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

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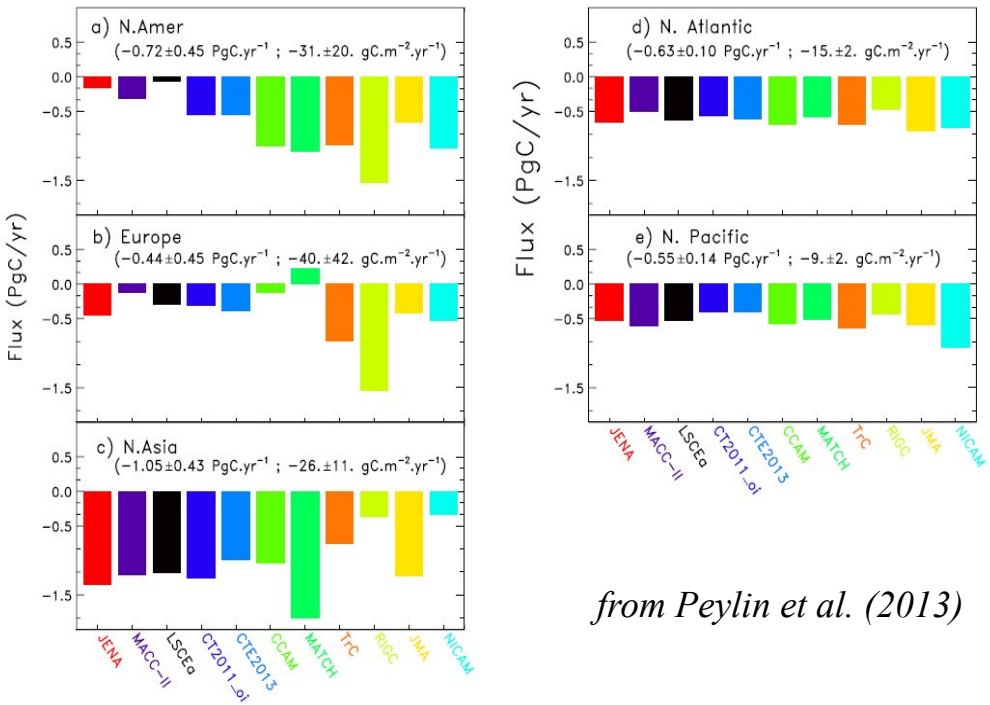
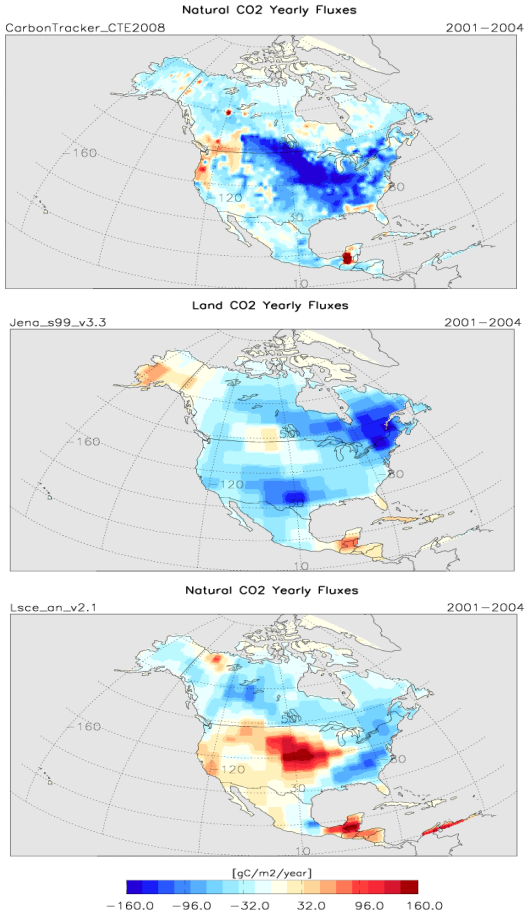
Atmospheric inversion model inter-comparison



from Peylin et al. (2013)

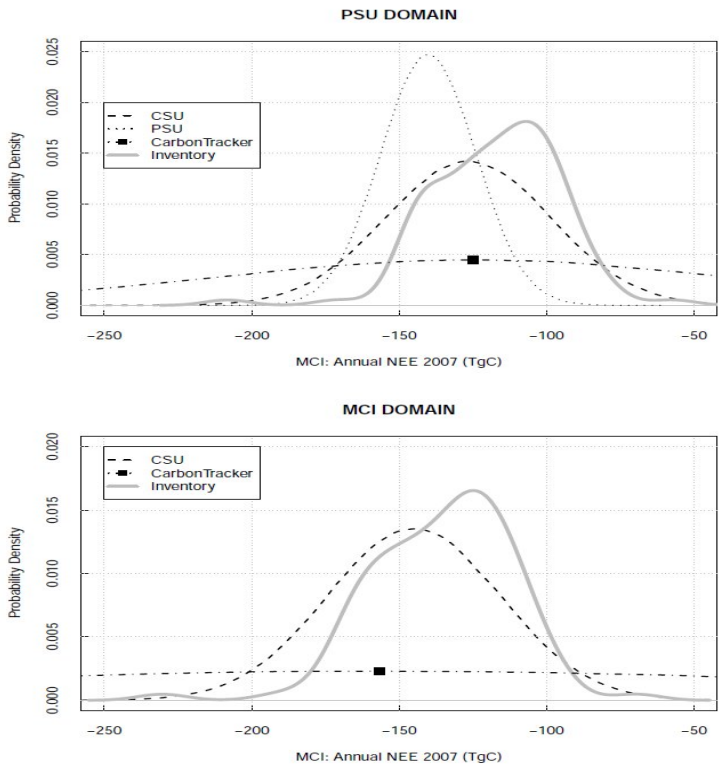


Comparison of posterior CO2 fluxes from 11 global inversions of the Global Carbon Project for 5 Transcom ecoregions, in PgC/year.

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

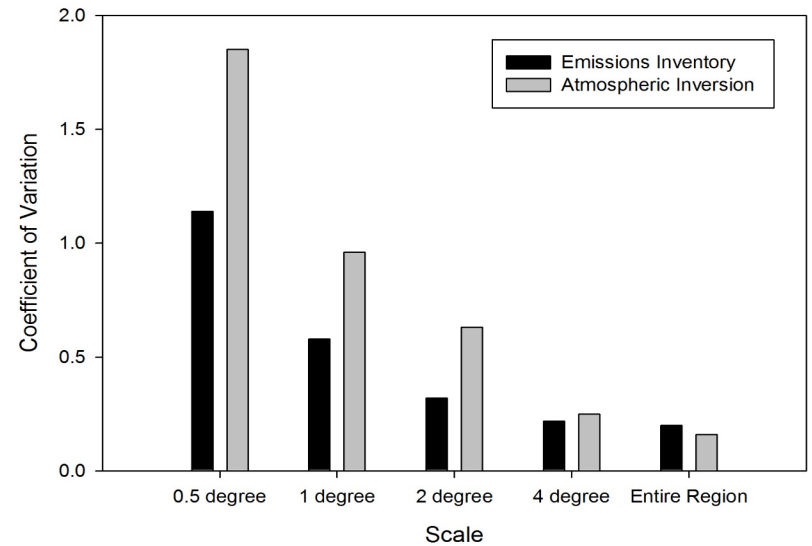
CarboScope (ICOS program, European Commission)

Transport model errors and spatial scales



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.

Project summary: main objectives

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.

Project summary: sub-objectives

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):

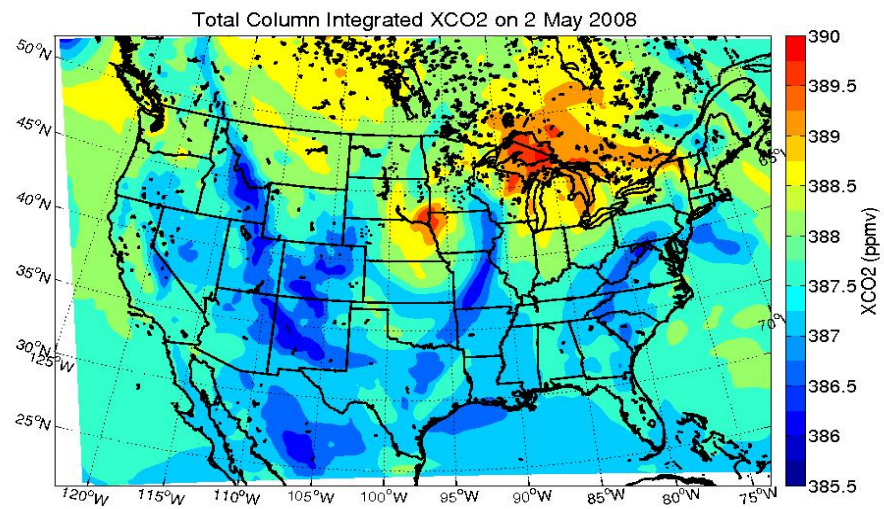
Weather Research and Forecasting (WRF) model version 3.6 modified for multiple passive tracers (Lauvaux et al., 2012)

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 CO_2 at 7:00 am EST (b) on 2 May 2008 using the WRF system at 30km resolution

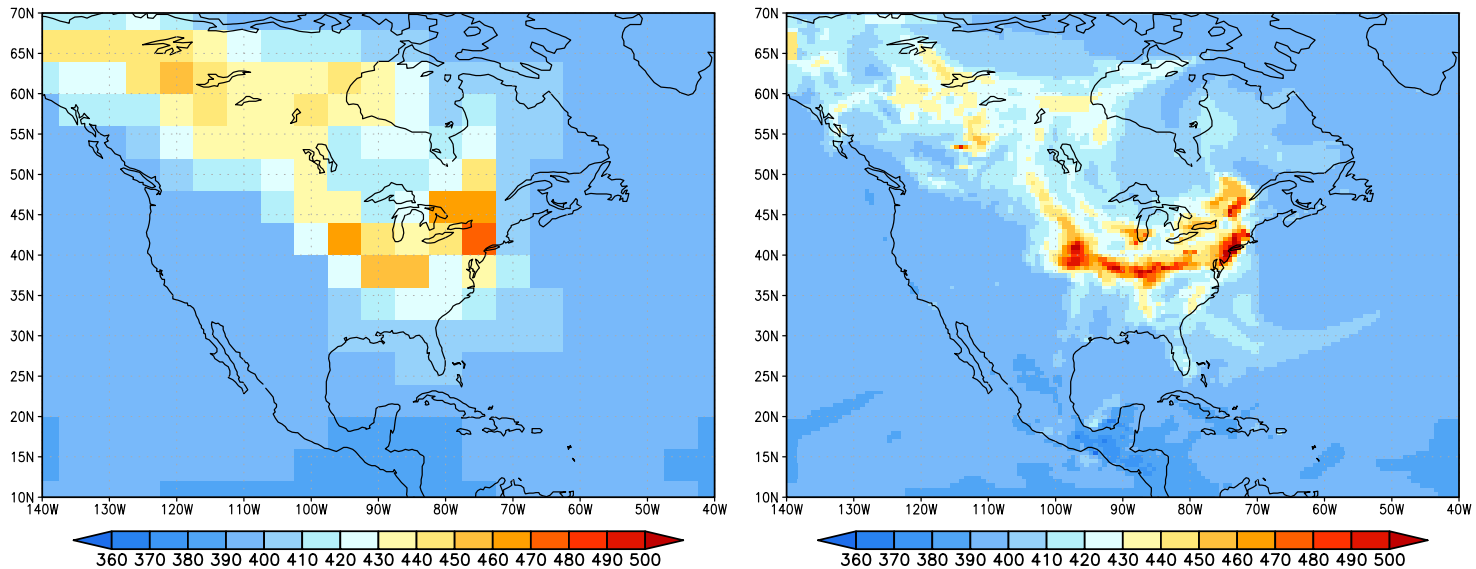
NASA CMS-Flux inversion system

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)

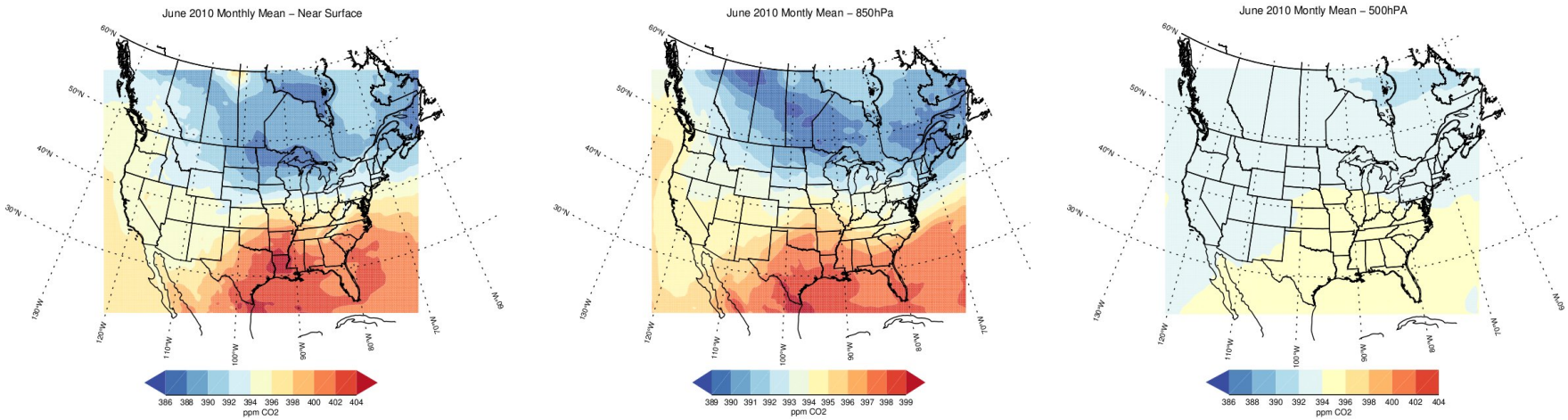
Coupling WRF and the NASA CMS-Flux system

WRF-CMS system (offline coupling)

WRF coupled to GEOS-Chem 4°x5° for surface fluxes and boundary conditions

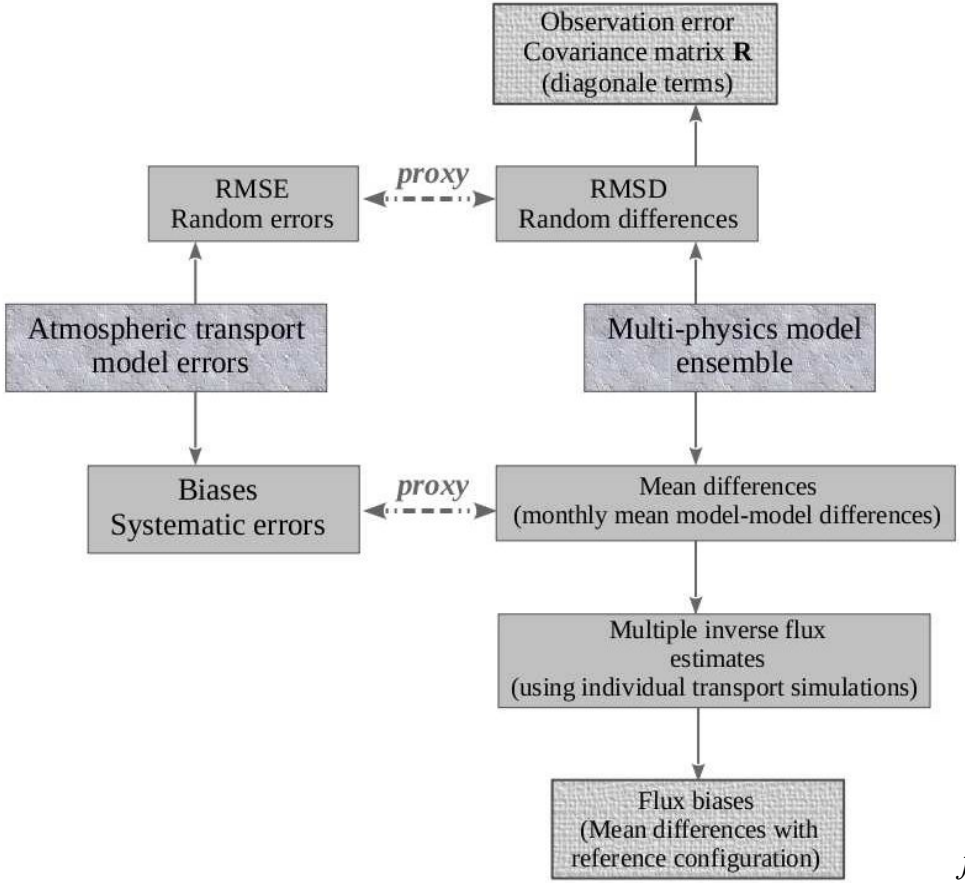
- Bilinear interpolation at the boundaries (continuous flow with 6-hourly fields)

- 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



from Lauvaux and Davis, 2014

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

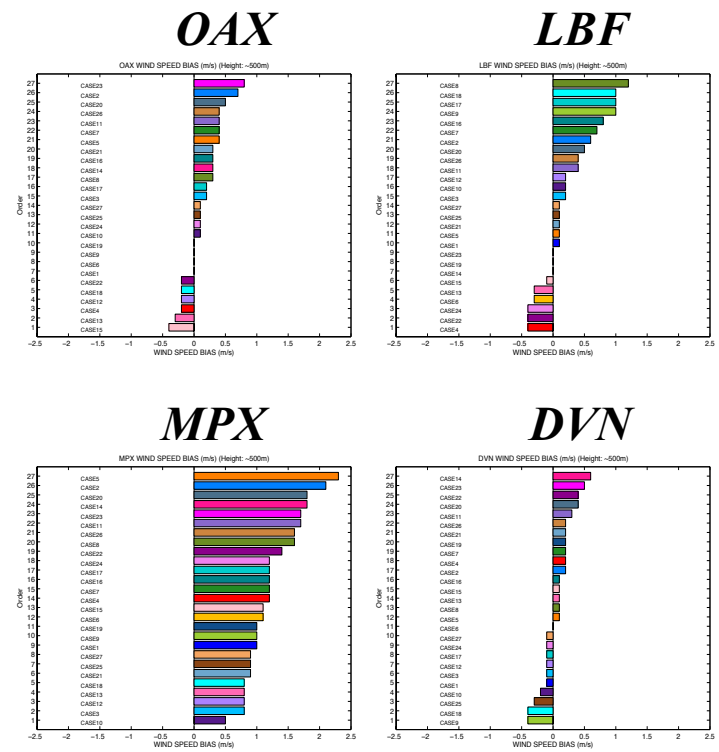
Ensemble-based statistics and transport errors

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),

Analysis				Cases	LSM Scheme	PBL Scheme	Cumulus Scheme	Microphysics Schemes	Nested Simulations	No Cumulus
Microphysics	Cumulus	PBL	LSM	Case 1 New	Noah	YSU	Kain-Fritsch	WSM 5-class	X	X
				Case 2 New	Noah	MYJ	Kain-Fritsch	WSM 5-class	X	X
				Case 5 New	Noah	MYNN 2.5	Kain-Fritsch	WSM 5-class	X	
		PBL		Case 4 New	RUC	YSU	Kain-Fritsch	WSM 5-class		
				Case 3 New	RUC	MYJ	Kain-Fritsch	WSM 5-class		
				Case 6 New	RUC	MYNN 2.5	Kain-Fritsch	WSM 5-class	X	X
		PBL		Case 1 SLAB	Thermal Dif.	YSU	Kain-Fritsch	WSM 5-class	X	X
				Case 2 SLAB	Thermal Dif.	MYJ	Kain-Fritsch	WSM 5-class		
				Case 3 SLAB	Thermal Dif.	MYNN 2.5	Kain-Fritsch	WSM 5-class		
		PBL	LSM	Case 7 New	Noah	YSU	Grell-3D	WSM 5-class		
				Case 8 New	Noah	MYJ	Grell-3D	WSM 5-class		
				Case 11 New	Noah	MYNN 2.5	Grell-3D	WSM 5-class		
		PBL		Case 10 New	RUC	YSU	Grell-3D	WSM 5-class		
				Case 9 New	RUC	MYJ	Grell-3D	WSM 5-class		
				Case 12 New	RUC	MYNN 2.5	Grell-3D	WSM 5-class		
		PBL		Case 4 SLAB	Thermal Dif.	YSU	Grell-3D	WSM 5-class		
				Case 5 SLAB	Thermal Dif.	MYJ	Grell-3D	WSM 5-class		
				Case 6 SLAB	Thermal Dif.	MYNN 2.5	Grell-3D	WSM 5-class		
	Cumulus	PBL	LSM	Case 13 New	Noah	YSU	Kain-Fritsch	Thompson		
				Case 14 New	Noah	MYJ	Kain-Fritsch	Thompson		
				Case 17 New	Noah	MYNN 2.5	Kain-Fritsch	Thompson		
		PBL		Case 16 New	RUC	YSU	Kain-Fritsch	Thompson		
				Case 15 New	RUC	MYJ	Kain-Fritsch	Thompson		
				Case 18 New	RUC	MYNN 2.5	Kain-Fritsch	Thompson		
		PBL		Case19 New	Noah	YSU	Grell-3D	Thompson		
				Case 20 New	Noah	MYJ	Grell-3D	Thompson		
				Case 23 New	Noah	MYNN 2.5	Grell-3D	Thompson		

Physics-based ensemble using 27 WRF model configurations of the PBL, land surface, and convection/microphysics schemes

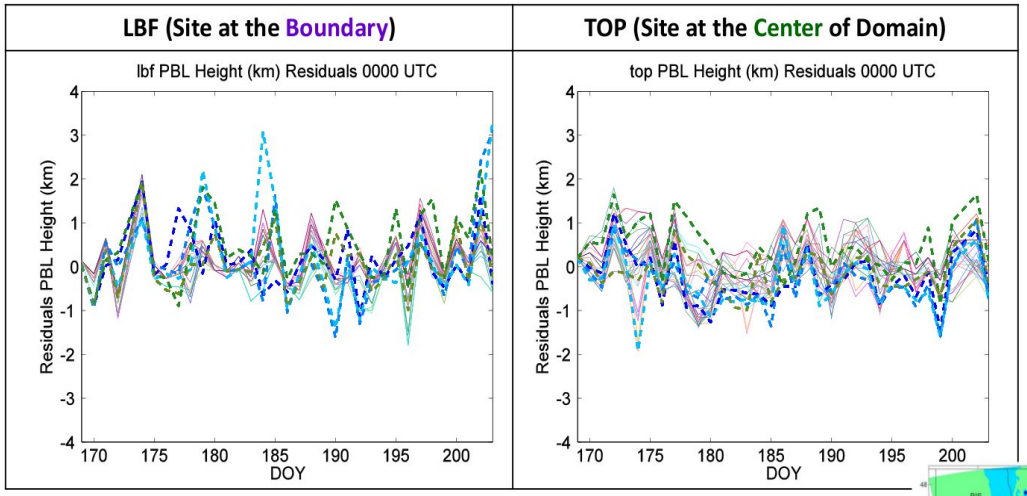


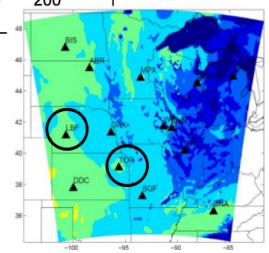
Mean bias in the mean horizontal wind speed at 300m high using 00z radiosonde measurements for June 2008 at four sites across the US upper Midwest

Courtesy of Liza Diaz-Isaac

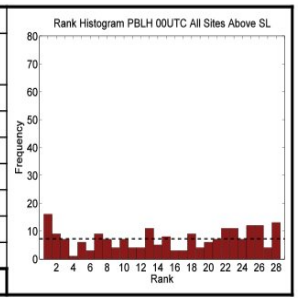
Example: Calibration of a large ensemble

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

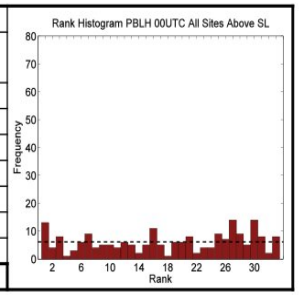




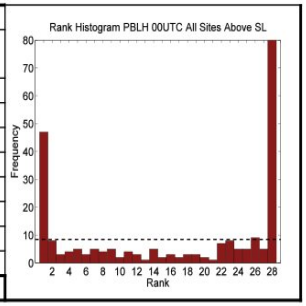
Rank Histogram Score	
Planetary Boundary Layer Height	
Sites	N = 27
OAX	1.7
MPX	1.3
DVN	0.9
ILX	1.5
TOP	0.9
ABR	1.7
All Sites	1.8



Rank Histogram Score	
Planetary Boundary Layer Height	
Sites	N = 32
OAX	1.8
MPX	1.2
DVN	0.9
ILX	1.6
TOP	1.3
ABR	2
All Sites	1.9



Rank Histogram Score	
Planetary Boundary Layer Height	
Sites	N = 27
LBF	4.7
GRB	4
SGF	2.1
DDC	6.5
BIS	2.2
BNA	13.2
APX	16.4
All Sites	32.9



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Planetary Boundary Layer Height	
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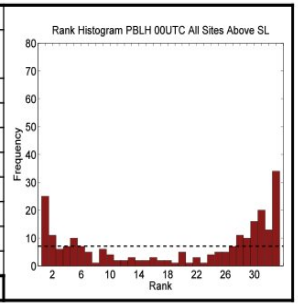
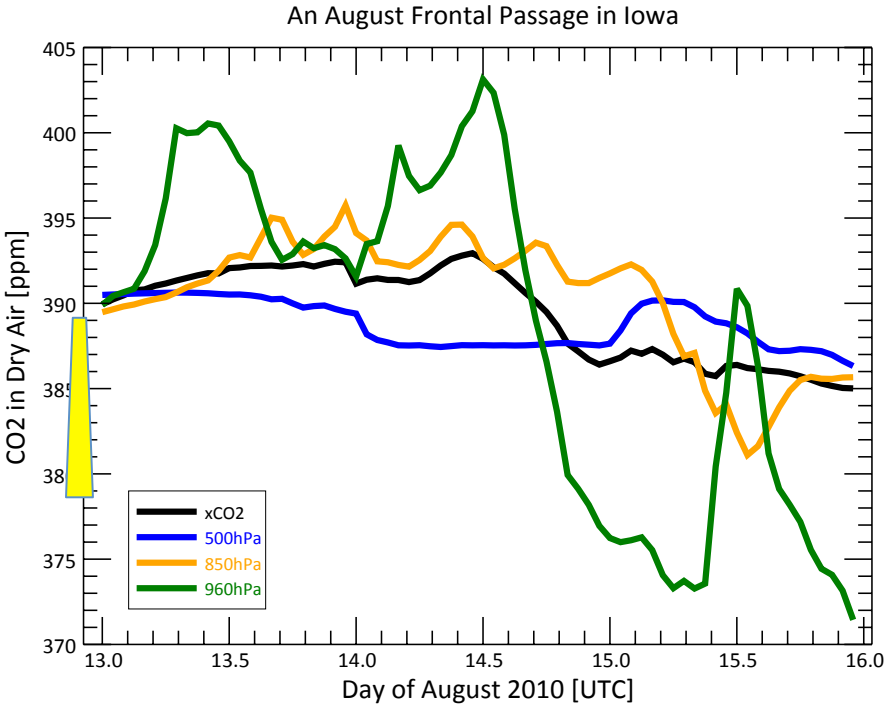
GRB	1.9
SGF	0.9
DDC	2.2
BIS	1.8
BNA	4.6
APX	5.2
All Sites	7.7



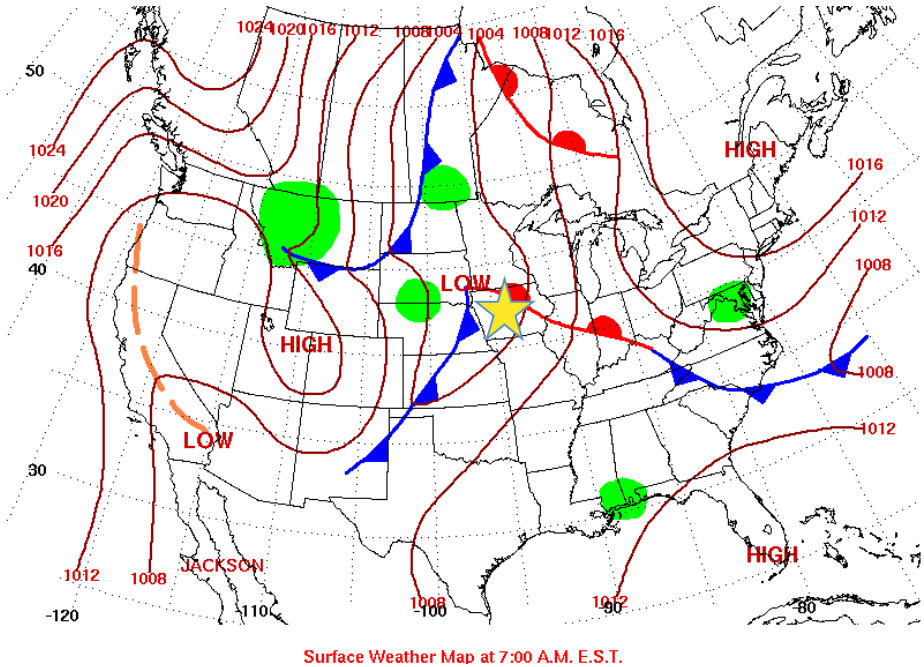
Rank histograms for the PBL depth using 13 radiosonde sites over 35 days (00z only) compared to WRF simulations at 10km resolution over the MCI domain

Courtesy of Liza Diaz-Isaac

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)

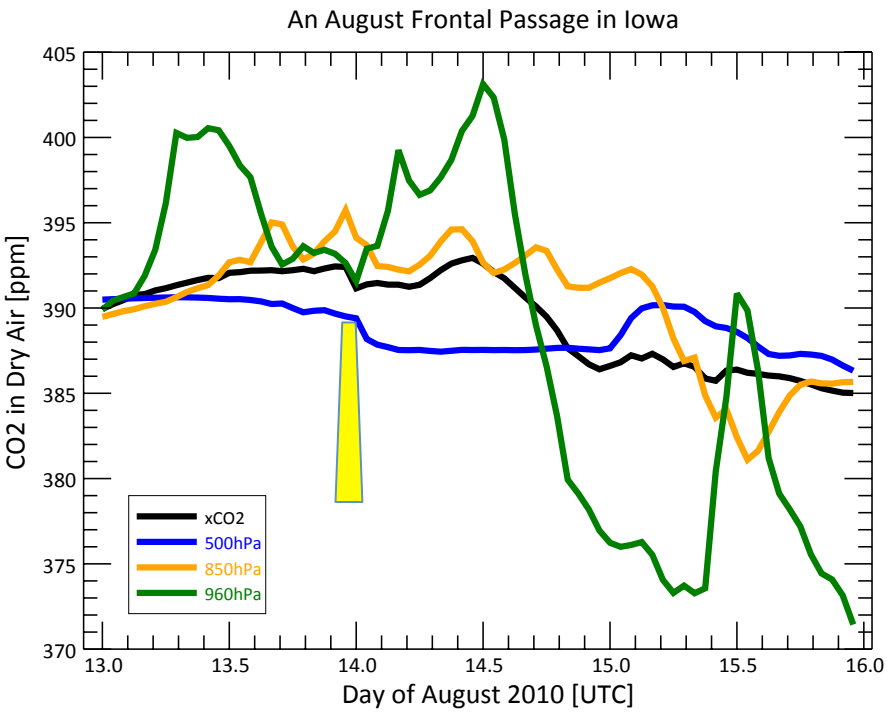


Corresponding weather map at 12 UTC of the same day

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



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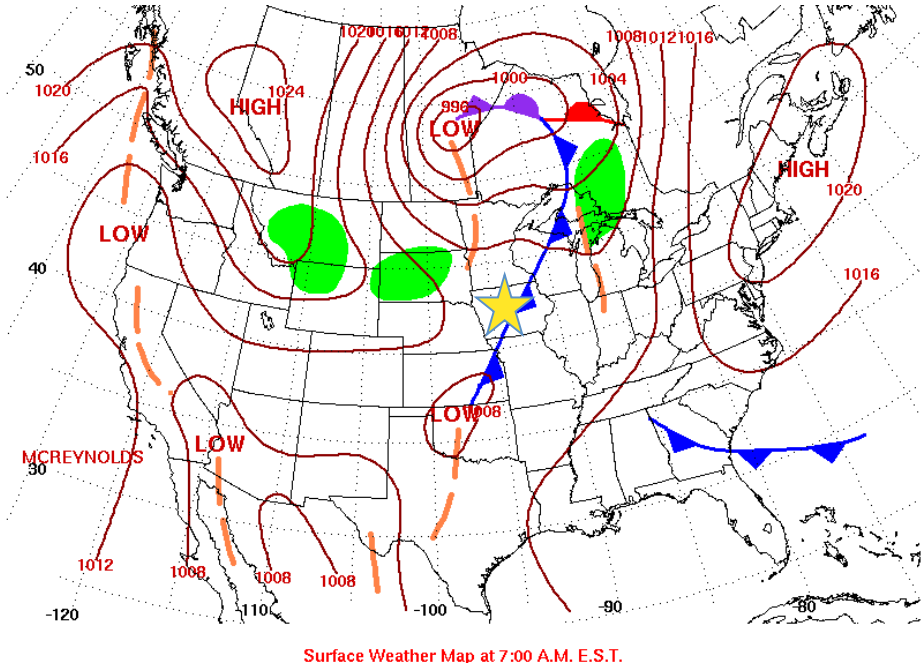

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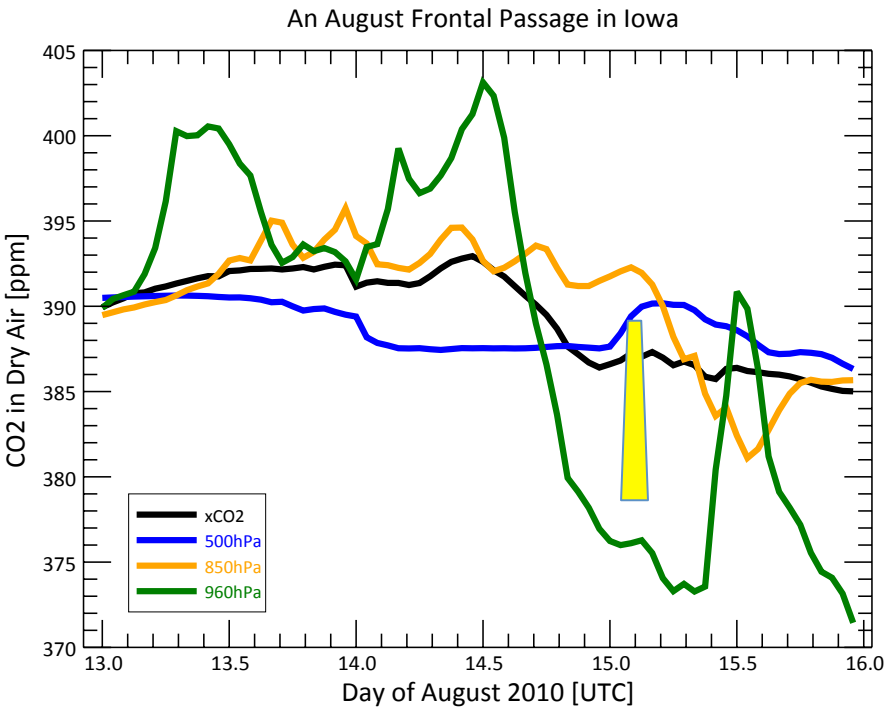
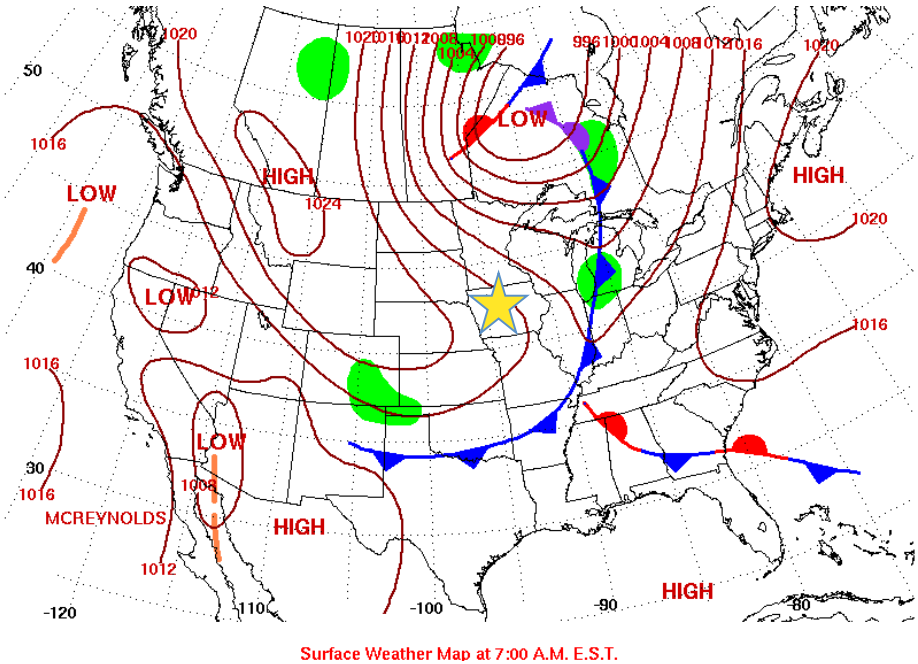


Simulated GOSAT XCO2 data (in black), low altitude in-situ CO2 (in green), Lower Troposphere in-situ CO2 (in orange), and Mid Troposphere in-situ CO2 (in blue)



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)

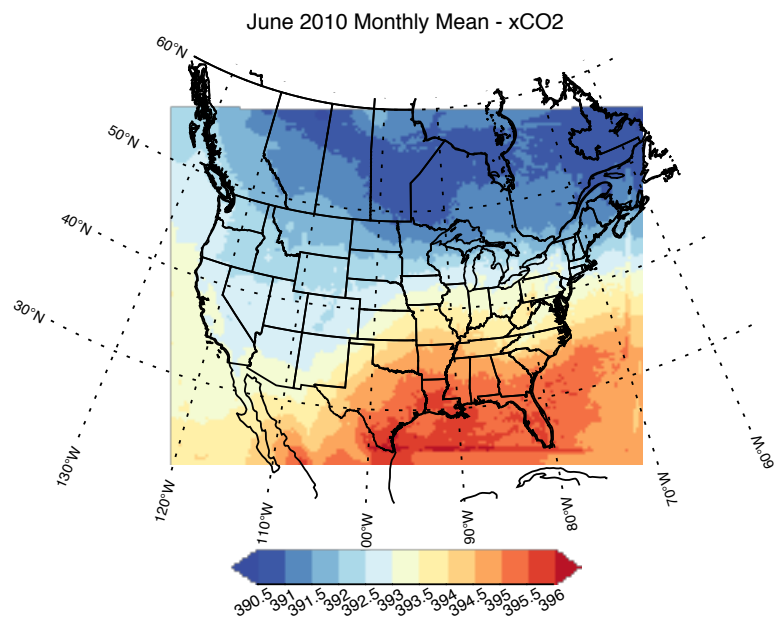
Production of GOSAT simulated measurements

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