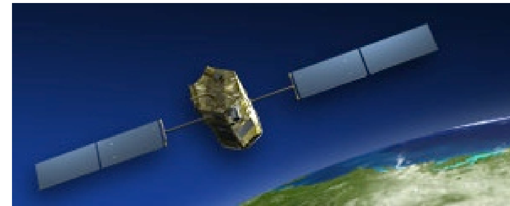
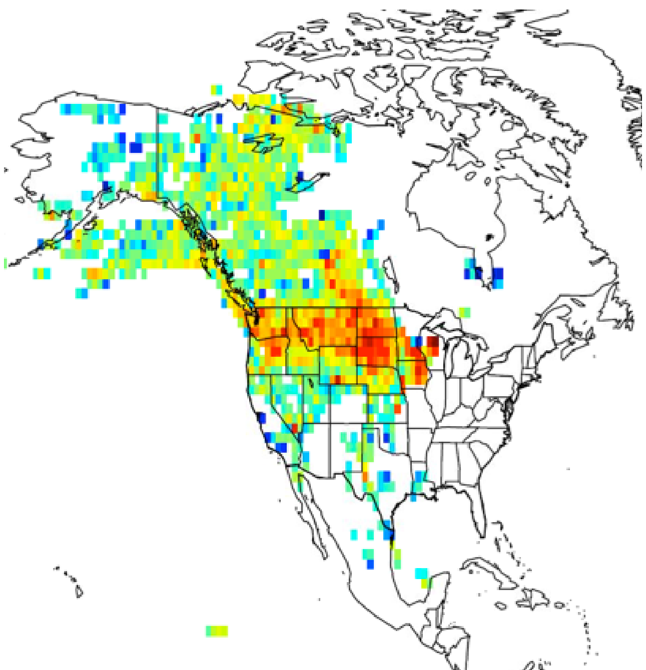


CarbonTracker-Lagrange: A new tool for regional- to continental-scale flux estimation

NOAA/ESRL[1] & CIRES[2]: Arlyn Andrews[1], Kirk Thoning[1], Michael Trudeau[1,2], Pieter Tans[1]
Carnegie Institution for Science[3] & Stanford University[4]: Anna Michalak[3,4], Vineet Yadav[3]
AER, Inc.: Janusz Eluszkiewicz, Marikate Mountain, Thomas Nehrkorn, J. Hegarty
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:


Proceedings of the National Academy of Sciences of the United States of America

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> Early Edition > Scot M. Miller

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Anthropogenic emissions of methane in the United States

Scot M. Miller[a,1], Steven C. Wofsy[a], Anna M. Michalak[b], Eric A. Kort[c], Arlyn E. Andrews[d], Sebastien C. Biraud[e], Edward J. Dlugokencky[d], Janusz Eluszkiewicz[f], Marc L. Fischer[g], Greet Janssens-Maenhout[h], Ben R. Miller[i], John B. Miller[i], Stephen A. Montzka[d], Thomas Nehrkorn[f], and Colm Sweeney[i]

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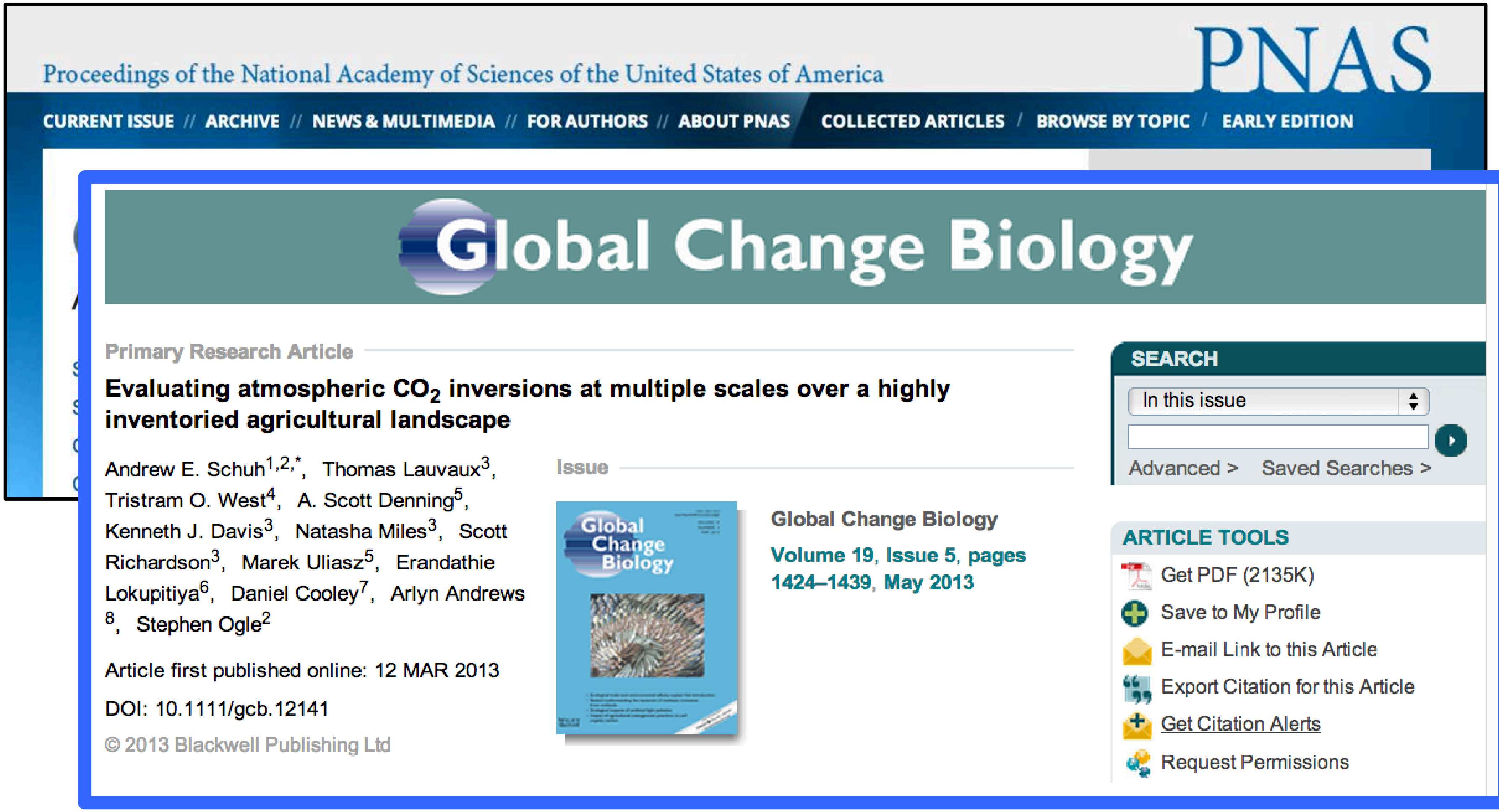
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Global Change Biology

Primary Research Article

Evaluating atmospheric CO_2 inversions at multiple scales over a highly inventoried agricultural landscape

Andrew E. Schuh[1,2,*], Thomas Lauvaux[3], Tristram O. West[4], A. Scott Denning[5], Kenneth J. Davis[3], Natasha Miles[3], Scott Richardson[3], Marek Uliasz[5], Erandathie Lokupitiya[6], Daniel Cooley[7], Arlyn Andrews [8], Stephen Ogle[2]

Article first published online: 12 MAR 2013

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Global Change Biology

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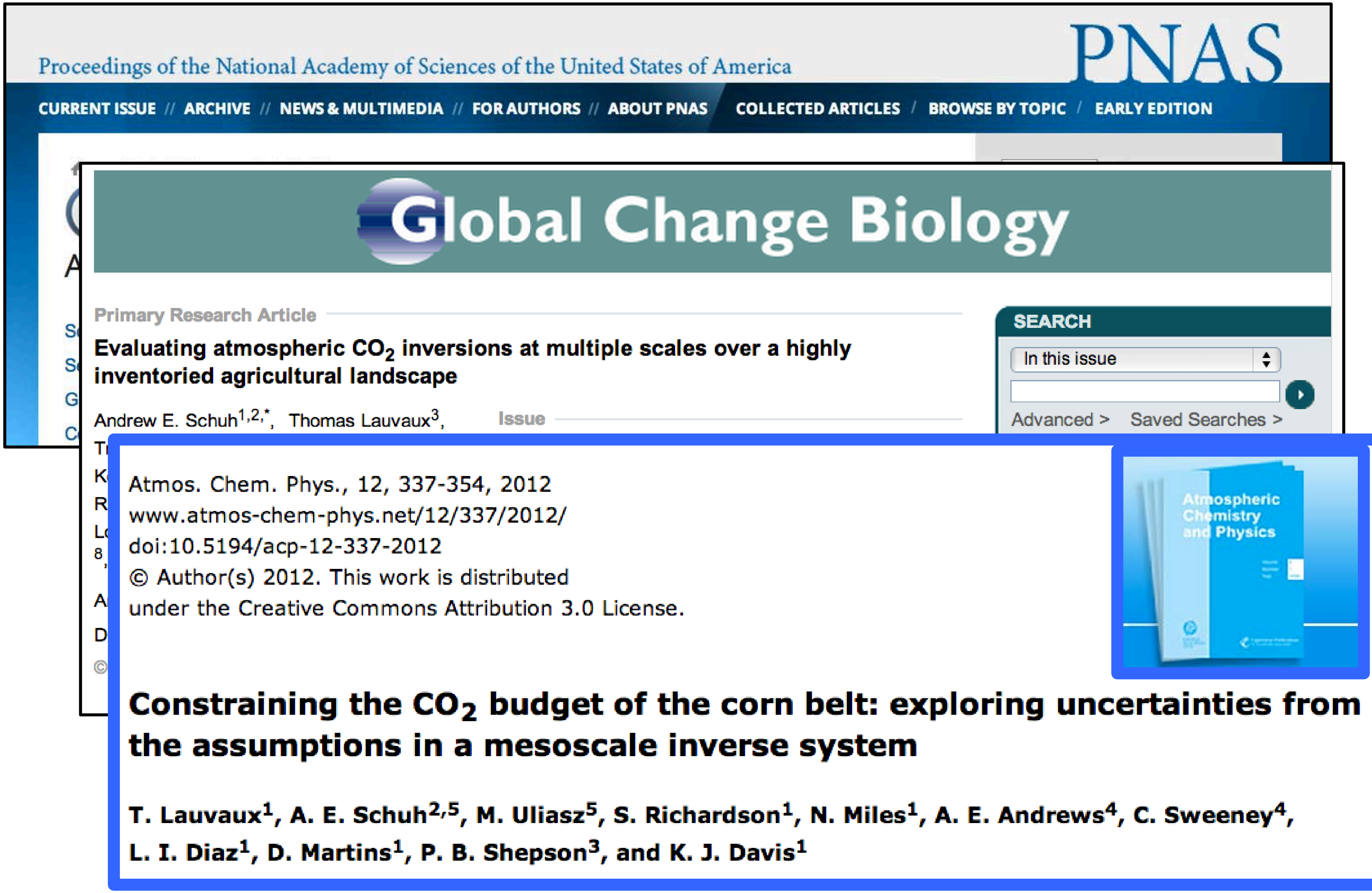
Recent studies have demonstrated the usefulness of regional Lagrangian inverse modeling for greenhouse gas flux estimation:



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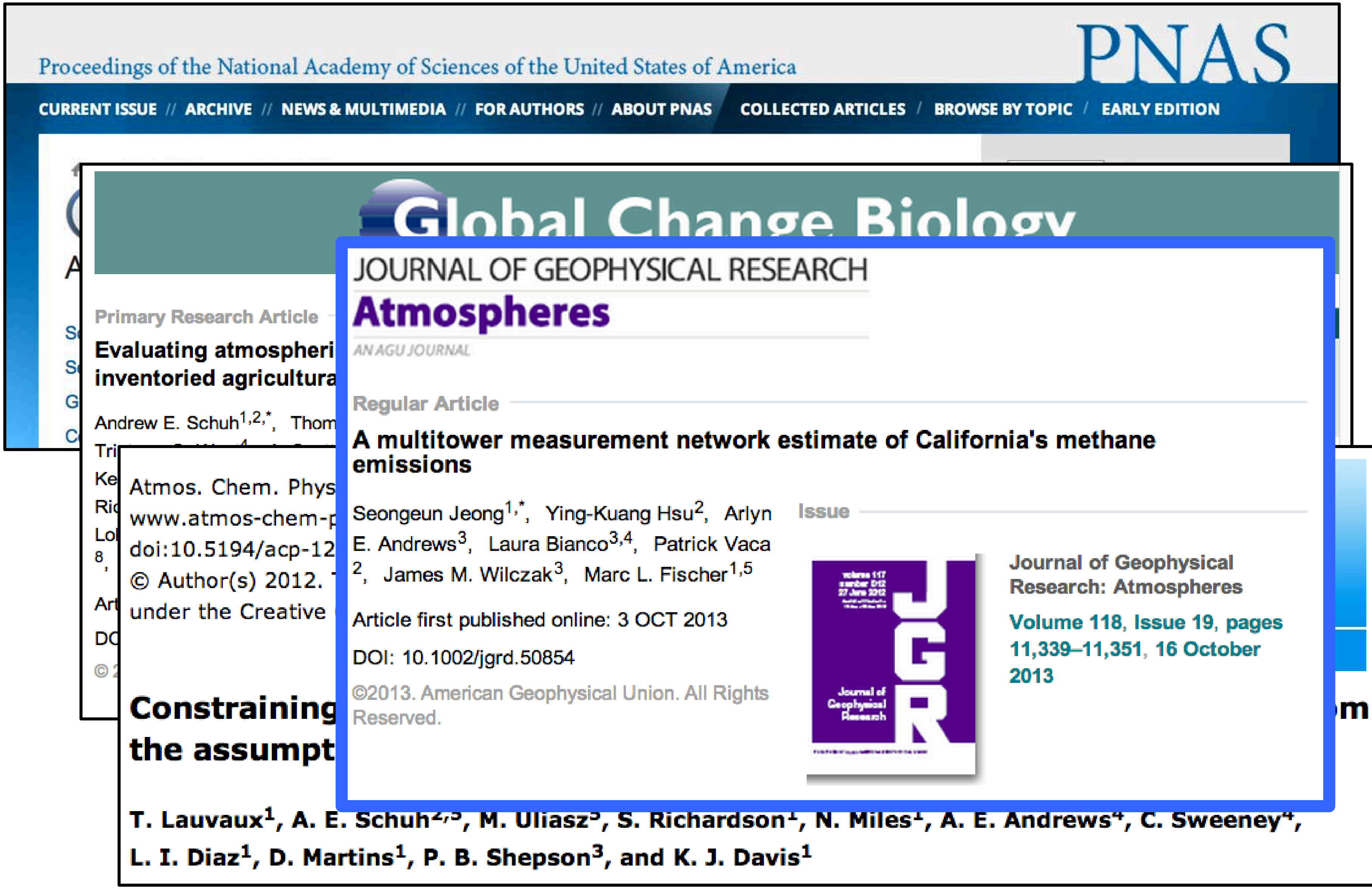

Introduction to Lagrangian Particle Dispersion Modeling

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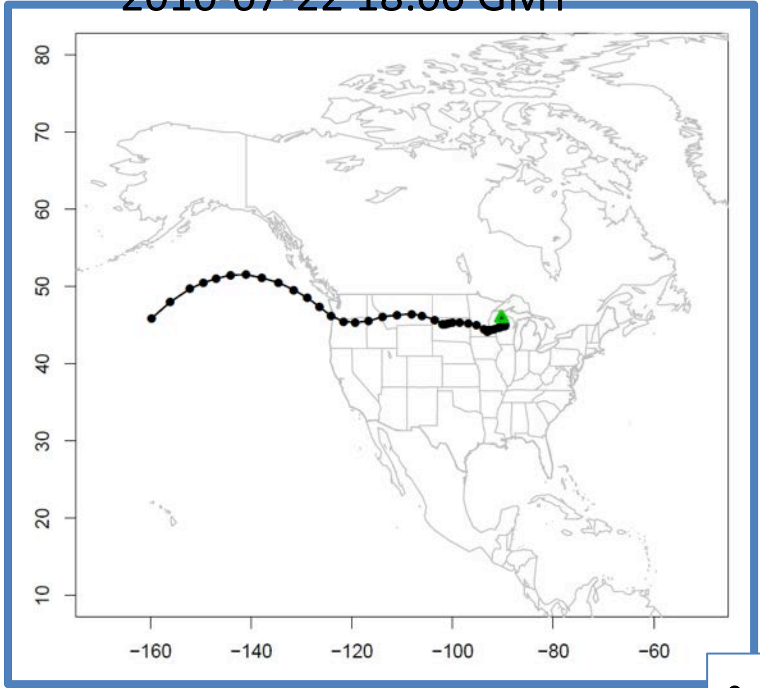

- Simple 10-day back trajectory using archived meteorological fields from a model (e.g. WRF).
- Air parcel is simulated as an infinitesimally small particle subjected to advection and sometimes convection.

Introduction to Lagrangian Particle Dispersion Modeling

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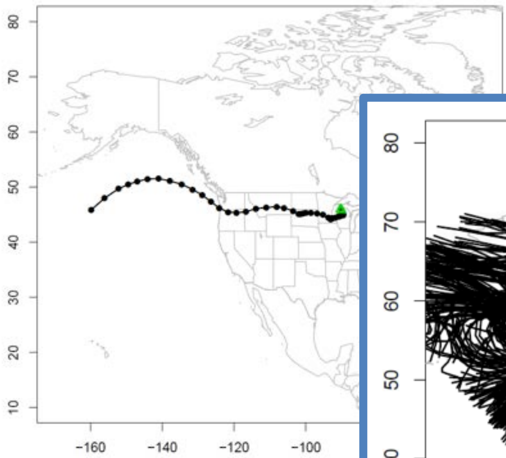

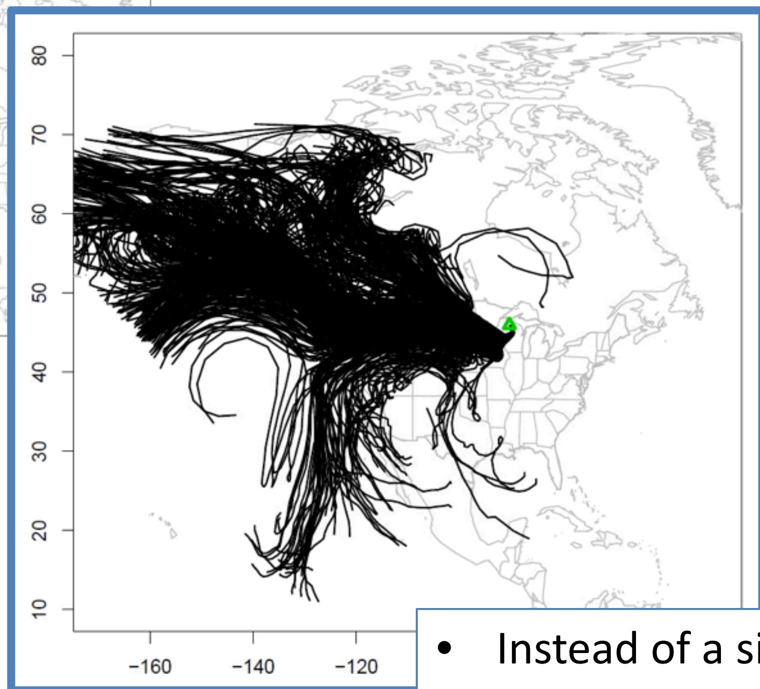

- Instead of a single mean-wind trajectory, many trajectories are generated.
- Dispersion is simulated by adding random perturbations to the velocities.

Introduction to Lagrangian Particle Dispersion Modeling

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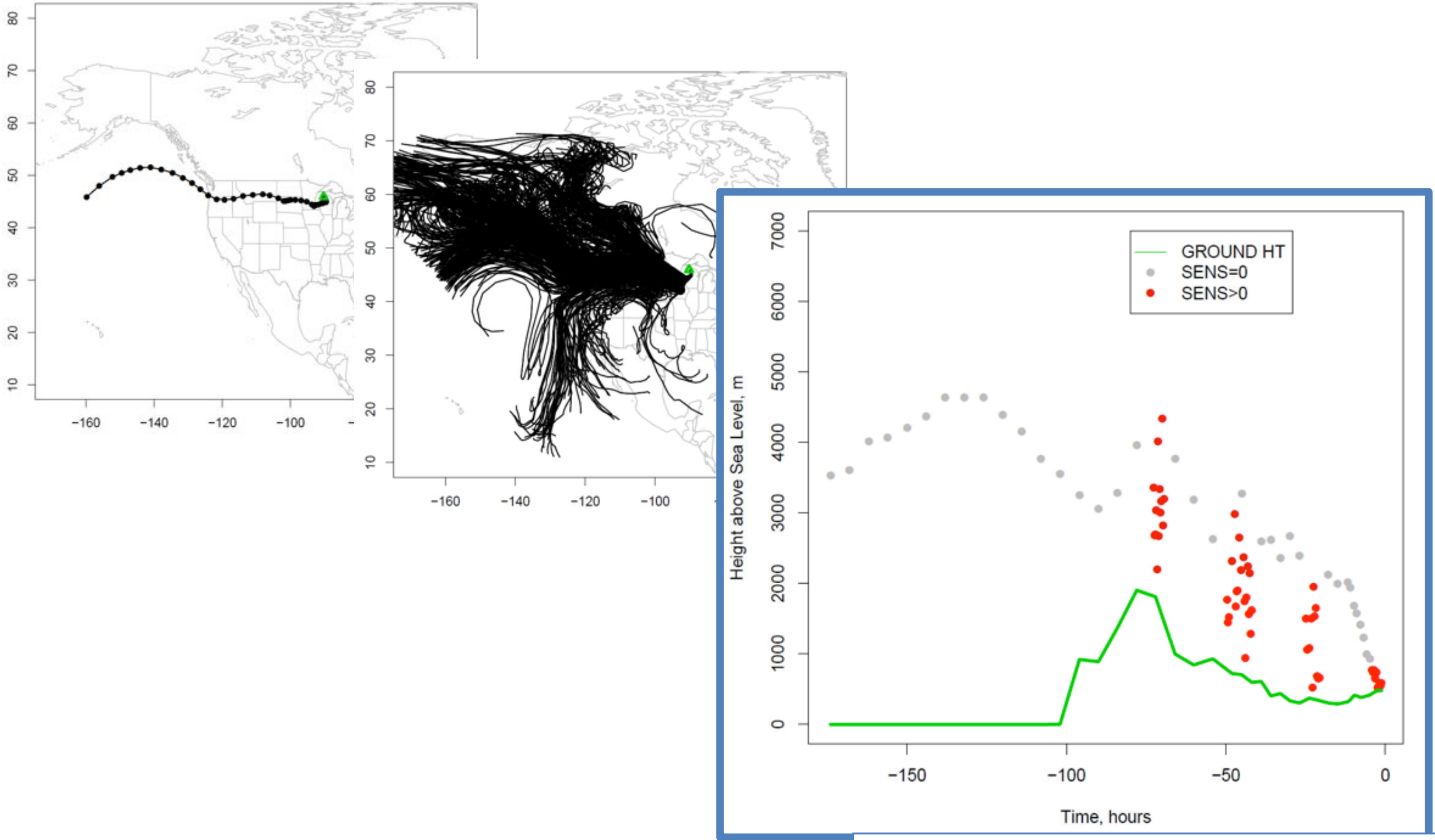

- Time spent in the planetary boundary layer is tracked along with boundary layer height and used to compute the sensitivity to surface emission and uptake.

Introduction to Lagrangian Particle Dispersion Modeling

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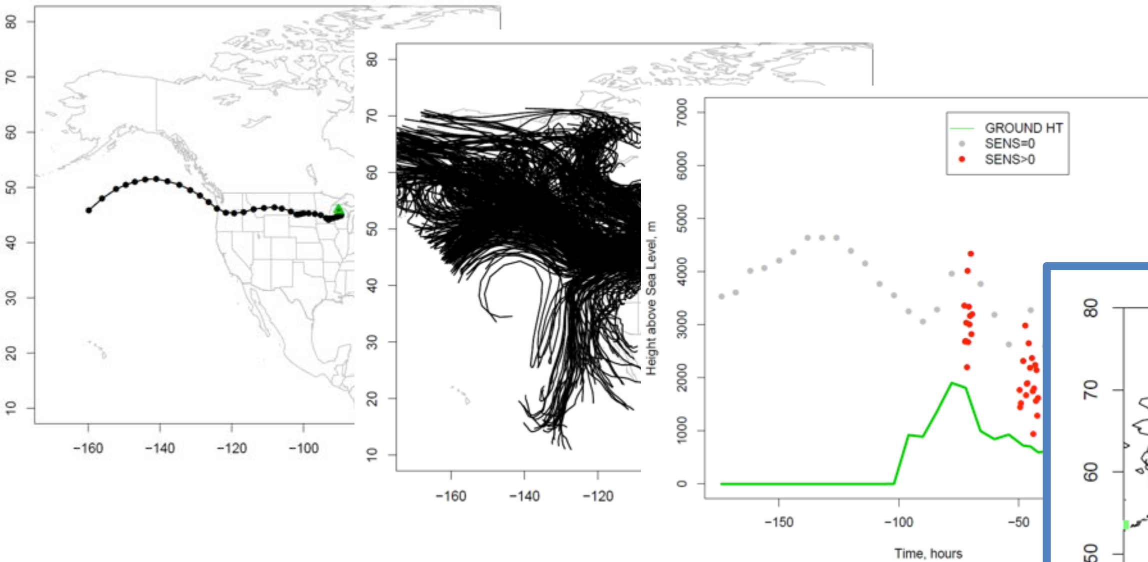

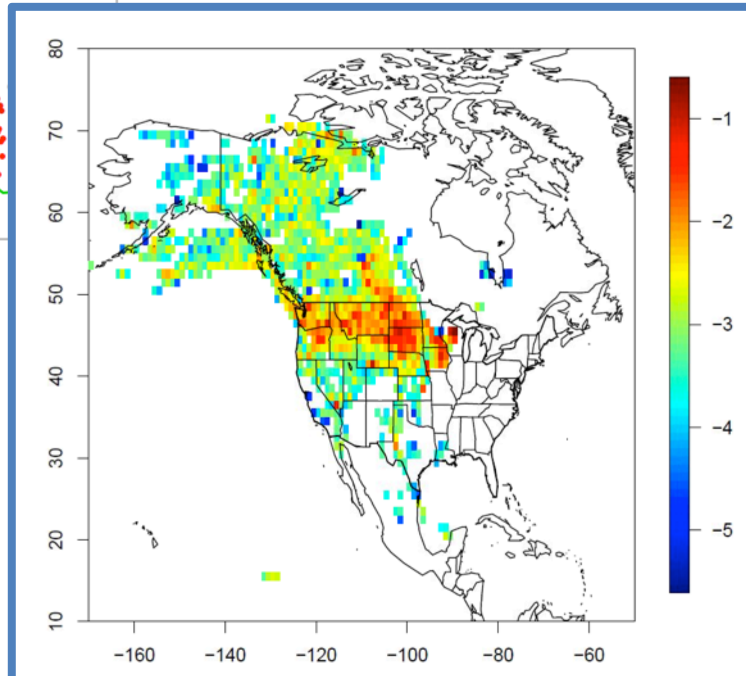

A gridded footprint (a.k.a. influence function) is computed by binning and averaging over all particles. Our footprints have 1°lon x1° lat x hourly resolution.

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:

- NOAA & CIRES: A. Andrews, K. Thoning, M. Trudeau, R. Draxler, A. Stein, L. Hu, L. Bruhwiler, J. Miller, H. Chen, C. Alden, K. Masarie, A. Karion
- 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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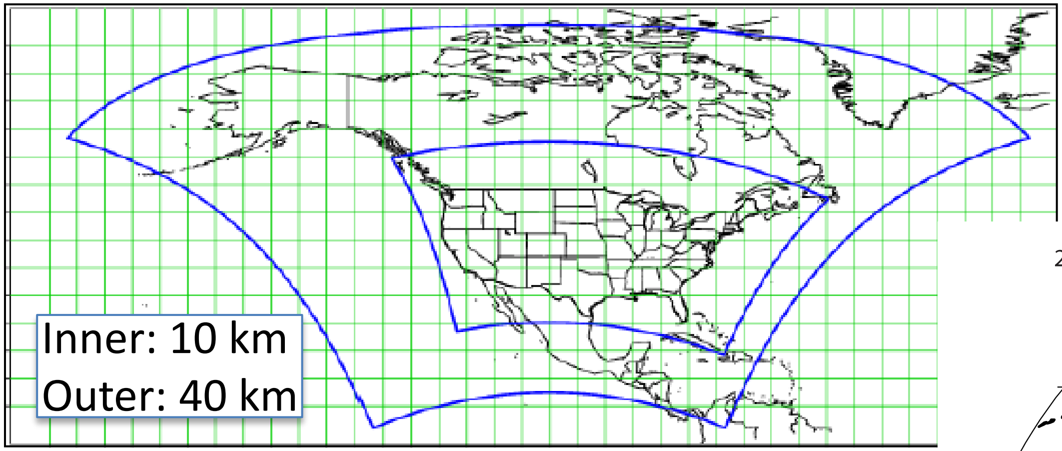

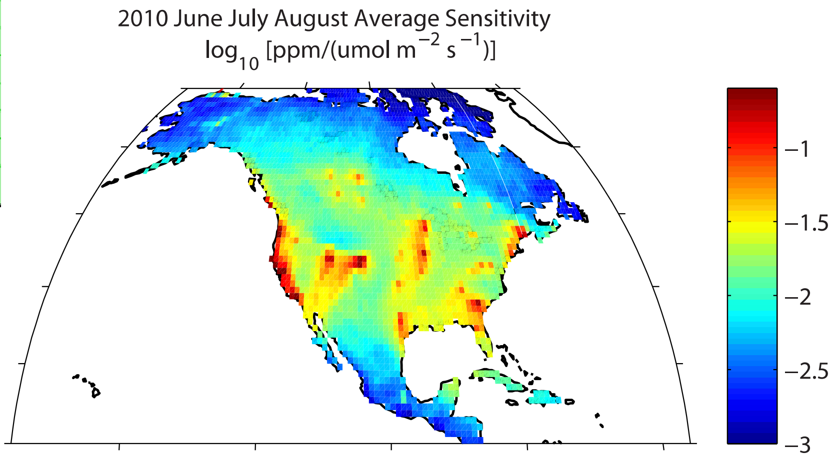

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  - Multiple data-weighting scenarios
  - Varied mathematical construct
    - Form of state vector
    - Bayesian or Geostatistical optimization
  - Multiple priors

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    - Multiple data-weighting scenarios
    - Varied mathematical construct
        - Form of state vector
        - Bayesian or Geostatistical optimization
    - Multiple priors
- Modular python software leverages new techniques from colleagues in academia and facilitates use of alternative transport models.
- New boundary value optimization capability!

$$\hat{\mathbf{s}} = \mathbf{s}_p + (\mathbf{HQ})^T (\mathbf{HQH}^T + \mathbf{R})^{-1} (\mathbf{z} - \mathbf{Hs}_p)$$

Yadav and Michalak, *Geosci. Model Dev.*, *6*, 583–590, 2013

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
ŝ is a vector containing the revised fluxes

Modified framework:

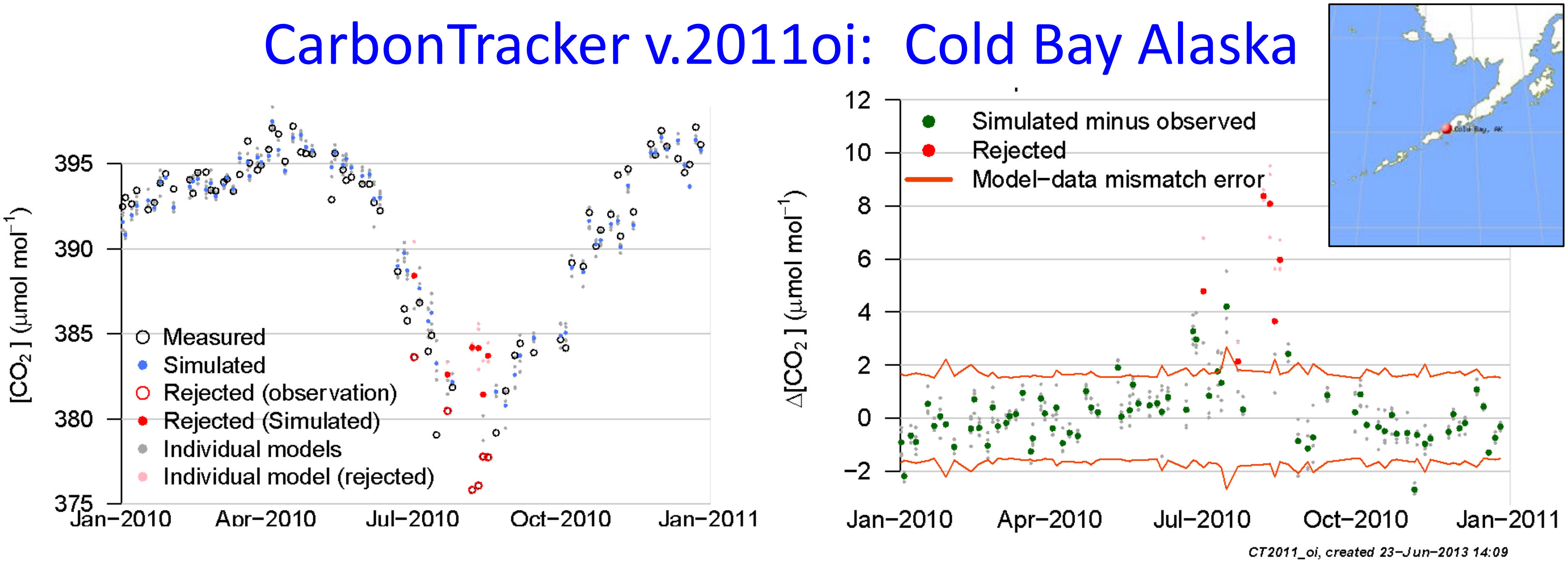
- H has additional columns for boundary value grid cells
- s_p and ŝ contains additional elements
- Q contains additional rows and columns. No cross-correlation between boundary values and fluxes

Why is simultaneous estimation of boundary inflow and surface influence necessary?

Why is simultaneous estimation of boundary inflow and surface influence necessary?

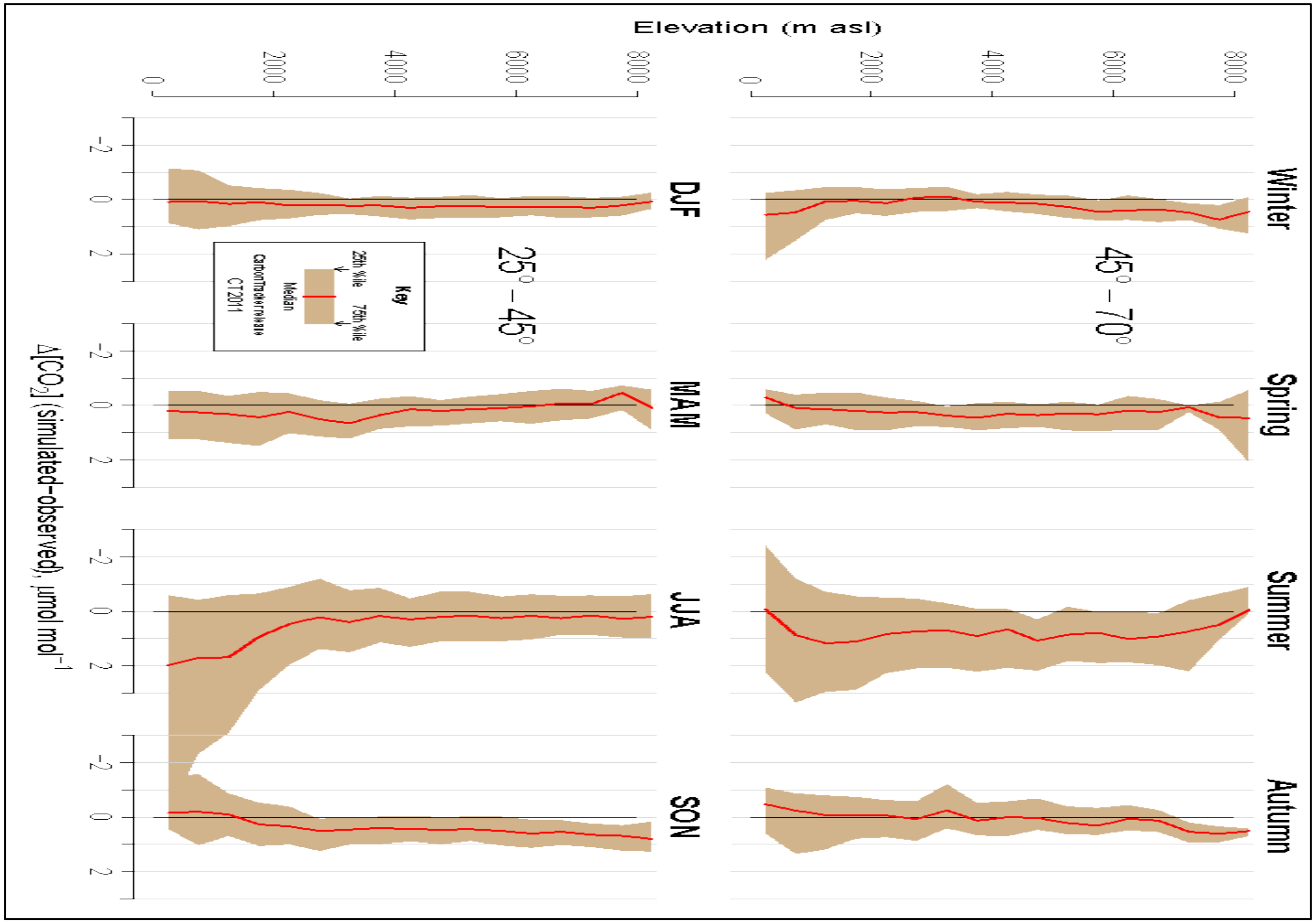
1. Accurate 4-dimensional estimates of the boundary inflow are not readily available.

CarbonTracker v.2011oi: Cold Bay Alaska



- 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:

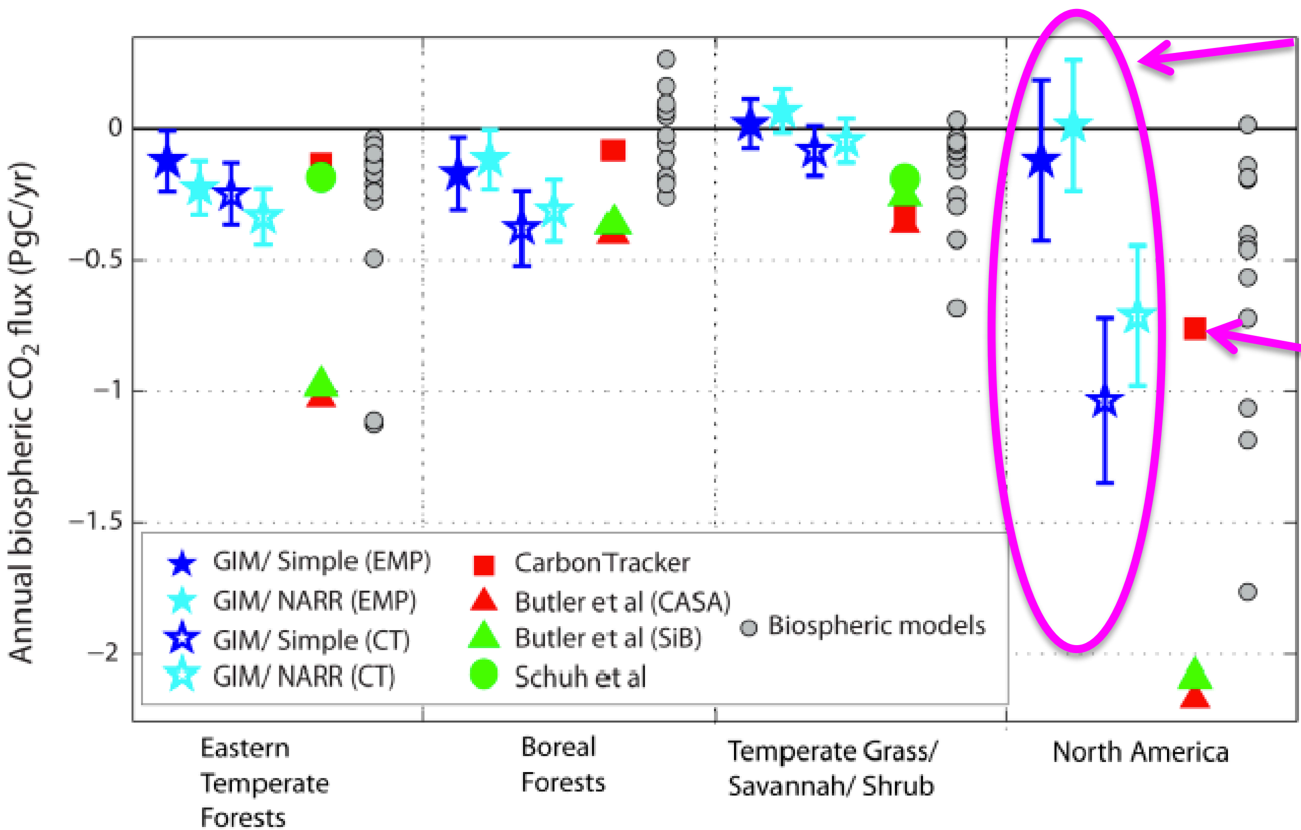
http://www.esrl.noaa.gov/gmd/ccgg/aircraft/data.html

Principal Investigator: Colm Sweeney

A NOAA contribution to the North American Carbon Program

Why is simultaneous estimation of boundary inflow and surface influence necessary?

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.

S. Gourdji et al., "North American CO_2 Exchange: Inter-Comparison of Modeled Estimates with Results from a Fine-Scale Atmospheric Inversion." *Biogeosciences* (2012)

Boundary/Initial Condition Footprints

-Derived from trajectories:

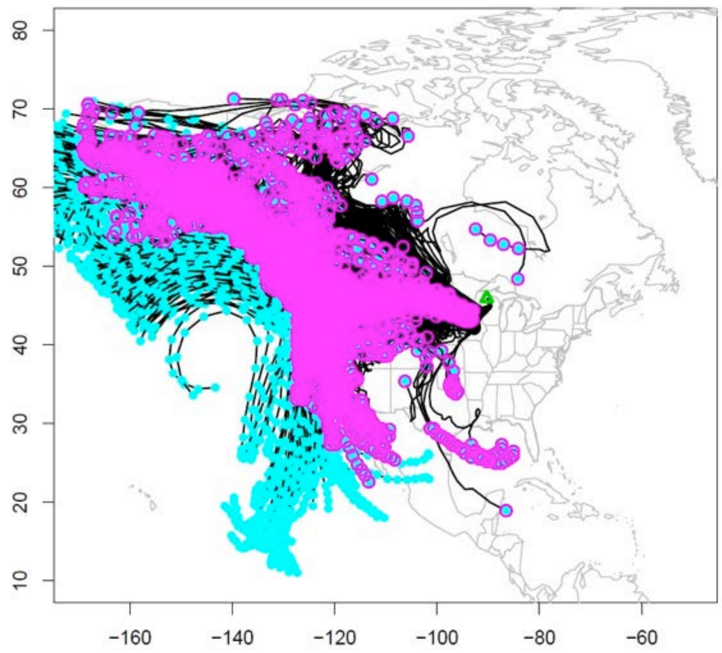
-3 types of boundary values:

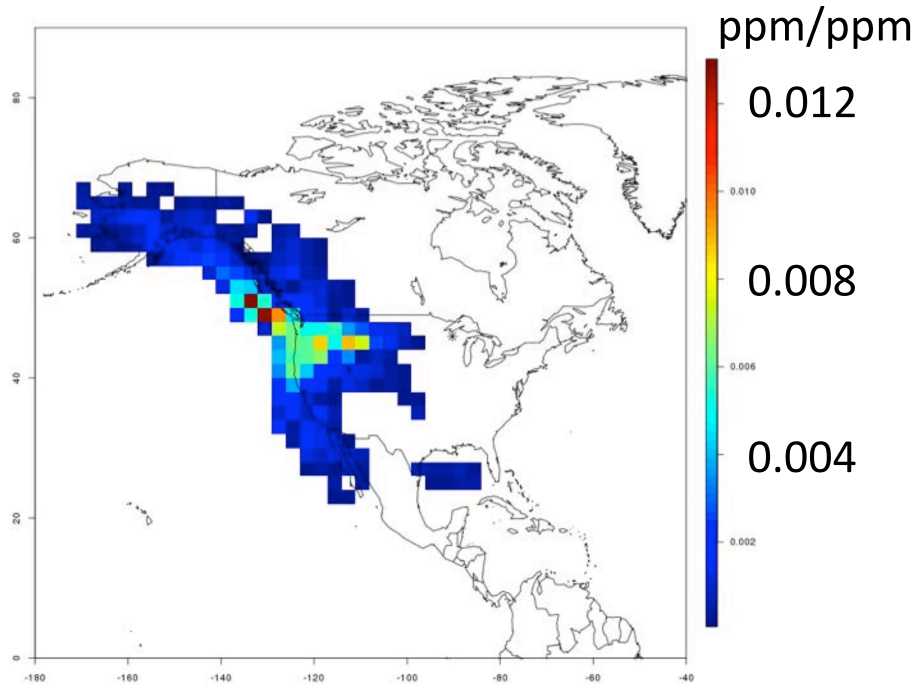
- Exit domain via the marine boundary layer
- Exit domain via the free troposphere
- Still within domain at end of 10 day run

-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)

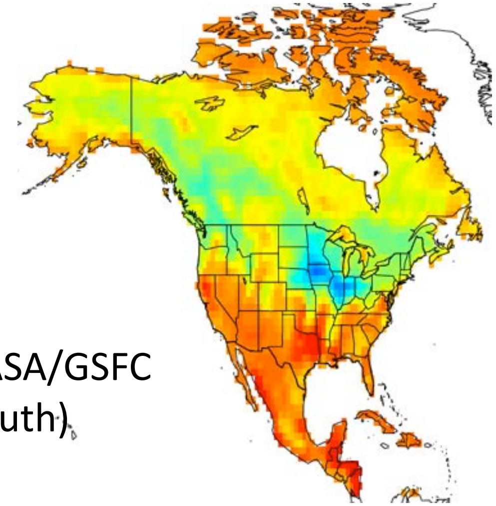
-Boundary value estimation domain limited to region around N. America



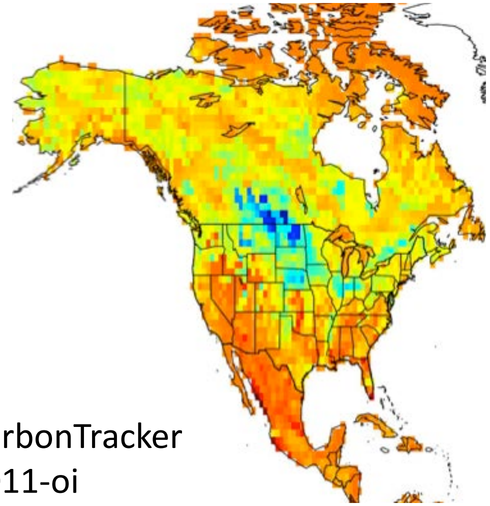


Synthetic Data Exercise: Can CT-L recover known "truth" with weak prior?

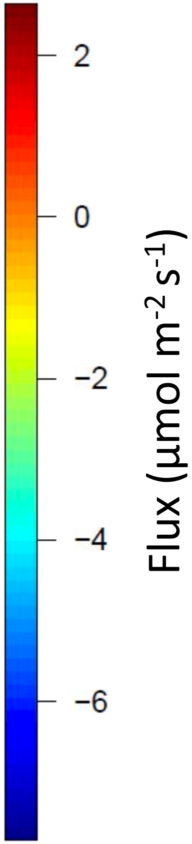
Monthly Mean July 2010



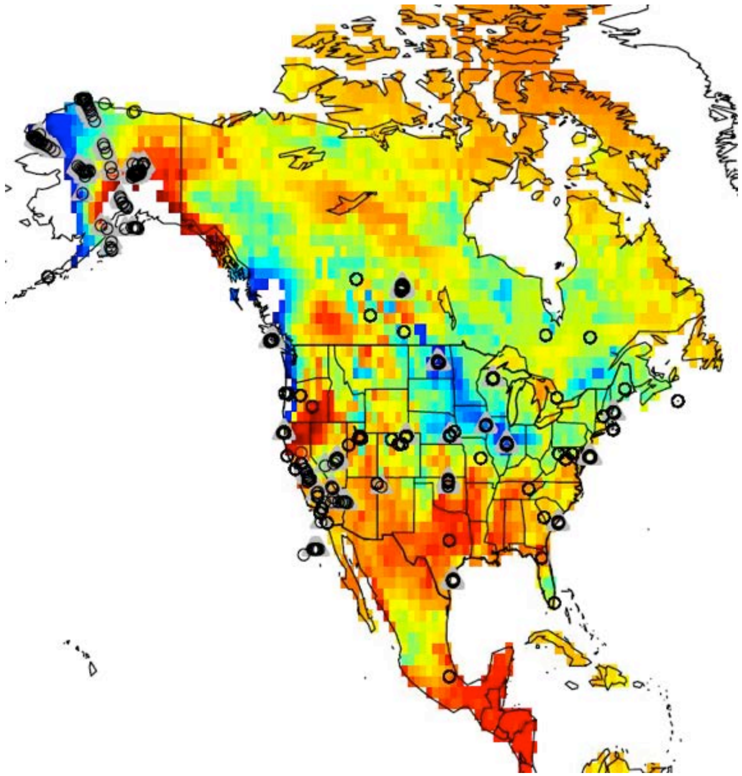
CASA/GSFC (truth)



CarbonTracker 2011-oi (prior)



CT-L Posterior Flux Estimate



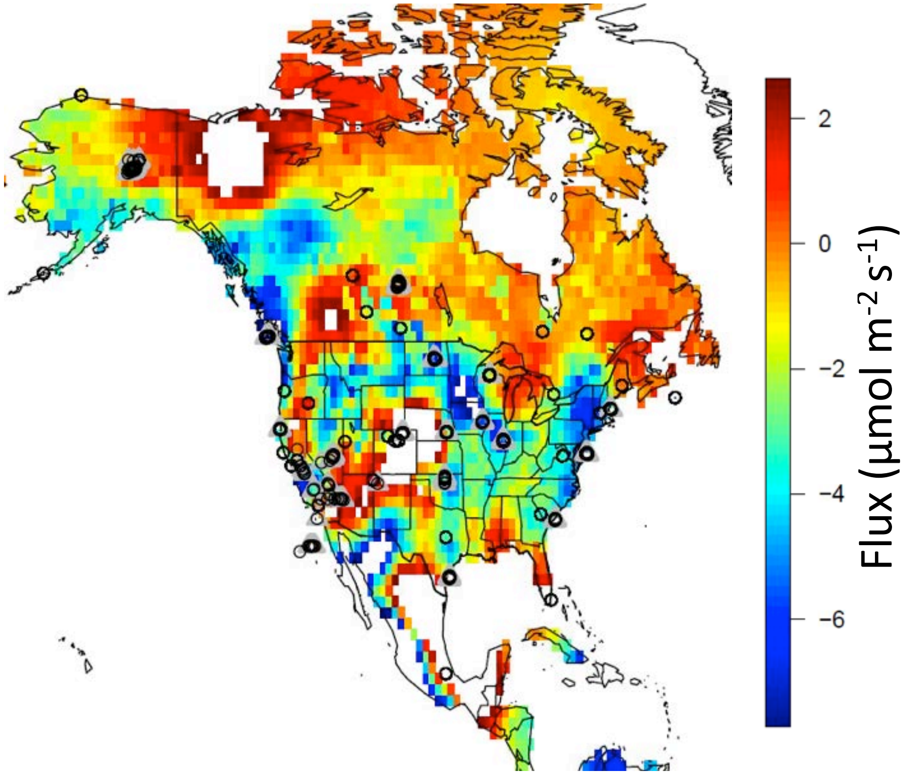
PgC	CASA/GSFC	CT2011-oi	CT-L
N. America	-9.84	-8.46	-12.55
20°-50° N	-4.81	-4.25	-5.66

CASA/GSFC fluxes courtesy of G. J. Collatz; CarbonTracker fluxes courtesy of A. Jacobson.

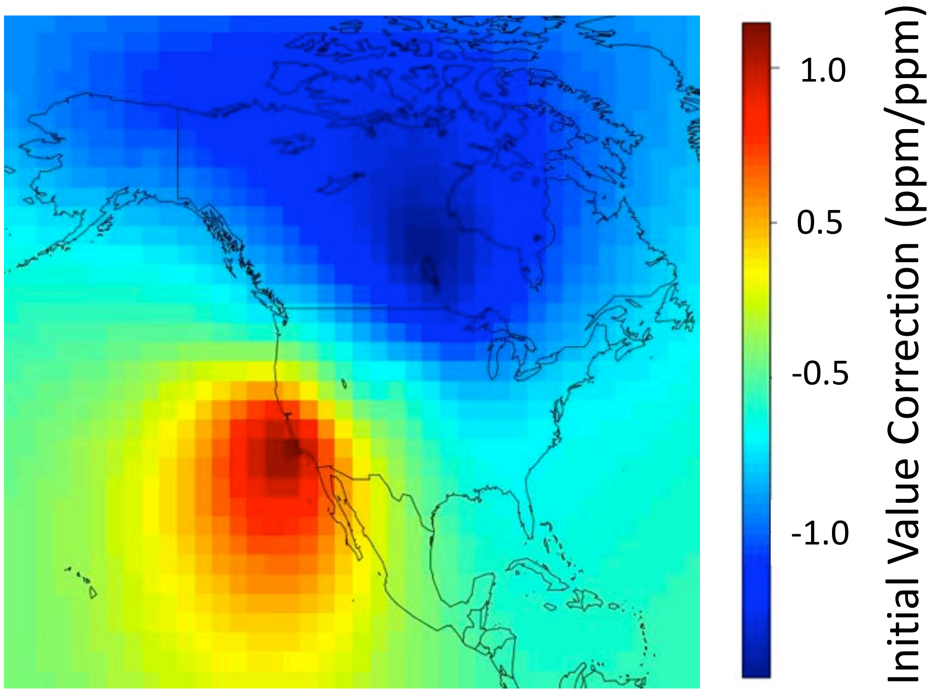
First Real Data Inversion: CT2011-oi used as weak prior

Monthly Mean July 2010

Surface Fluxes



Mole Fraction Adjustment



PgC	CASA/GSFC	CT2011-oi	CT-L
N. America	-9.84	-8.46	-9.72
20°-50° N	-4.81	-4.25	-5.40

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.