TOP-DOWN REGIONAL CO_2 FLUXES FOR NORTH AMERICA ESTIMATED FROM NOAA-CMDL CO_2 OBSERVATIONS

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ABSTRACT

We present an analysis of terrestrial net CO_2 fluxes from North America for the period 2000-2004. These fluxes consist of hourly maps at ~70km×100km resolution that are consistent with observed atmospheric CO_2 mixing ratios, as well as with varying climatic conditions across different ecosystems as observed from space. The flux maps are created in a newly developed ensemble data assimilation system that consists of the atmospheric Transport Model v5 (TM5), the Vegetation Photosynthesis Respiration Model (VPRM), and an efficient Bayesian least-squares algorithm to optimize the fluxes from different biomes in VPRM against CO_2 mixing ratios from the NOAA-CMDL observing network. The stochastic nature of the ensemble data assimilation system allows us to consistently include uncertainty on net CO_2 fluxes from the neighboring oceans and more distant continents in the flux estimates for North America.

METHOD

NOAA-CMDL is committed to provide detailed estimates of the distribution and magnitude of sources and sinks of CO_2 within the conterminous United States. Therefore, the atmospheric observation network is rapidly expanding as part of the North American Carbon Program (NACP). New atmospheric observations need to be combined (assimilated) into a tracer transport model to untangle regional scale CO_2 fluxes that are optimally consistent with the observations. Ideally, this transport model spans the global domain to ensure consistency with observed global constraints on the carbon cycle, and to compare the North American carbon budget to that of other countries. However, data assimilation with many observations and many unknown fluxes in a global-to-regional scale framework poses many challenges.

We have built such a data assimilation system combining state-of-the-art Ensemble Kalman Filter techniques with the two-way nested global transport model TM5. TM5 satisfies the need for high-resolution modeling in a global domain in a computationally efficient way by calculating detailed transport (~70×100km) for the US, nested within a global simulation with a coarser (~400×600km) grid. The System for Ensemble Assimilation of Tracers in the Atmosphere (SEAT-A) can ingest quasi-continuous observations, estimate surface fluxes and their uncertainty at the model grid-scale, and requires only forward model simulations. SEAT-A can easily be extended to additionally assimilate CO_2 isotopes or weakly non-linear tracers such as CO or CH_4.

Terrestrial carbon fluxes vary at time scales of minutes mostly due to varying sunlight and temperature conditions, and at spatial scales of several kilometers due to differences in vegetation cover. Such small scale flux variability is nearly impossible to quantify from atmospheric CO_2 observations alone. Fortunately, the factors controlling this variability, i.e., the characteristics of the underlying vegetation and variations in light and temperature, are known quite well even on such small scales. Therefore, biosphere models can be used to transform these known driving forces into CO_2 fluxes that can be an extra constraint in top-down flux estimates.

We use the VPRM biosphere model developed at Harvard to add such extra constraints to our problem. The VPRM model predicts photosynthesis and respiration fluxes for different biome types using satellite observed Photosynthetically Active Radiation (PAR), Enhanced Vegetation Index (EVI) and Land Surface Water Index (LSWI; both from MODIS), and model calculated temperature. After calibration of the modeled fluxes to eddy-flux measurements for different biome types, hourly fluxes created by VPRM were shown to accurately capture the seasonal and synoptic behavior of the local net CO_2 flux. In our framework, the calibrated VPRM hourly fluxes serve as a first guess of the unknown true net CO_2 surface flux. Photosynthesis and respiration are then scaled separately for each biome type to yield an optimized net flux consistent with atmospheric CO_2 mixing ratios from flasks collected at the surface, flasks collected from aircraft, and quasi-continuous CO_2 observations from tall towers.

In addition to the best estimate of the terrestrial CO_2 fluxes, SEAT-A returns estimates of the covariance on these fluxes. These covariances represent the Gaussian probability density function of the predicted fluxes and contain information on the uncertainty of our estimates. This uncertainty includes shortcomings in our modeling framework, the faith we put on our prior fluxes and CO_2 observations, the uncertainty on terrestrial fluxes from other continents, as well as uncertainty on ocean and fossil fuel fluxes that we do not yet optimize in this study. Thus, our estimate reflects the range of likely CO_2 flux patterns for North America given incomplete knowledge of other CO_2 fluxes around the globe.

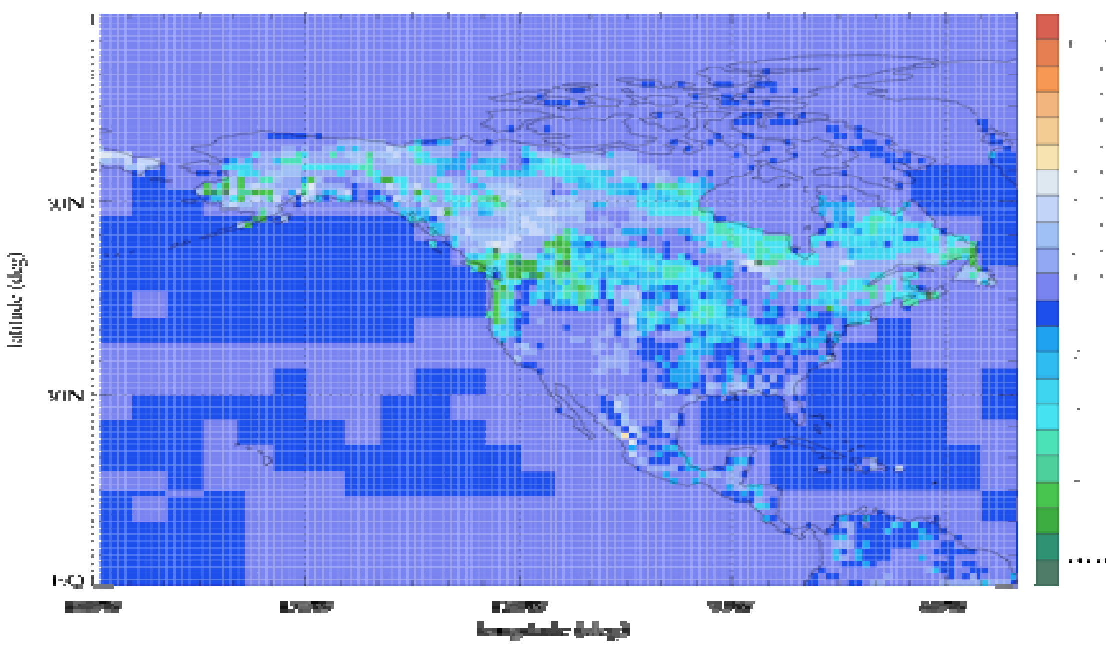

Fig. 1: An example of the North American terrestrial CO_2 flux for July 2000 after optimization of the flux across 42 ecosystems using atmospheric CO_2 mixing ratio observations. Units are in $kgC/m^2/s$.