**Data fusion to determine North American sources and sinks of carbon dioxide at high spatial and temporal resolution**

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We have developed and tested a method for extrapolating these surface-layer measurements of CO2 at flux towers to atmospheric mixed-layer values under convective (daytime) conditions, creating inexpensive “virtual tall towers (VTT).” These VTT estimates have been compared to six years of actual vertical differences measured at the WLEF tall tower. We find that hourly daytime mixed-layer mixing ratios can be estimated from surface layer values and measured fluxes to within 0.5 ppm in winter, within 0.2 ppm in summer, and within 0.05 ppm in fall and spring (Butler *et al.*, in prep). Accurate extrapolation of surface-layer data to the mixed-layer allows Ameriflux towers to contribute to regional flux estimation by inversion of large-scale transport models which cannot resolve surface-layer gradients.

We have developed several different methods for estimation of continental carbon budgets from CO2 mixing ratio observations which combine traditional weekly flask sampling with continuous in-situ measurements. This is very challenging because of the vastly greater data volume with hourly compared to weekly observations. Older methods have estimated monthly fluxes for large regions, but this leads to unacceptable bias due to errors in the assumed spatial patterns of fluxes within regions. Finer resolution is possible using mesoscale models, but variations of CO2 at the lateral boundary conditions is required in this case. Our strategy has been to use a global model to perform relatively coarse estimation of monthly mean fluxes, and then to use the resulting optimized 4-dimensional CO2 field as a “first guess” for lateral boundary conditions for much higher resolution inversions using a mesoscale model.

Global inversions and transport modeling have been performed with additional support from NASA using the Parameterized Chemical Transport Model (PCTM), which is driven by analyzed meteorology produced by the NASA Goddard Modeling and Assimilation Office. We are using this model to separately estimate monthly photosynthesis and respiration for 47 regions, with 10 in North America.

At the regional scale, we have developed a method to perform flux estimation on a 100 km x 100 km grid over North America using the CSU Regional Atmospheric Modeling System (RAMS) and a backward-in-time Lagrangian Particle Dispersion Model (LPDM). RAMS transport fields are archived and used by LPDM to calculate influence functions, (partial derivative of observed CO2 variations with respect to upstream fluxes at previous times). With a continental network of 10-20 towers making hourly measurements, it is not possible to estimate fluxes every hour for every 100 km grid cell. We aggregate fluxes for 10 days at a time using the Simple Biosphere (SiB) model coupled to RAMS, which estimates photosynthesis (GPP) and respiration every 5 minutes from physiological principles and satellite imagery. We have evaluated SiB-RAMS by comparing simulated fluxes to eddy covariance measurements. We convolved the LPDM-derived influence functions separately with simulated GPP and respiration in SiB-RAMS to produce maps of the influence of each component flux at every grid cell over 10 days on the observed mixing ratio at each tower in each hour. The inverse problem was then formulated as an estimation of multiplicative model bias in GPP and respiration in SiB-RAMS for each grid cell. Optimal estimates of these biases were applied to the simulated gridded fluxes at each time step to produce time-varying maps of GPP and respiration on the 100-km grid which are consistent with the mixing ratio variations.

We found that uncertainty in GPP and respiration was substantially reduced only in a very limited region (a few hundred km radius) around each tower unless spatial error covariance structures were introduced into the optimization. We have applied a very flexible procedure based on the Maximum Likelihood Ensemble Filter (MLEF) to perform the optimization of model bias. Unlike previous studies, we allowed for generalized error covariance and did not specify an exponential decay of spatial autocorrelation with distance. We found that with sufficiently dense observing networks (e.g., the DOE-supported Ring of Towers in 2004), the method could recover complicated spatial structures in model bias quite well. On the other hand, we found that without allowing for spatially correlated model bias the current observing network at the continental scale is insufficiently dense to constrain spatial structures over many areas.

We have used observed fluxes to study the impact of uncertain model parameters in SiB on errors in simulated fluxes (Prihodko et al, in press), and showed that model skill at synoptic to seasonal time scales was often controlled by a handful of parameters. Ricciuto et al (in press) confirmed that a model with a small number of parameters could simulate daily, synoptic and seasonal flux variability well, but Ricciuto (2006) showed that even a tuned ecosystem model had limited skill in predicting interannual variability of net ecosystem-atmosphere exchange (NEE) of CO2 across 5 eastern U.S. temperate forest AmeriFlux sites. This suggests that changes in model structure, rather than simple parameter tuning may be required to capture interannual variability. Assimilation of multi-year records from the flux towers yielded good convergence of the parameters governing photosynthesis and forest phenology, and the parameter values were similar across these sites. Convergence of parameter values governing heterotrophic respiration, however, was weak and relatively inconsistent.

We showed that synoptic to seasonal variations were coherent across a number of towers, but that mean annual fluxes were surprisingly heterogeneous, even over a small area. Different processes control variations at different time scales. Butler et al (in prep) show that spatially coherent responses to climate anomalies can influence timing of seasonal fluxes across a large region, producing widespread anomalies in CO2 mixing ratio that should be interpretable via inverse modeling.

We have studied the nature of the very strong synoptic variability in CO2 mixing ratios at continental sites using observations at six towers, the global PCTM and the coupled SiB-RAMS models. We found that variations are predominantly driven by horizontal advection rather than changes in vertical mixing, and that they can be predicted reasonably well by the models. This is encouraging for the feasibility of regional flux inversion using these models.

Full Proposal

Final Report

Publications

Students