Quantification of the sensitivity of NASA CMS-Flux inversions to uncertainty in atmospheric transport

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Comparison of posterior CO2 fluxes from 11 global inversions of the Global Carbon Project for 5 Transcom ecoregions, in PgC/year.

Natural flux component, annual mean (averaged over 2001-2004), from 3 different inversion systems (ecoregions and pixel-based)

*CarboScope (ICOS program, European Commission)*
Mean estimates for the three inverse estimates and the inventory with their associated posterior uncertainties in TgC

*from Schuh et al. (2013)*

Coefficient of variation between the inventory and the inverse fluxes from 0.5 degree resolution to the entire domain

*from Ogle et al., sub.*
Objective 1: Assess the transport error in the global NASA CMS-Flux system and the mesoscale WRF-LPDM based upon meteorological data and CO2 profiles from airborne measurements over North America.

Objective 2: Represent transport error by a physics-based ensemble of transport configurations in WRF.

Objective 3: Estimate the contribution of transport uncertainty over North America to global flux uncertainty.
Objective 1:
- NASA CMS-Flux system coupled offline to the mesoscale WRF (WRF-CMS)
- Performed 1-year simulation at 30km resolution
- Extraction of GOSAT column pseudo-data
  - Collect meteorological data and CO2 aircraft flask samples
  - Compare GEOS-CMS and WRF-CMS performances

Objective 2:
- Perform ensemble simulations with WRF-CMS over North America
  - Explore calibration techniques
- Sample GOSAT column pseudo-data for the ensemble
- Perform GEOS-CMS inversions with WRF-GOSAT pseudo-data

Objective 3:
- Assessment of transport uncertainty on global flux uncertainty
- Identify sources of errors (i.e. convection, PBL schemes,...)
Mesoscale modeling over North America

The PennState Mesoscale system (WRF-CMS):

Weather Research and Forecasting (WRF) model version 3.6 modified for multiple passive tracers (Lauvaux et al., 2012)

30km resolution domain over North America using:
- Mellor-Yamada-Nakanishi-Niino 2.5 (PBL scheme)
- NOAH scheme (Land surface model)
- Single-Moment 5-class scheme (Microphysics scheme)
- Kain-Fritsch scheme (Cumulus scheme)

Individual tracers for each CMS Flux component:
- Biogenic (prior daily, prior monthly, posterior)
- Ocean
- Fire
- Ship
- fossil fuel

Simulated column-integrated dry air mole fraction of CO2 at 7:00 am EST (b) on 2 May 2008 using the WRF system at 30km resolution
NASA CMS-Flux inversion system

*NASA CMS-Flux inversion system (Liu et al., 2012)*

Produce monthly inverse fluxes at 4°x5° globally using GOSAT data

Newly implemented nested mode over North America: GEOS-Chem 4°x5° with GEOS-Chem NA-nested (0.5°x0.6°)

Combination of surface in-situ CO2 measurements (using Obspack by NOAA-ESRL)

Simulated CO2 concentrations (in ppm) near the surface on 20 January 2010 at 4°x5° resolution (left panel) and GEOS-Chem NA-nested at 0.5°x0.6° (right panel)
Coupling WRF and the NASA CMS-Flux system

**WRF-CMS system (offline coupling)**

WRF coupled to GEOS-Chem 4° x 5° for surface fluxes and boundary conditions

- Bilinear interpolation at the boundaries (continuous flow with 6-hourly fields)

- Surface fluxes: CMS flux product components (fossil fuel, biogenic, ocean,...)

Simulated CO$_2$ atmospheric mixing ratios averaged over June 2010 using the WRF-CMS modeling system at 30km resolution near the surface (left panel), at 850hPa (middle panel), and at 500hPa (right panel)
Sampling transport errors in WRF-CO2

Representation of transport errors in an inverse system using an ensemble approach to define the random and systematic errors

from Lauvaux and Davis, 2014
Ensemble-based statistics and transport errors

Two different approaches with ensemble methods to represent transport errors:

1. Generate the statistics with controlled perturbations,
2. Generate a large ensemble and sub-sample it (calibration),

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Cases</th>
<th>LSM Scheme</th>
<th>PBL Scheme</th>
<th>Cumulus Scheme</th>
<th>Microphysics Schemes</th>
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Physics-based ensemble using 27 WRF model configurations of the PBL, land surface, and convection/microphysics schemes

Mean bias in the mean horizontal wind speed at 300m high using 00z radiosonde measurements for June 2008 at four sites across the US upper Midwest

Courtesy of Liza Diaz-Isaac
Example: Calibration of a large ensemble

Planetary boundary layer height time series (00z only) observed (in black) and simulated by WRF (27 colors) for June 2008, at two radiosonde sites

Rank histograms for the PBL depth using 13 radiosonde sites over 35 days (00z only) compared to WRF simulations at 10km resolution over the MCI domain

Courtesy of Liza Diaz-Isaac
Low pressure center over Iowa, i.e. strong vertical mixing between PBL and Free Troposphere
Cloud/rain with no photosynthesis, so limited uptake and no convective PBL
CO2 concentrations are similar throughout the column
Synoptic event in GOSAT pseudo-data

An August Frontal Passage in Iowa

CO2 concentrations are similar throughout the column

Low pressure center over Iowa, i.e. strong vertical mixing between PBL and Free Troposphere
Cloud/rain with no photosynthesis, so limited uptake and no convective PBL
Synoptic event in GOSAT pseudo-data

Simulated GOSAT XCO2 data (in black), low altitude in-situ CO2 (in green), Lower Troposphere in-situ CO2 (in orange), and Mid Troposphere in-situ CO2 (in blue)

Corresponding weather map at 12 UTC of the same day

Aug 15th: Second front (cold) but no cloud, GPP starts, and wind direction shifts (corn area upwind)

Lower concentrations in the convective PBL
Conclusions and Perspectives

One year simulation at 30km resolution using WRF-CMS (2010)

Production of GOSAT simulated measurements

Evaluation/Comparison of GEOS-Chem and WRF-CMS using aircraft CO$_2$ profiles, meteorological measurements (radiosondes, surface stations), and in-situ CO$_2$ measurements

Perform inversions with NASA CMS-Flux inversion system using WRF-GOSAT data

Perform the ensemble of WRF simulations

Provide initial flux uncertainty assessment including transport errors

*Simulated XCO$_2$ averaged over June 2010 using the WRF-CMS modeling system at 30km resolution*