CarbonTracker-Lagrange: A new tool for regional- to continental-scale flux estimation

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Colorado State University: Christopher O'Dell
Outline

- Overview of Lagrangian inverse modeling for regional flux estimation
- Magnitude and impacts of errors in regional boundary values
- Implementation of boundary value estimation in the new CarbonTracker-Lagrange inverse modeling system
- Preliminary results for inversions using continuous and discrete in situ measurements
- Future work
Recent studies have demonstrated the usefulness of regional Lagrangian inverse modeling for greenhouse gas flux estimation:
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Constraining the CO₂ budget of the corn belt: exploring uncertainties from the assumptions in a mesoscale inverse system

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Recent studies have demonstrated the usefulness of regional Lagrangian inverse modeling for greenhouse gas flux estimation:
Simple 10-day back trajectory using archived meteorological fields from a model (e.g. WRF).

Air parcel is simulated as an infinitesimally small particle subjected to advection and sometimes convection.
• Instead of a single mean-wind trajectory, many trajectories are generated.
• Dispersion is simulated by adding random perturbations to the velocities.
• Time spent in the planetary boundary layer is tracked along with boundary layer height and used to compute the sensitivity to surface emission and uptake.
A gridded footprint (a.k.a. influence function) is computed by binning and averaging over all particles. Our footprints have 1°lon x 1°lat x hourly resolution.
CarbonTracker - Lagrange

- New Lagrangian assimilation framework under development at NOAA Earth System Research Laboratory in collaboration with many partners
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Modeling team:
• AER, Inc.: J. Eluszkiewicz, T. Nehrkorn, M. Mountain
• Carnegie Institution for Science/Stanford: A. Michalak, V. Yadav, Mae Qui
• Colorado State University: C. O’Dell
• Harvard University: S. Wofsy, B. Xiang, S. Miller, J. Benmergui

Data Providers:
• NOAA Earth System Research Laboratory’s Global Monitoring Division
• Penn State University (K. Davis, S. Richardson, N. Miles)
• NCAR (B. Stephens)
• Oregon State University (B. Law, A. Schmidt)
• Lawrence Berkeley National Lab (M. Torn, S. Biraud, M. Fischer)
• Earth Networks (C. Sloop)
• Environment Canada (D. Worthy)
• Harvard University (S. Wofsy, J. W. Munger)
• U of Minnesota (T. Griffis)
• CalTech (D. Wunch, P. Wennberg; S. Newman) & JPL (G. Toon)
• GOSAT-ACOS team
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• Supported by NOAA Climate Program Office’s Atmospheric Chemistry, Carbon Cycle, & Climate (AC⁴) Program and the NASA Carbon Monitoring System
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- High-resolution WRF-STILT atmospheric transport model customized for Lagrangian simulations (Nehrkorn et al., *Meteorol. Atmos. Phys.*, 107, 2010). Species independent footprints are computed and stored for each measurement.
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- Efficient algorithm enables many permutations of the inversion (Yadav and Michalak, *Geosci. Model Dev.*, 6, 583-590, 2013)
  - Multiple data-weighting scenarios
  - Varied mathematical construct
    - Form of state vector
    - Bayesian or Geostatistical optimization
  - Multiple priors
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• Modular python software leverages new techniques from colleagues in academia and facilitates use of alternative transport models.

• New boundary value optimization capability!
\[ \hat{s} = s_p + (HQ)^T (HQBHT + R)^{-1} (z - HS_p) \]


H is atmospheric transport operator (i.e. the footprints)
Q is the prior error covariance matrix
R is the model-data mismatch matrix
\( s_p \) is a vector containing the prior flux estimate
\( \hat{s} \) is a vector containing the revised fluxes

Modified framework:
• H has additional columns for boundary value grid cells
• \( s_p \) and \( \hat{s} \) contains additional elements
• Q contains additional rows and columns. No cross-correlation between boundary values and fluxes
Why is simultaneous estimation of boundary inflow and surface influence necessary?
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1. Accurate 4-dimensional estimates of the boundary inflow are not readily available.

- Model is biased high by several ppm during summer.
- Seasonal pattern of residuals for 2010 is typical of all years.
Comparison with NOAA/ESRL aircraft data shows that vCT2011 summertime bias is pervasive in the Northern Hemisphere:

NOAA/ESRL Global Monitoring Division Aircraft Program:
http://www.esrl.noaa.gov/gmd/ccgg/aircraft/data.html
Principal Investigator: Colm Sweeney
A NOAA contribution to the North American Carbon Program
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2. Flux estimates are apparently very sensitive to errors in assumed boundary values.

Changing the boundary condition makes the North American carbon sink disappear!

Using CarbonTracker for the boundary condition produces a flux estimate similar to CarbonTracker’s.

Boundary/Initial Condition Footprints

- Derived from trajectories:
- 3 types of boundary values:
  - Exit domain via the marine boundary layer
  - Exit domain via the free troposphere
  - Still within domain at end of 10 day run
- Number of endpoints within a grid cell determines the weight.
- Current grid resolution 2° lat x 3° lon x 1 day x (pbl, transition, or free troposphere)
- Boundary value estimation domain limited to region around N. America
Synthetic Data Exercise: Can CT-L recover known “truth” with weak prior?

Monthly Mean July 2010

<table>
<thead>
<tr>
<th>Region</th>
<th>CASA/GSFC</th>
<th>CT2011-oi</th>
<th>CT-L</th>
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<td>N. America</td>
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<td>-8.46</td>
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<td>20°-50° N</td>
<td>-4.81</td>
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CASA/GSFC fluxes courtesy of G. J. Collatz; CarbonTracker fluxes courtesy of A. Jacobson.
First Real Data Inversion: CT2011-oi used as weak prior

**Monthly Mean July 2010**

**Surface Fluxes**

**Mole Fraction Adjustment**

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Summary and Next Steps

• CarbonTracker-Lagrange is a new inverse modeling framework that includes boundary value optimization.

• Footprint libraries and source code will be available for download.

• Additional synthetic-data experiments to optimize simultaneous estimation of inflow and surface fluxes using existing and potential future data (network design studies).

• Improved real data inversions using In Situ, GOSAT, and TCCON data.

• We are seeking potential collaborations and novel applications.