1. Introduction

Around one-half of the global CO₂ emissions from fossil fuel combustion and deforestation accumulate in the atmosphere, where it contributes to global warming. The rest is taken up by vegetation and the ocean. The precise contribution of the two, and the location and year-to-year variability of the CO₂ sink are not well understood though.

As part of the NASA Goddard GEOS-Carb project, we conduct a traditional Bayesian inversion at relatively high resolution to estimate the global distributions of CO₂ fluxes during 2009-2010. In this top-down approach, fluxes are inferred from atmospheric CO₂ measurements by means of an atmospheric transport model linking the measurements to flux regions upstream, subject also to prior constraints. A focus of this work is the use of column CO₂ measurements from the Greenhouse Gas Observing SATellite (GOSAT), available since 2009 (Takashita et al., 2009). In addition to measurements from well-established ground-based networks, satellites generally provide greater spatial coverage than current ground-based networks, though with less sensitivity to the boundary layer of the atmosphere.

2. Objectives

- Understand recent variability of the carbon cycle
- Evaluate the bottom-up flux estimates used for the priors
- Compare fluxes and uncertainties inferred using GOSAT vs. in situ observations
- Compare our Bayesian inversion with other inversion approaches, such as Kalman filters and variational data assimilation, which are more computationally efficient but rely on approximations

3. Methods

- Observations of CO₂ mixing ratio
  - In situ measurements
  - Individual flask observations (NOAA ESRL), afternoon averages for continuous observations (NOAA ESRL and JMA)
  - GOSAT column-average mixing ratios
  - ACOS 83.4 release-3 retrieval (June 2009 onward), provided by C. O'Dell; filtered and bias-corrected
  - We averaged observations over each model grid cell and hour
- Prior constraints
  - Net ecosystem production (NEP) and biomass burning fluxes from CASA-GFED v3 model, driven by satellite observations and observed meteorology. Modeled biosphere generally neutral except for imposed crop sink in U.S. Midwest.
  - Measurement-based ocean fluxes from Takahashi et al. (2009)
  - Fixed fossil CO₂ emissions from CDiac
- Transport model
  - PCTM (Kawa et al., 2004), with meteorology from NASA GEOS-5 MERRA reanalysis
  - Grid used: 2° latitude x 2.5° longitude x 5x levels to 0.4 mb, output hourly
  - Model sampled at observation times
- Inversion method
  - "TransCom" style batch Bayesian simulation inversion
  - Optimize natural fluxes in 108 regions (see map below) over 8-day intervals; cf. 22 regions, monthly intervals in TransCom
  - Initial concentrations derived from a multi-year PCTM run with prior fluxes; optimized in the inversion
  - Neglected correlations in a priori and observation uncertainties
  - Have completed a 1.5 year inversion (Mar 2009-Aug 2010) from the start of the GOSAT period
- Although this inversion method is relatively simple mathematically, it is very time-consuming at this resolution.

4. Results

Net CO₂ flux (fossil fuel, terrestrial biosphere, biomass burning, and ocean), 2009

5. Results aggregated to “TransCom-3” regions

Fluxes below include only NEP and ocean fluxes (no fossil fuel, biomass burning)

8-day averages

Land regions

Ocean regions

Seasonal averages (with 1σ uncertainties)

Error bars represent 1σ uncertainties

6. Comparison with a different inversion (CarbonTracker)

- NOAA’s CarbonTracker (CT) is an ensemble data assimilation system that uses multiple in situ observation networks to estimate fluxes over the past decade (Peter et al., 2007). CT uses a larger number of in situ observations than our current inversion.
- CT solves for uniform flux scale factors over ecoregions or vegetation types within each sub-continental region.
- Results are shown for a selected month, for the CT 2011_v.0 inversion.

7. Comparison of observed and model mixing ratios at selected sites (in situ only inversion)

- Prior concentrations are biased high at most locations, because the biosphere (in reality the biosphere is a net sink).
- Posterior concentrations match the observations quite well, even for most of the large dips and peaks.
- Transport model captures simplistic-scale variability.

8. Conclusions and further work

- Our optimal fluxes generally resemble those of other group’s inversions, for example indicating:
  - A net terrestrial biospheric CO₂ sink, including a significant one in temperate North America.
  - A stronger sink in some northern mid- to high-latitude regions in the GOSAT-only inversion compared to the in-situ only inversion.
  - A slight indication of less terrestrial growing season uptake in 2010 than in 2009 at higher latitudes of the Northern Hemisphere.
  - The GOSAT-only inversion gives smoother results with smaller flux uncertainties in many regions than the in-situ-only inversion, suggesting that satellite observations can benefit flux estimation with their greater spatial coverage.
  - However, possible remaining systematic errors in the GOSAT data could contribute to the spatial patterns seen in the results. On the other hand, in-situ network likely contains greater spatial sampling bias.
  - Applying a prior flux error correlations could improve constraint on fluxes, especially for the in-situ inversion.
  - Our results can contribute to assessment of effects of various methodological differences among groups.
  - We will extend this inversion through the end of 2010 and lengthen the spin-up, and use the other observational data sets (e.g., TCCON, HIPPO) both in the inversions and for independent evaluation.
  - We will later switch to a more computationally efficient inversion technique for working with large amounts of satellite and other data at high resolution.

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