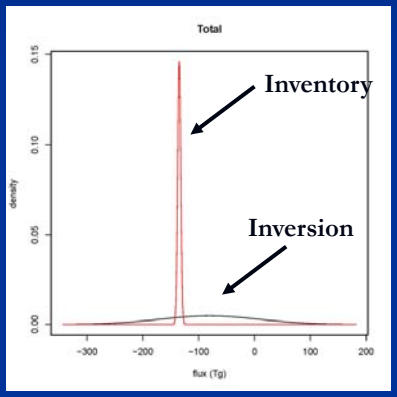
Combining inventory and inversion to obtain "reconciled" estimates and uncertainty (sources)

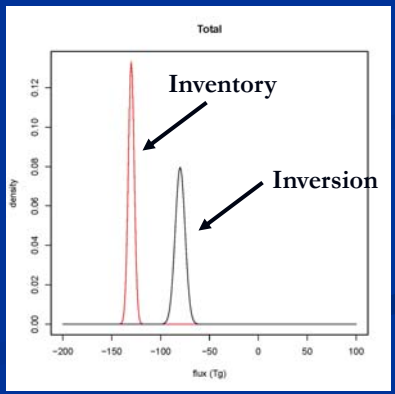
Research & Development

- Inventory methods
  - Requires estimates for sources not typically reported in national GHG inventory
    - Including non-anthropogenic impacts on sources
  - Challenge to obtain all of the necessary activity data and emission "factor" estimates
- Inversion methods
  - Further development of sub-continental inversions frameworks
    - Observational data density, boundary conditions and transport methods
    - New satellite missions gathering CO_2 concentration data could be used to inform inversions and increase observation data density
  - Uncertainties are not well quantified
    - Prior, boundary conditions and transport

What if uncertainties are not rigorous?

Combining data from inversion and inventory assumes that the underlying uncertainty is representative and contains the true estimate of CO_2 flux at a specified confidence level.





Concluding Remarks

- Atmospheric CO_2 inversions are a promising technology for verification of inventories
  - Constrained by mass balance of CO_2 concentration changes in the atmosphere across space and time
  - Requires more research and development, and an expanded network of atmospheric CO_2 observations before an inversion system could be operational
- Inventories will need to be further developed in order to compare with inversions
  - Requires additional sources not typically included a national inventory for reporting under IPCC GL