Meteorological and greenhouse gas measurements for the characterization of errors in mesoscale carbon inversions

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Introduction

High resolution inversion is a very promising tool with significant amount of information that could be extracted from data over targeted areas

However, components of the errors increase/vary with the resolution

Compared to global scales, regional/landscape scale inversions need to address new sources of errors that can be significant, i.e. impair the progress made thanks to the higher resolution

Introduction

Sources of errors in domain-limited inversions primarily from:

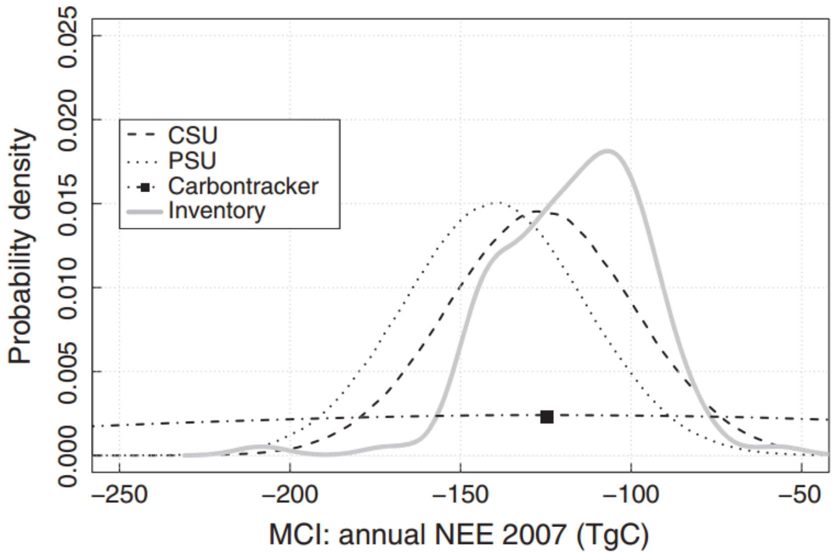
- boundary conditions
- incorrect prior errors
- incorrect and biased transport model errors
- lack of data

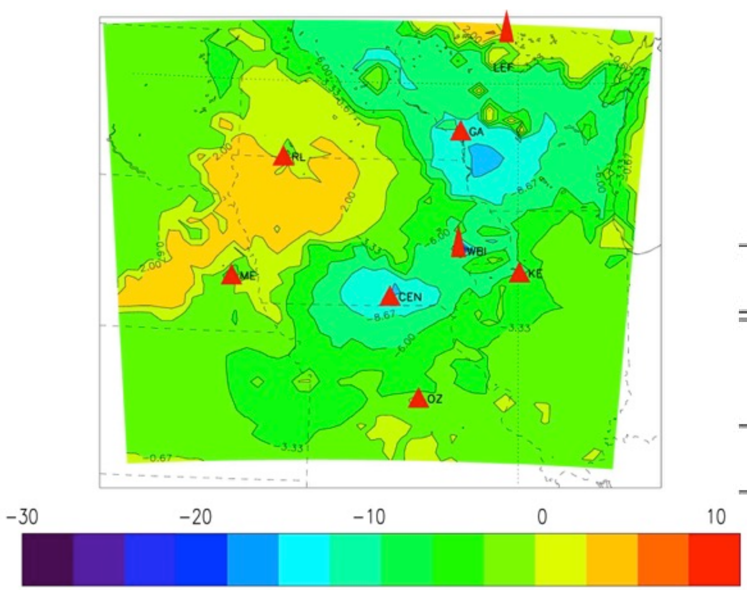
Introduction

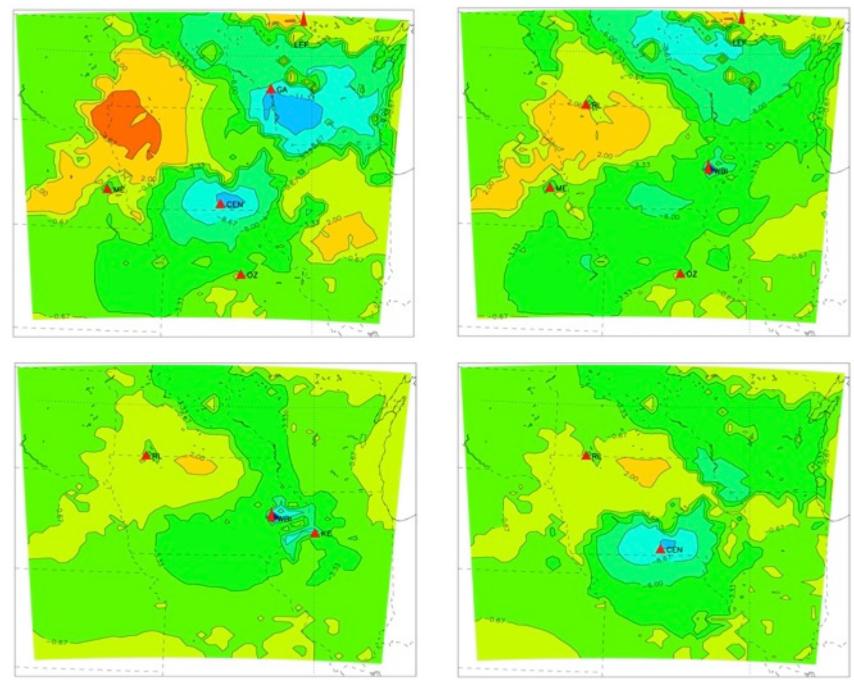
Sources of errors in domain-limited inversions primarily from:

- boundary conditions
  tower, remote sensing, and aircraft profiles of GHG
- incorrect prior errors
  eddy flux towers, aircraft flux campaigns
- incorrect and biased transport model errors
  Meteorological data (surface stations, rawinsondes, lidar, radar)
  Aircraft profiles of GHG
- lack of data
  no data available for this problem…

Lack of observations at regional scales



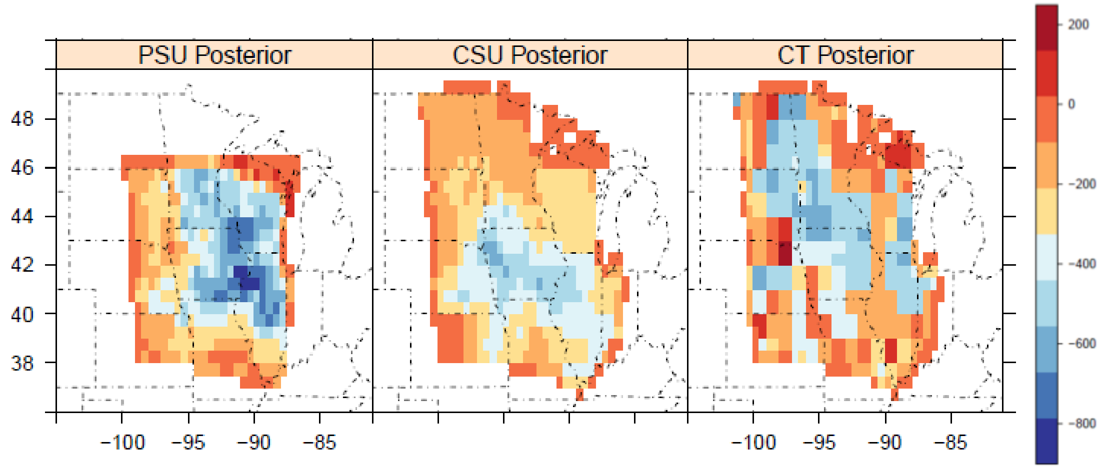




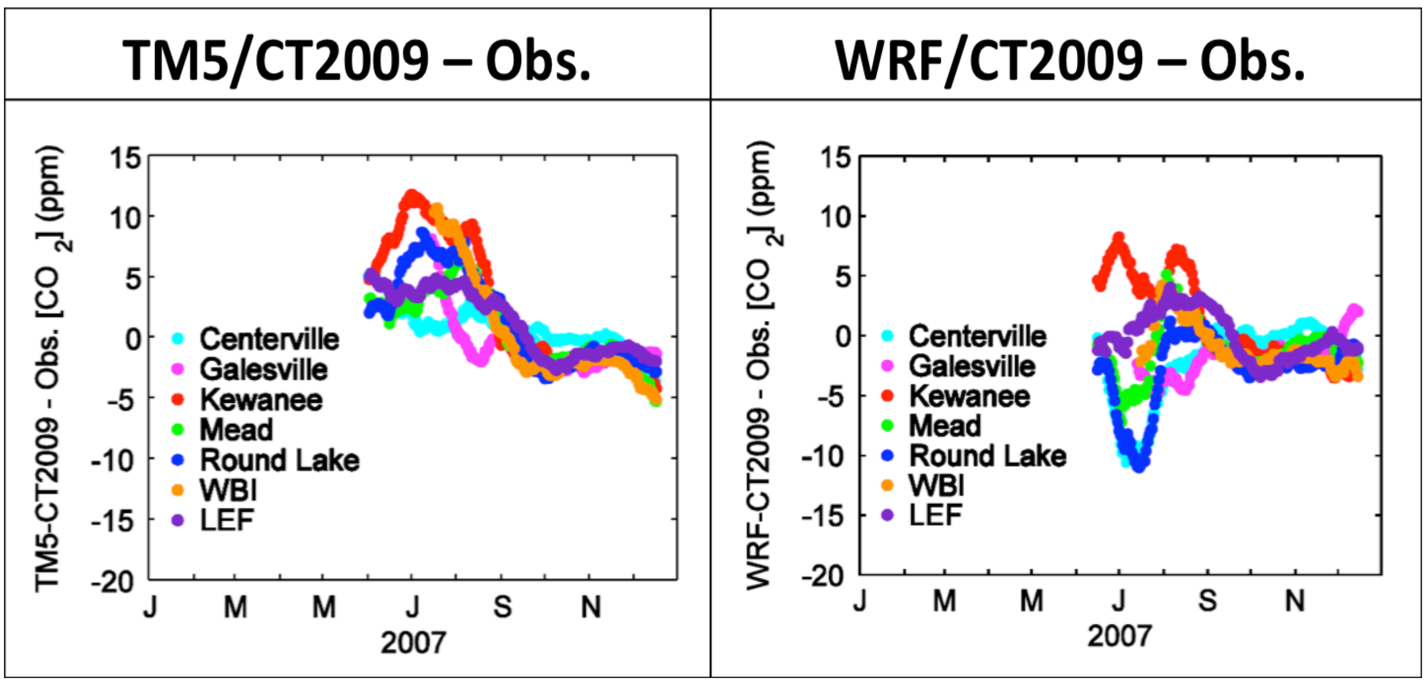
	prior	posterior (TR0)	NON-CORN (5 sites)	CORN (3 sites)	SPARSE (5 sites)	MIN (2 sites)
Regional carbon balance (TgC)	-110	-194	-179	-159	-185	-177
Total flux error (TgC)	35.5	32.1	32.7	33.1	32.5	33.6

from Schuh et al., 2013, Lauvaux et al., 2012b

Transport model errors at the mesoscale



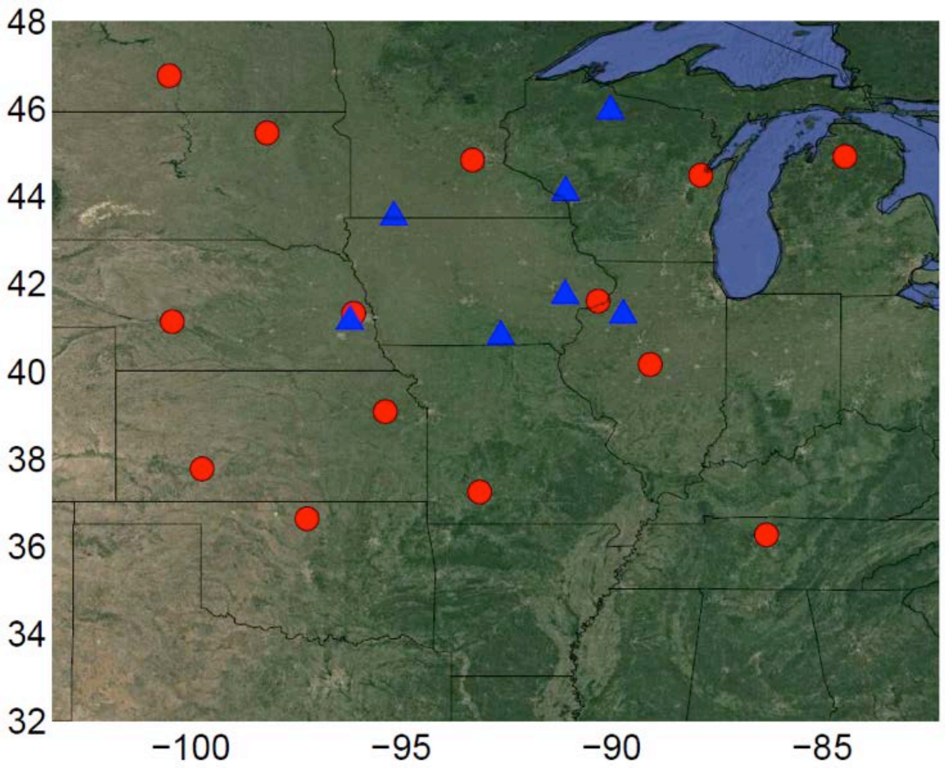
Posterior flux estimates for 2007 from three different inversion systems (inTgC per half degree): WRF-LPDM, RAMS-LPDM, TM5 (CarbonTracker)



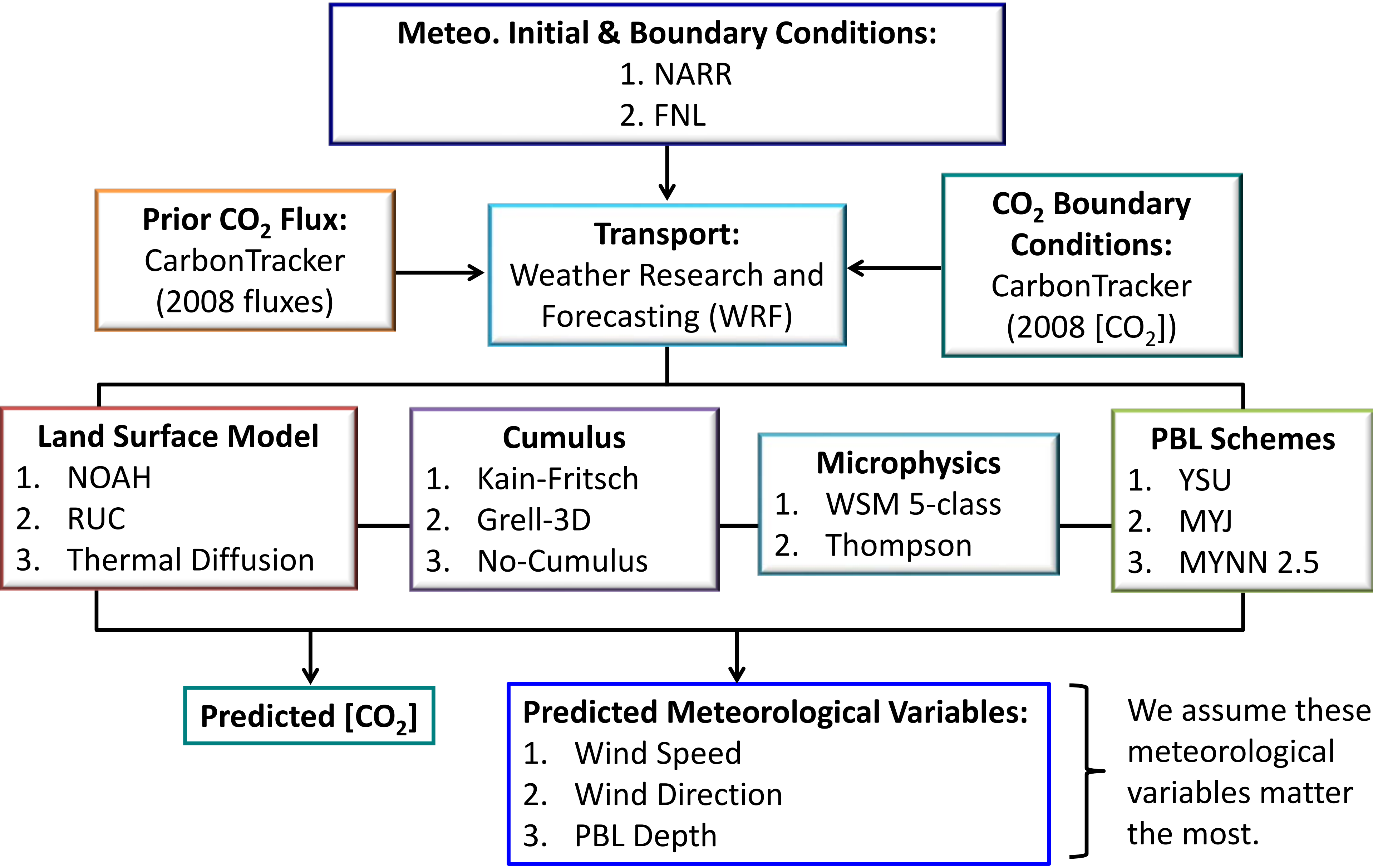
Diaz-Isaac et al., 2014

PennState

Transport evaluation using Meteorological measurements

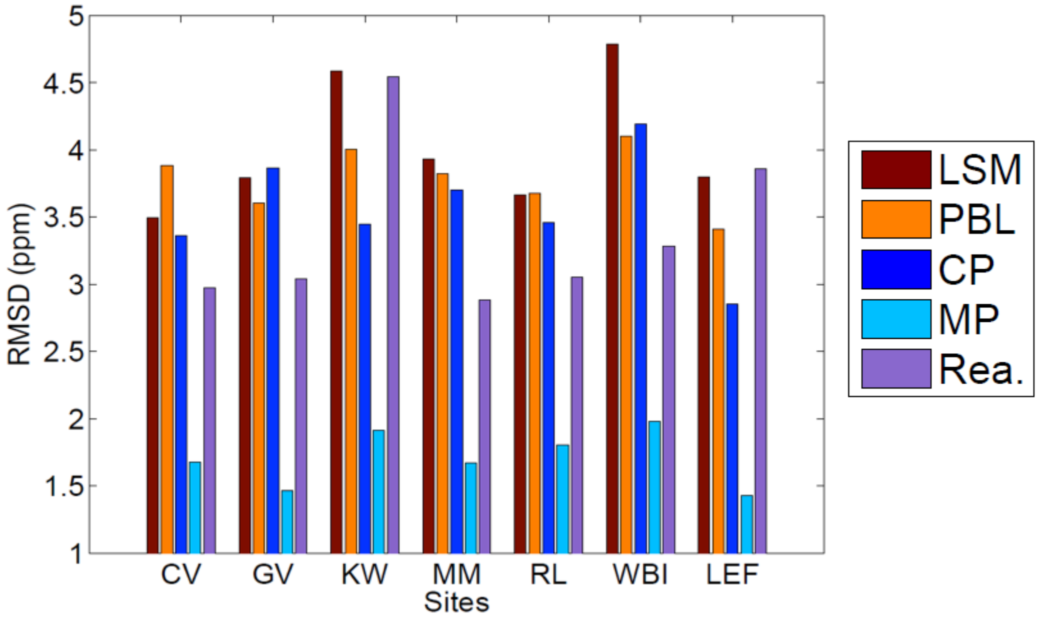


- Over a region there is a total of 14 rawinsondes (red circles).
- Some of the data that will be evaluated from these measurements are:
    1. Wind Speed (300m AGL)
    2. Wind Direction (300m AGL)
    3. PBL Depth
- For both model and observations the PBL depth was estimated using the virtual potential temperature gradient (θ_v) $\geq$ 0.2 K/m.
- Rawinsondes data was evaluated at 0000UTC.
- In-situ CO_2 mixing ratio measurements were evaluated from 1800 to 2200 UTC at seven communication towers (blue triangles), enveloping the U.S. "corn-belt".

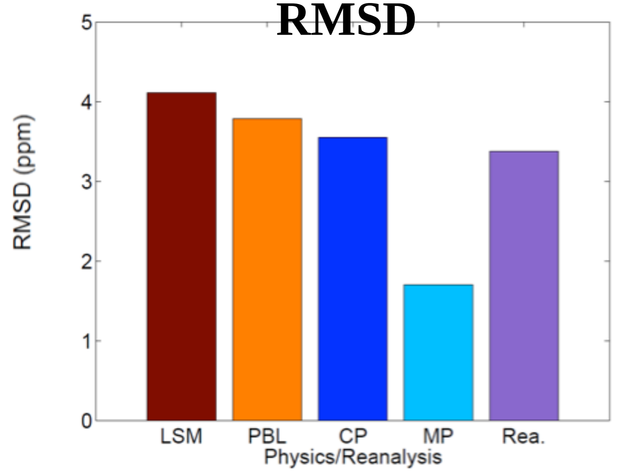

Meteo. Initial & Boundary Conditions:
1. NARR
2. FNL
Prior CO_2 Flux:
CarbonTracker
(2008 fluxes)
Transport:
Weather Research and Forecasting (WRF)
CO_2 Boundary Conditions:
CarbonTracker
(2008 [CO_2])
Land Surface Model
1. NOAH
2. RUC
3. Thermal Diffusion
Cumulus
1. Kain-Fritsch
2. Grell-3D
3. No-Cumulus
Microphysics
1. WSM 5-class
2. Thompson
PBL Schemes
1. YSU
2. MYJ
3. MYNN 2.5
Predicted [CO_2]
Predicted Meteorological Variables:
1. Wind Speed
2. Wind Direction
3. PBL Depth
We assume these meteorological variables matter the most.

Sensitivity to physics configurations

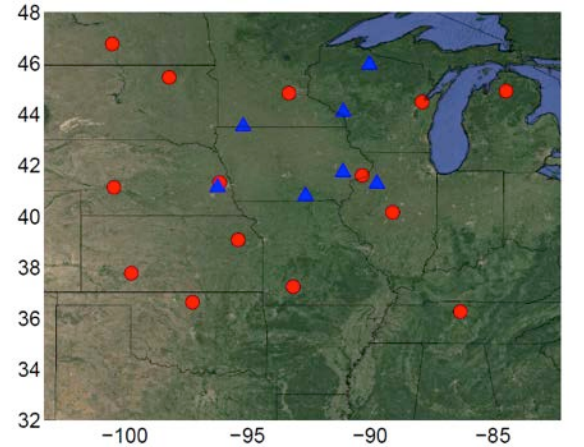
[CO_2] RMSD by Site



Regional [CO_2] RMSD

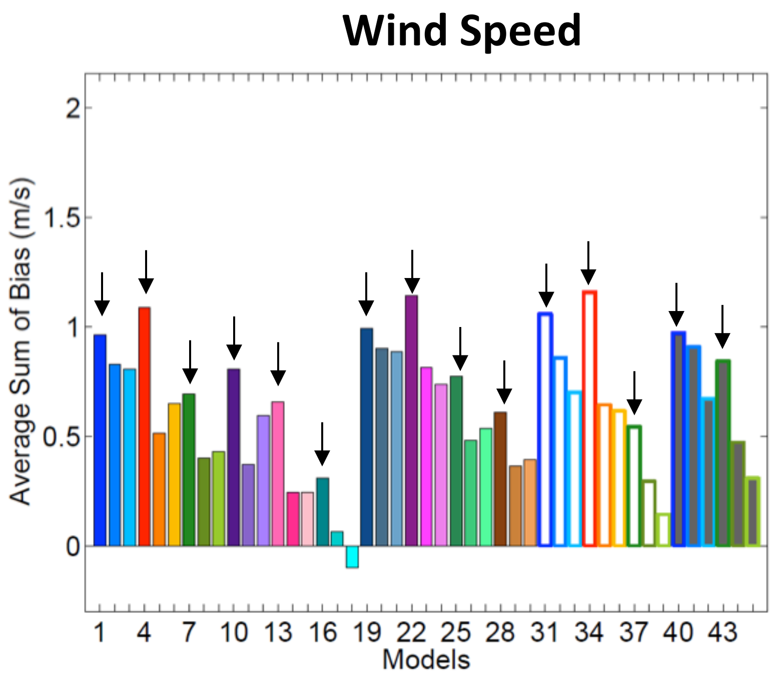


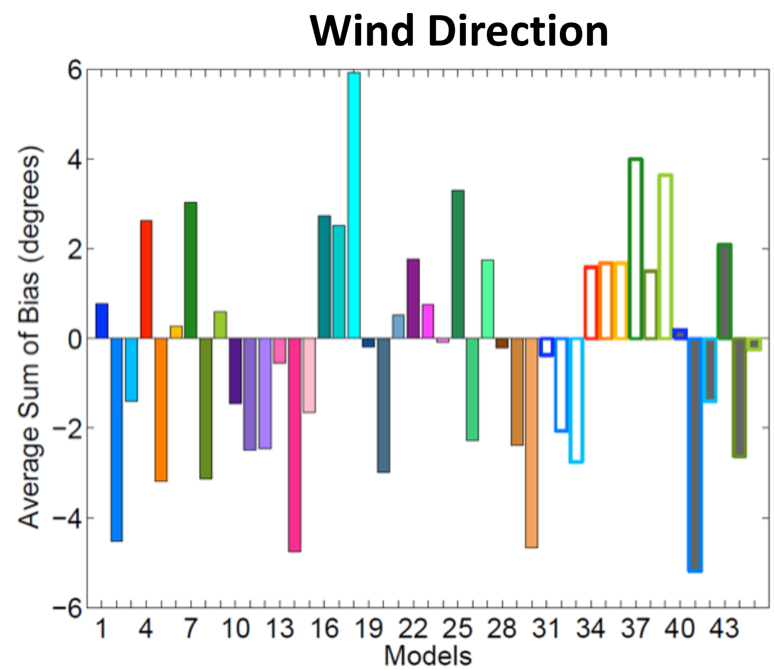
- *Model-Ensemble mean comparison used to isolate transport errors.*
- ***Local Scale:*** LSMs, PBL schemes and Cumulus parameterizations (CP) all have a big impact in CO_2 mole fraction errors.
- ***Regional scale:*** LSMs, PBL schemes, Cumulus parameterization(CP) and reanalysis have a big impact in CO_2 errors.
- ***PBL physics is not the only physics parameterization that matters.***

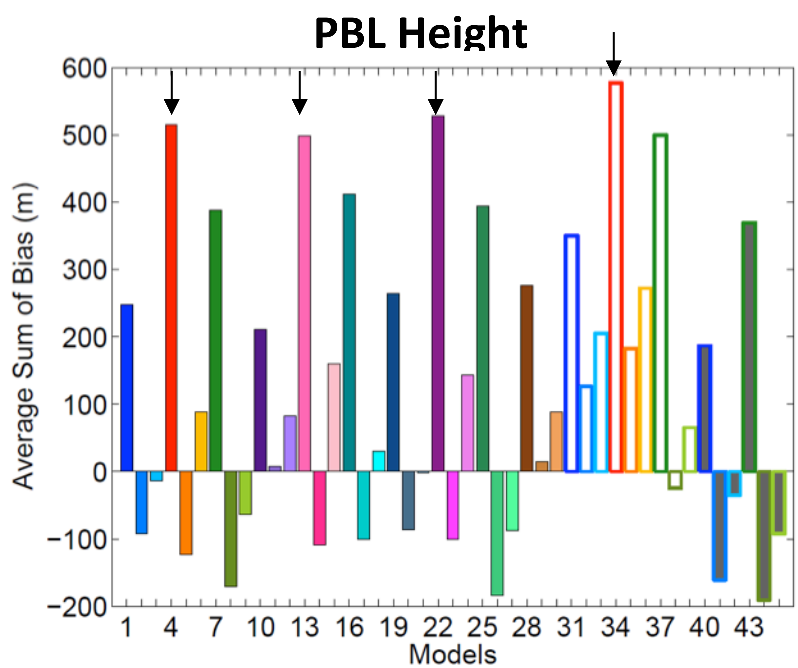


Sites: *blue triangles*

from Díaz-Isaac et al., in prep.

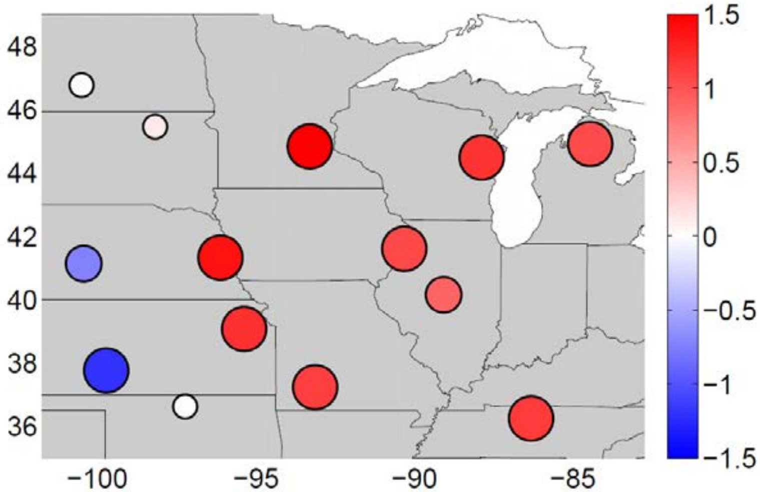




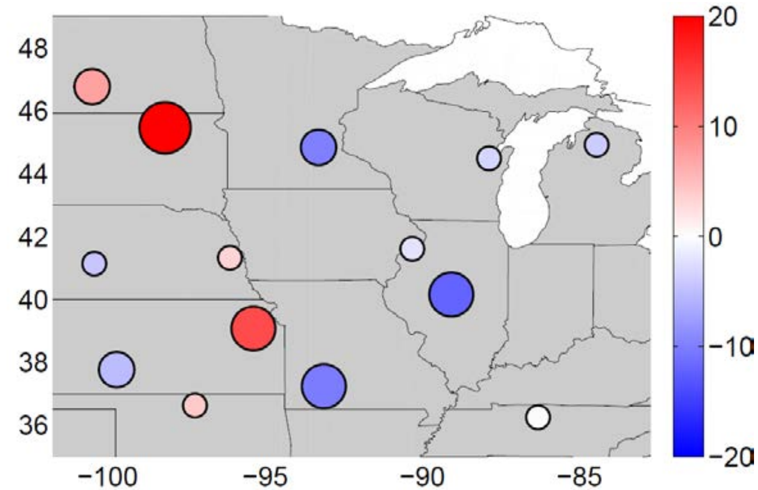


from Díaz-Isaac et al., in prep.

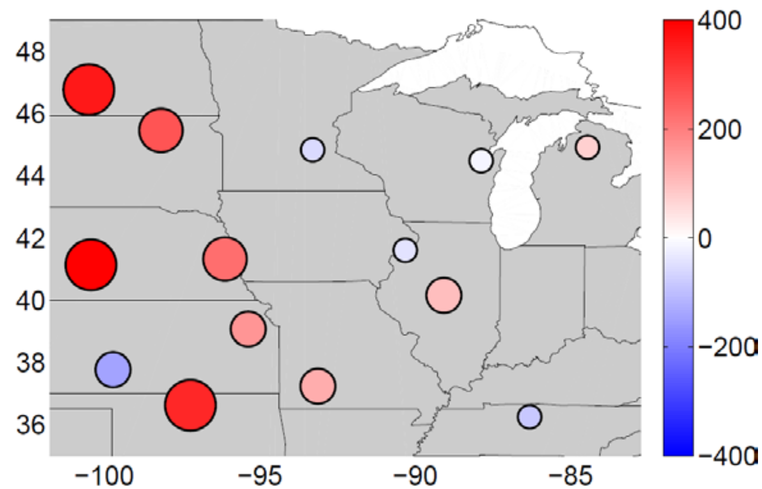
Wind Speed (m/s)



Wind Direction (degrees)



PBL Height (m)



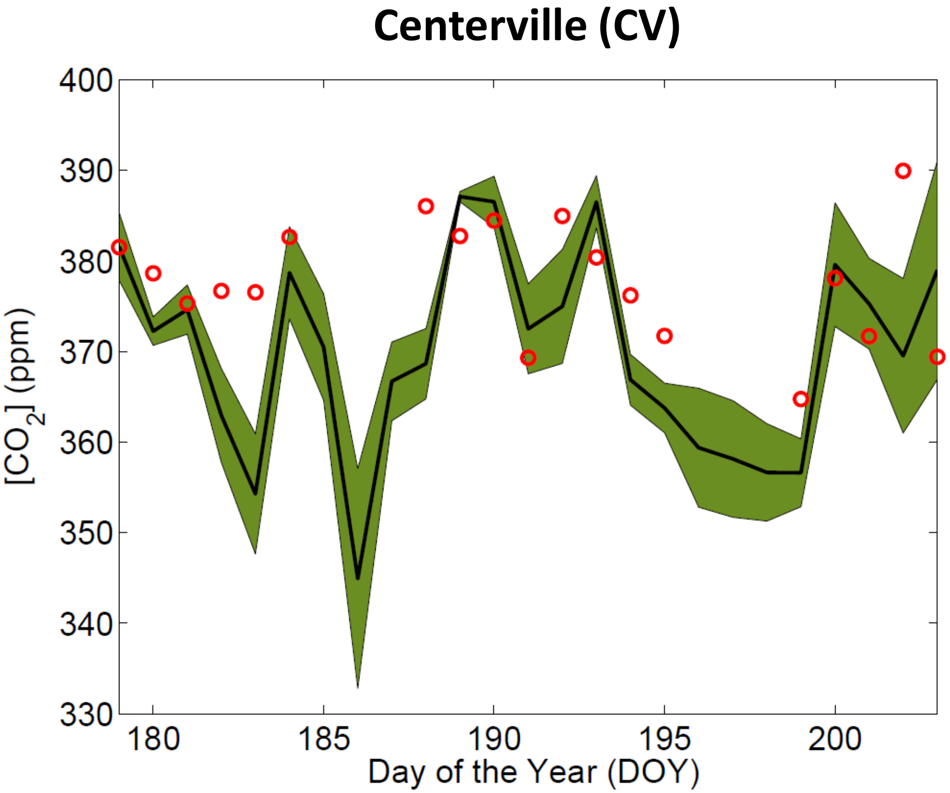
- Wind Speed errors show clear spatial structures and a dominant positive bias

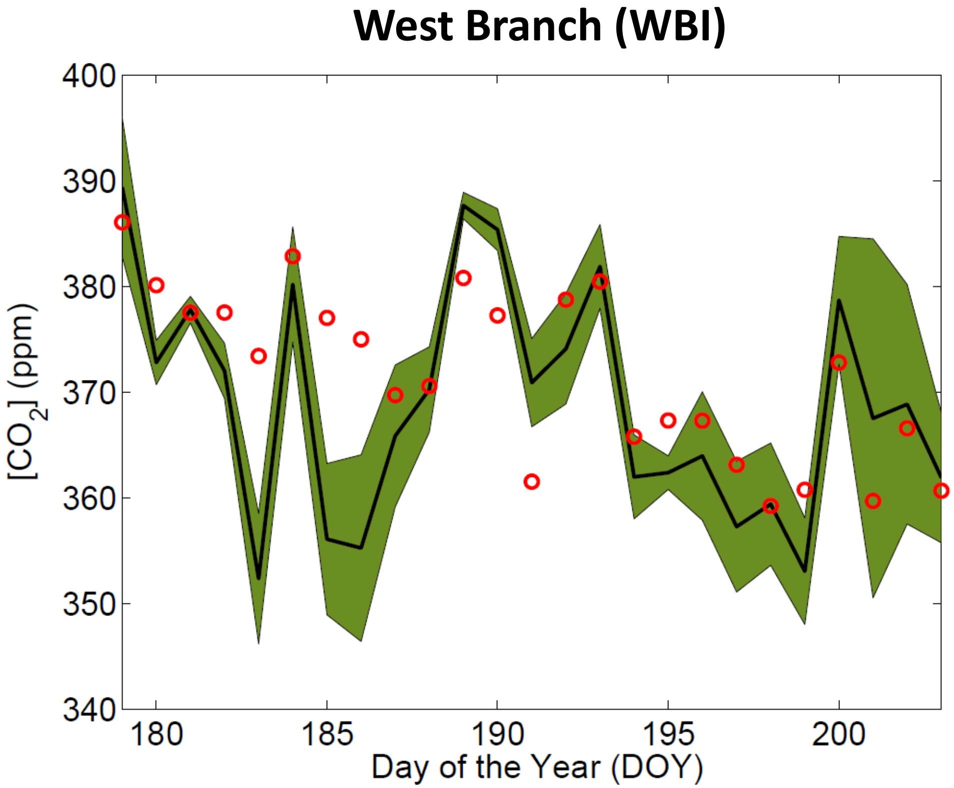
- MAE or RMSE do not reveal any spatial patterns for any variable

- PBL height errors show large positive ME in the West

from Díaz-Isaac et al., in prep.

Propagation of transport errors into [CO_2]





Propagation of transport errors into CO_2 atmospheric mixing ratios reveals some important variability in time and space that could be attributed to flux errors in the absence of a calibrated ensemble

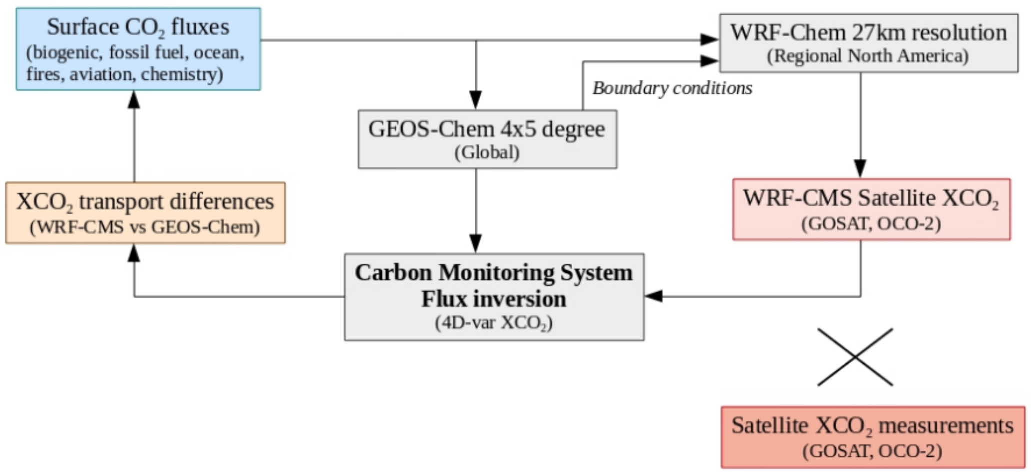
from Díaz-Isaac et al., in prep.

Continental scale inversion

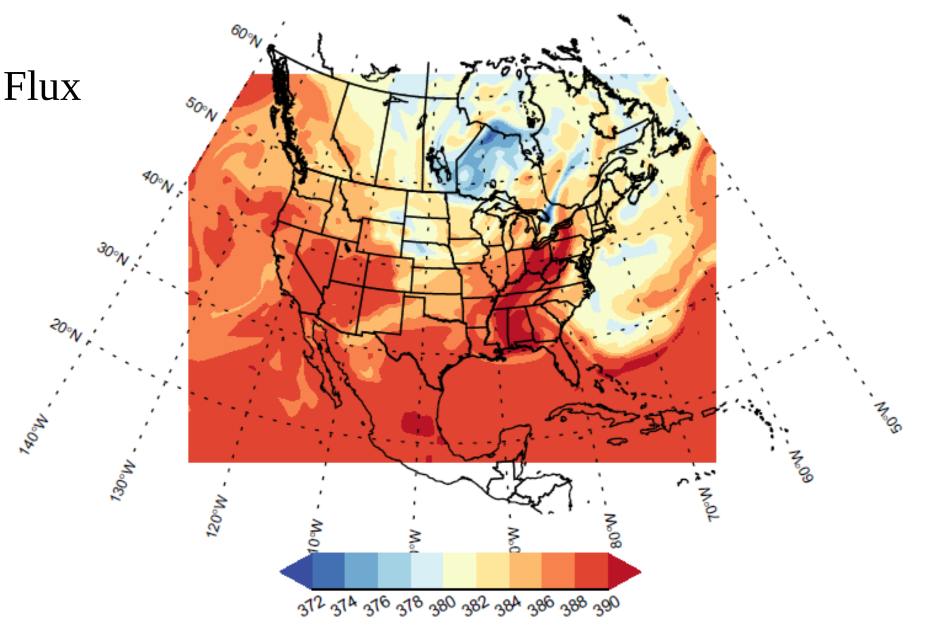
Based on this ensemble created for June 2008, over the upper Midwest,
can we characterize the errors for longer time scales and larger areas?

Seasonally? Over the entire continent?

Errors at the continental scale: WRF-CMS



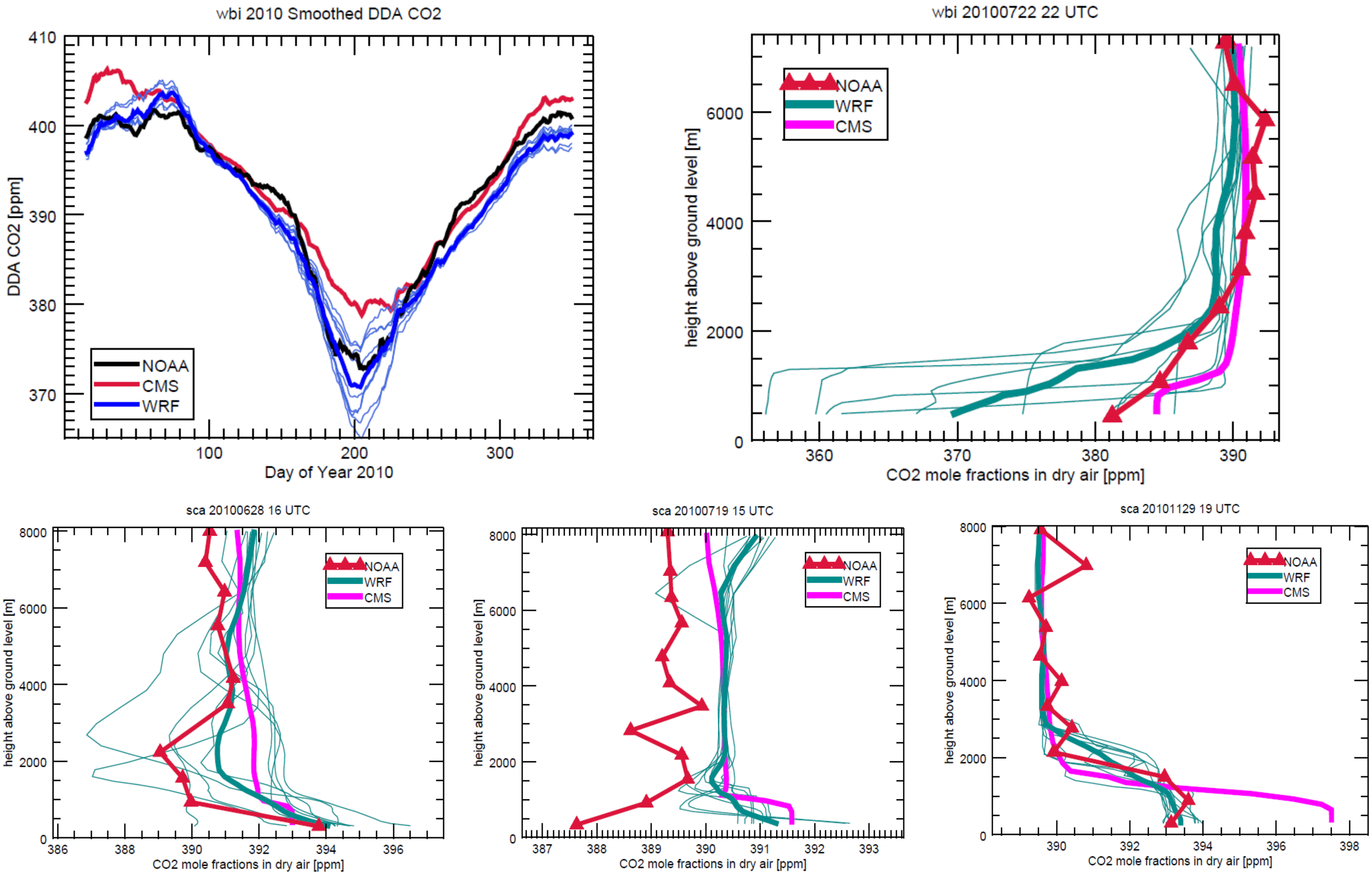
Coupling between WRF (27km resolution) and CMS Flux (GEOS-Chem) at 4x5 degree



From Butler et al., in prep.

15 August 2010, 14 UTC, 850 hPa CO_2

Transport evaluation using GHG aircraft measurements



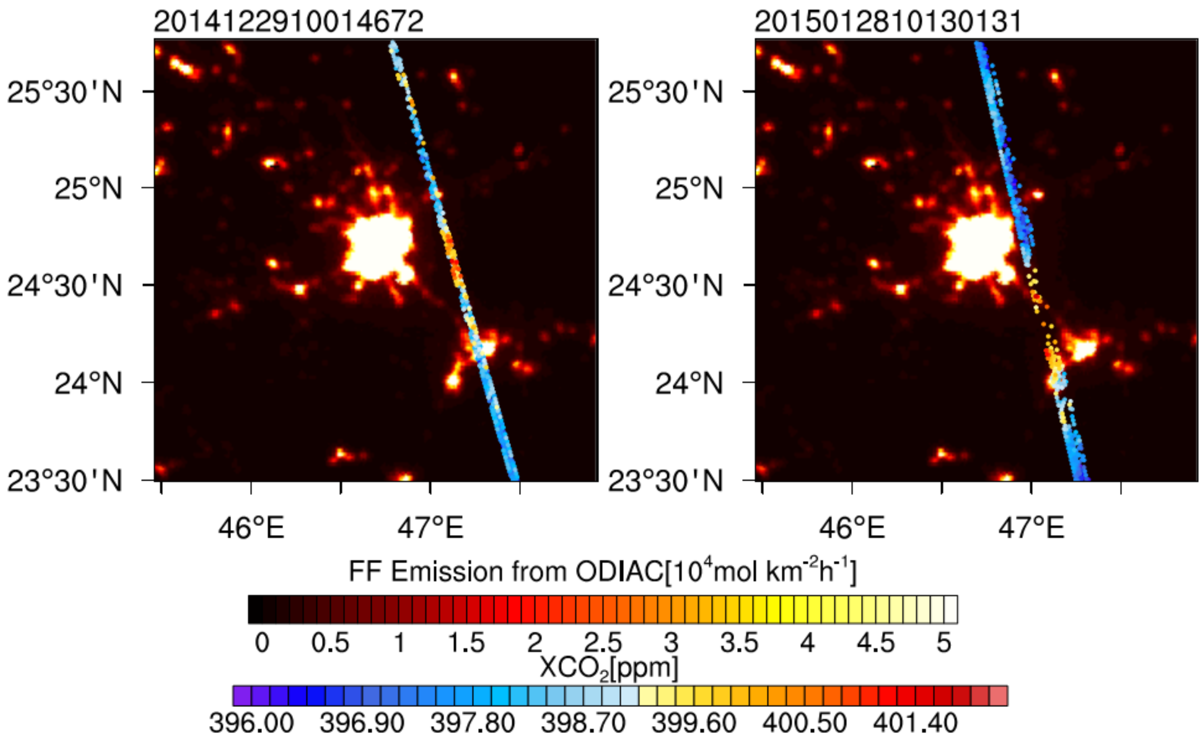
From Butler et al., in prep.

High resolution inversion

Simulating plume structures using mesoscale modeling systems

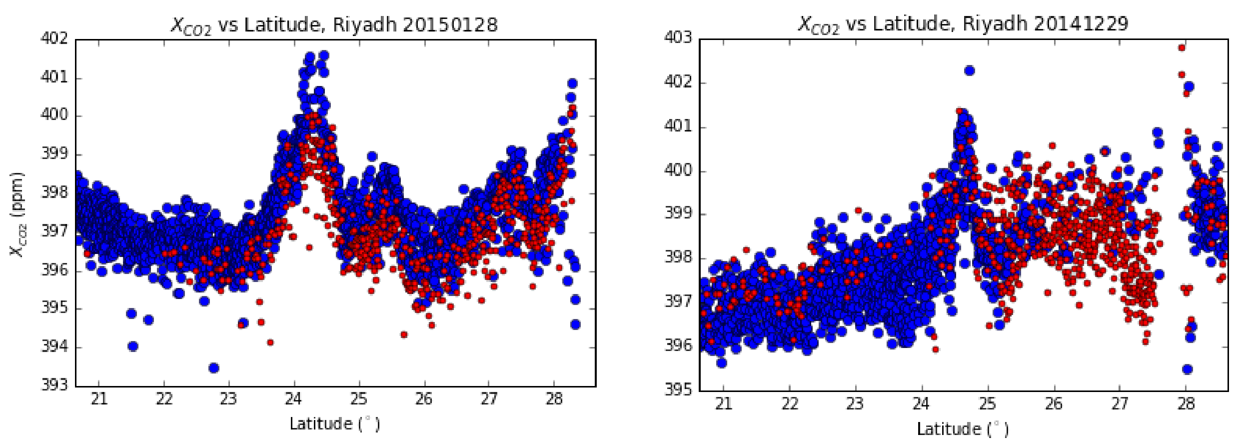
Can we characterize the errors for longer time scales and smaller areas?

Two OCO-2 Tracks observing Riyadh, Saudi Arabia



- Two tracks with XCO2 enhancements possibly by urban emissions are selected for direct simulation

- Observation time of the two tracks:
- 10:13 UTC Jan 28, 2015
- 10:02 UTC Dec 29, 2014

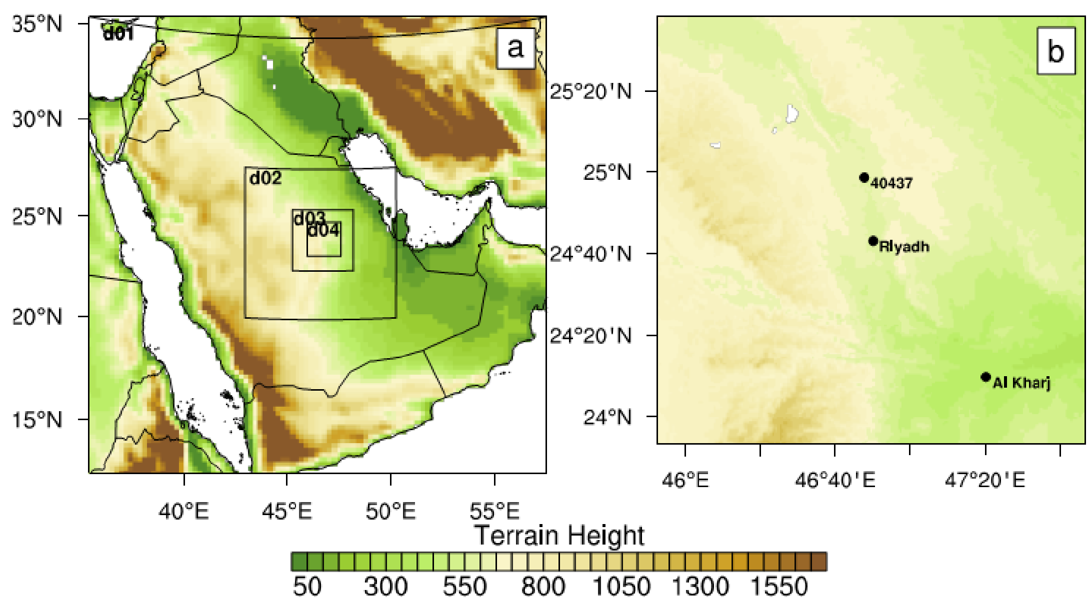


XCO₂ along OCO-2 track (by Emily Yang – University of Michigan)

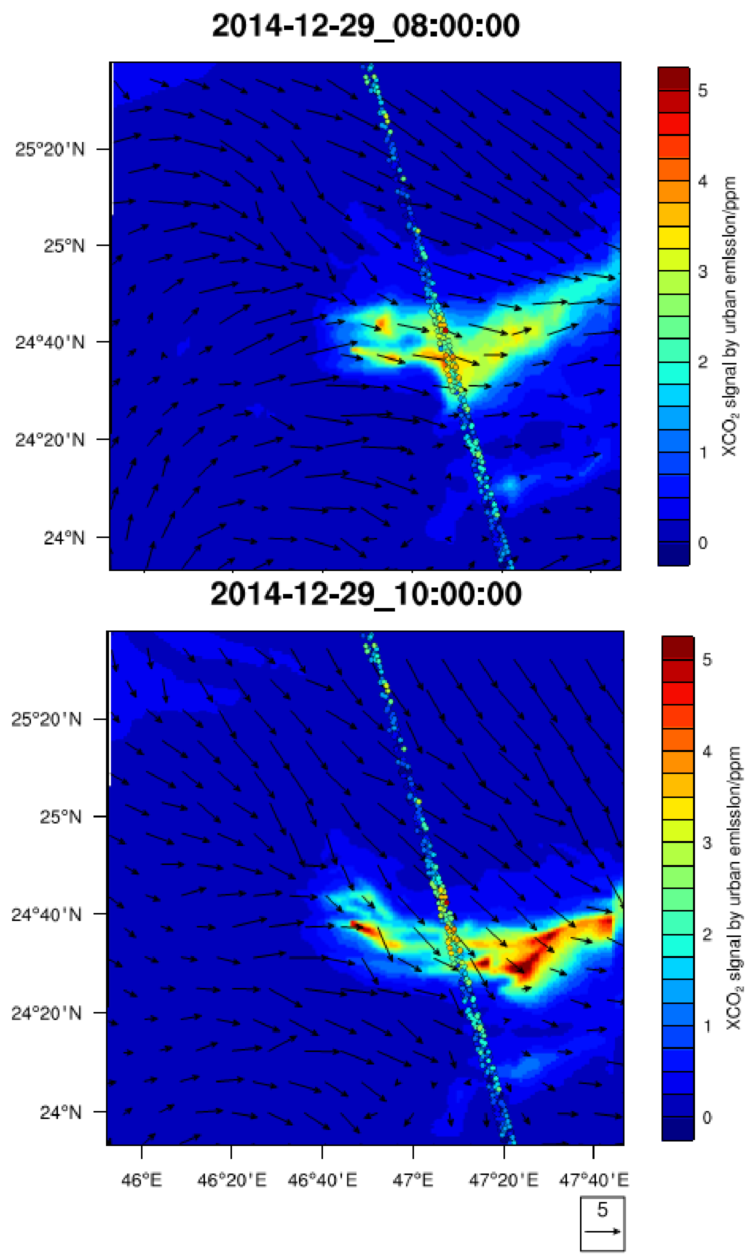
WRF-Chem configuration and Sensitivity Runs

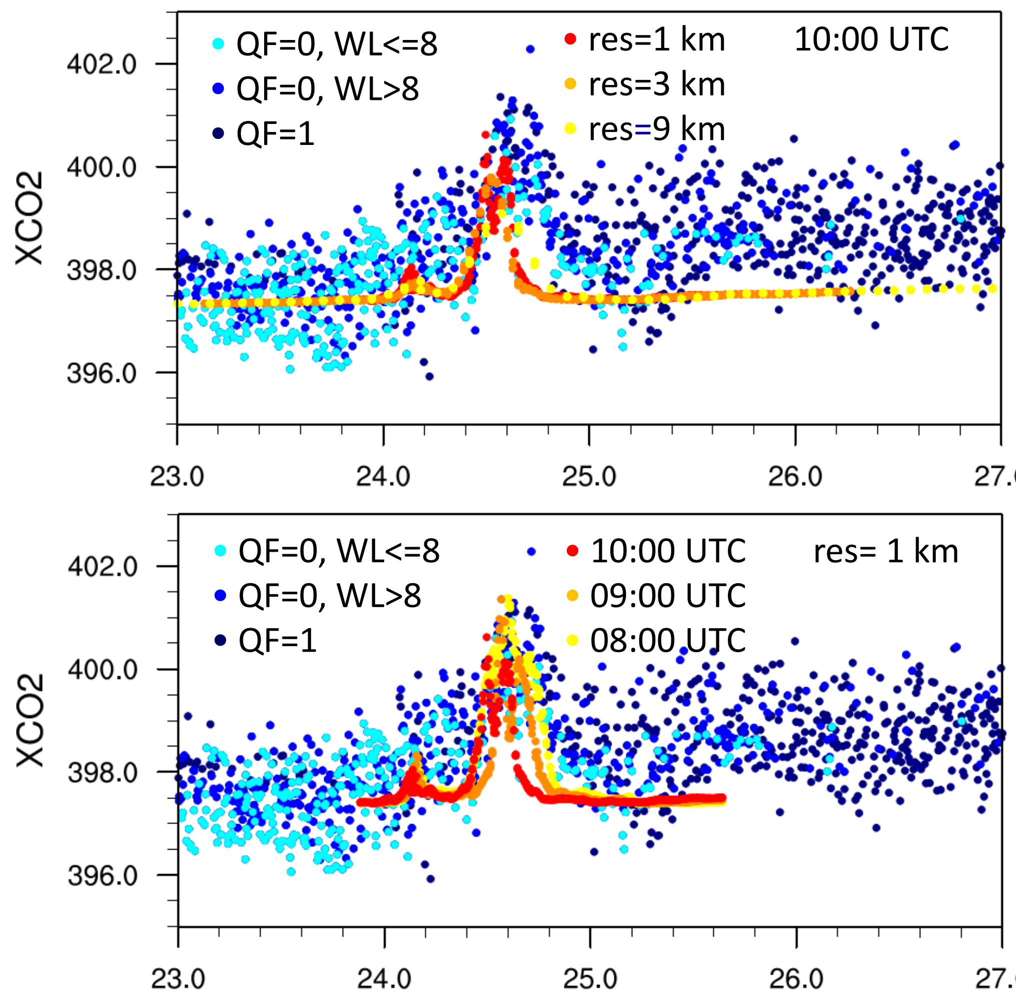
Model Settings			
Model version	WRF-Chem V3.5.1	**LW radiation**	RRTMG
Grid Resolution	27, 9, 3, 1 km	**SW radiation**	RRTMG
Vertical levels	51 eta-levels	**PBL physics**	MYNN2.5
Microphysics	Thompson	**Land Surface**	Noah LSM
Cumulus	Kain-Fritsch	**Surface layer**	MYNN

- CO_2 enhancement by urban emissions (***ODIAC***) was included in WRF-Chem as a passive tracer
- Sensitivity runs were conducted to examine the transport model error
- Surface wind and temperature observations at a station (WMO index: 40437) were used for model evaluation



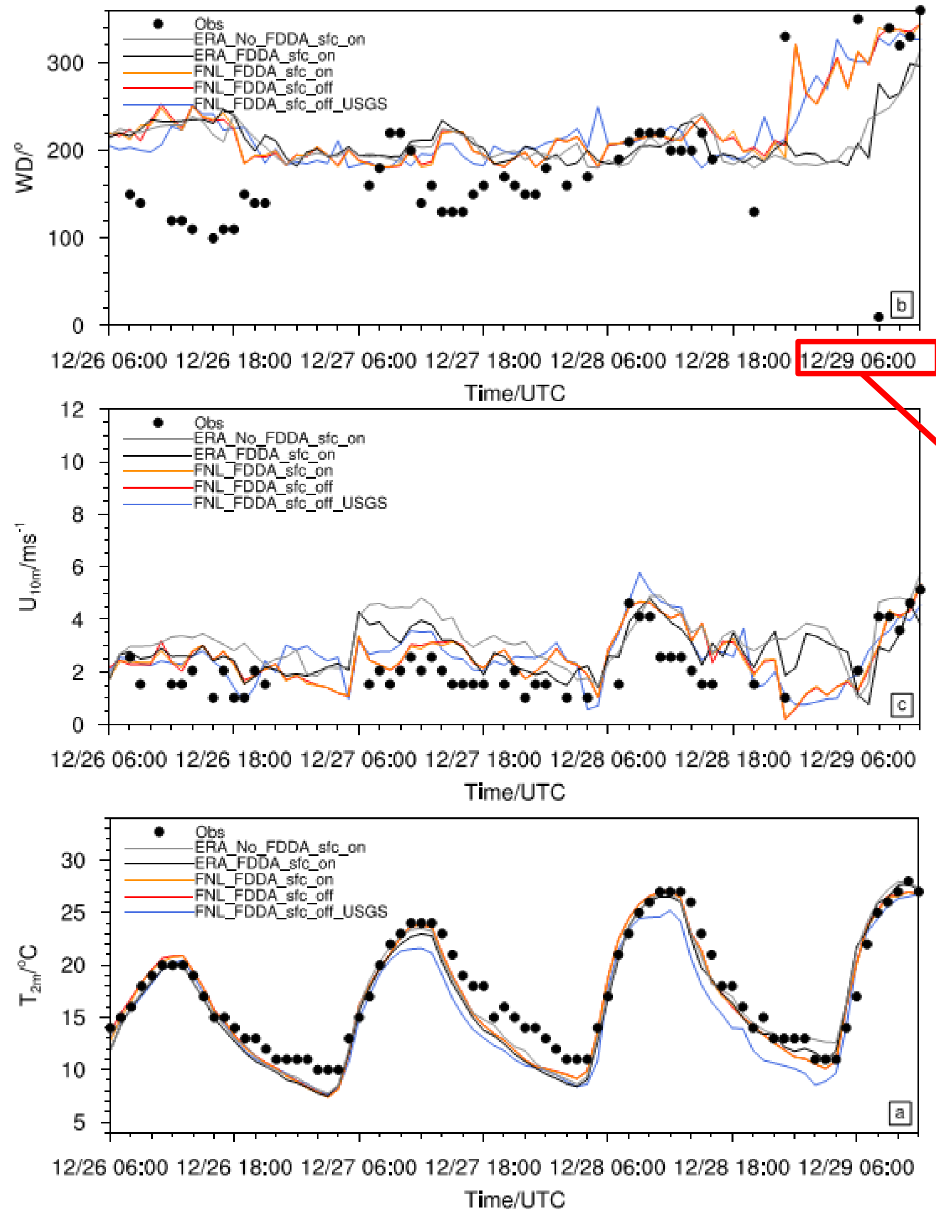
Simulated XCO2 along the OCO-2 Track (29 Dec 2014)





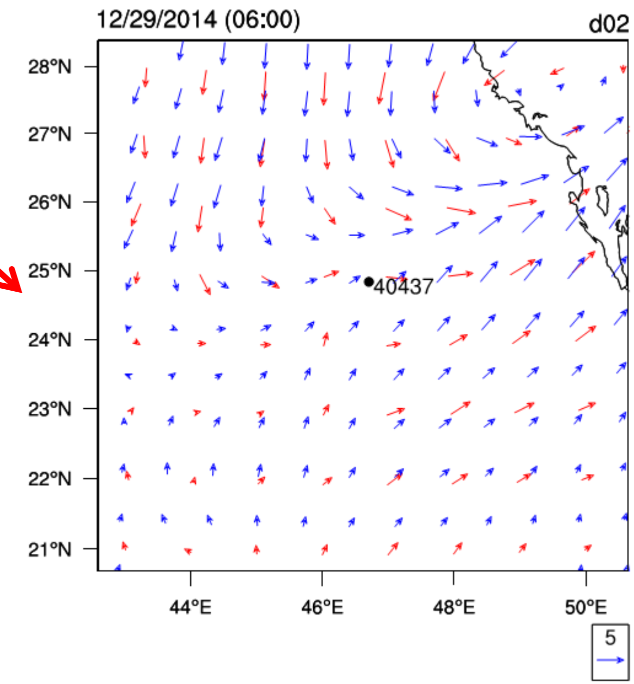
from Ye et al., in prep.

Evaluation of the simulated 1-km meteorological variables



- Evaluation of the WRF results for 26-29 Dec, 2014
- Global model forcing (IC & BC) has the most significant influence on simulation results

NB: Observation site: 40437(OERK, King Khaled International Airport)



Wind vector mismatch from ERA-Interim and FNL data (domain 02 shown)

Impact of data assimilation: model configuration

High resolution inverse modeling

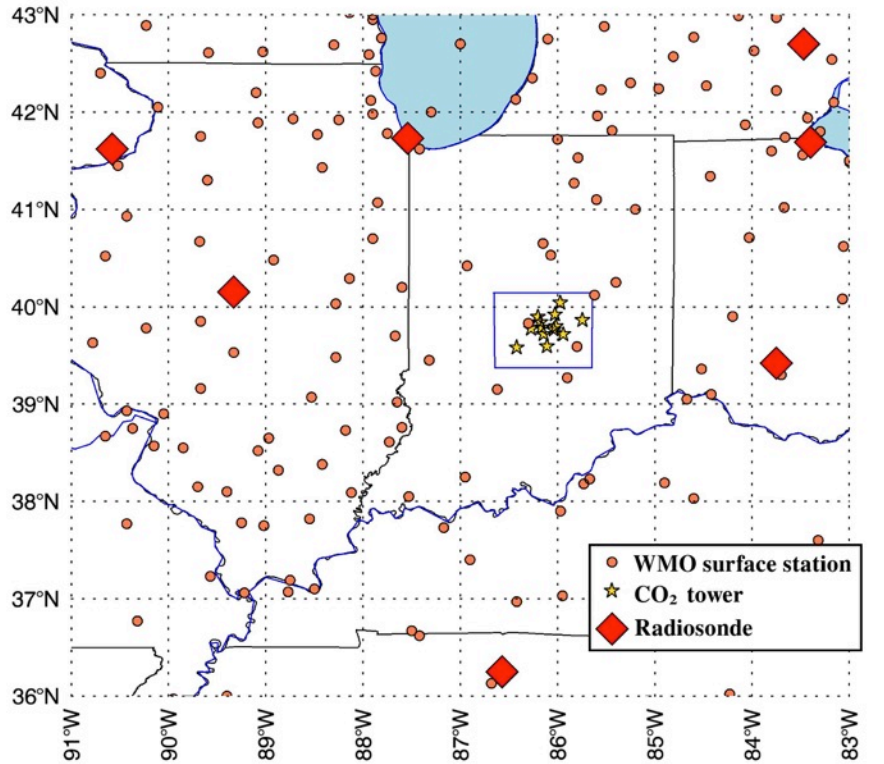
- Weather Research and Forecasting model : 9km/3km/1km (nesting)

- 3 configurations :
    - ***Historical mode – no data assimilation***
    - ***Nudging mode – WMO data only (no profile in the 1-km domain)***
    - ***Nudging mode – surface stations and Lidar in Indianapolis***

- Coupled to backward Lagrangian model (Uliasz et al., 1994) at 1km resolution using the Turbulent Kinetic Energy fields

Inversion framework

- Kalman matrix inversion using Hestia 2013 emissions as a priori



from Deng et al., in prep.

INFLUX Model-data evaluation: wind and temperature

		NOFDDA	FDDA_WMO	FDDA_WMO_Lidar	FDDA_WMO_Lidar_ACARS
Wind Direction	ME	4	2	-1	0
	MAE	26	24	15	14
Wind Speed	ME	0.2	-0.2	-0.2	-0.2
	MAE	2.0	2.0	1.3	1.2
Temperature	ME	0.8	1.0	1.0	0.5
	MAE	1.3	1.4	1.4	0.8

Mean error and mean absolute error of the WRF-predicted wind direction, wind speed and temperature over the 1-km grid verified hourly against the low-level (below 2 km AGL) INFLUX lidar measurements (winds only) and ACARS measurements (winds and temperatures) between 17and 22 UTC, averaged over the period between 00 UTC 27 August and 00 UTC 3 November 2013.

	NOFDDA	FDDA_WMO	FDDA_WMO_Lidar	FDDA_WMO_Lidar_ACARS
ME	25	103	83	-23
MAE	259	272	254	223

Mean error and mean absolute error (m) of the WRF-predicted PBL depth on the 1-km grid verified hourly against the Indianapolis INFLUX lidar measurements between 17and 22 UTC, for the period between 00 UTC 27 August and 00 UTC 3 November 2013.

from Deng et al., in prep.

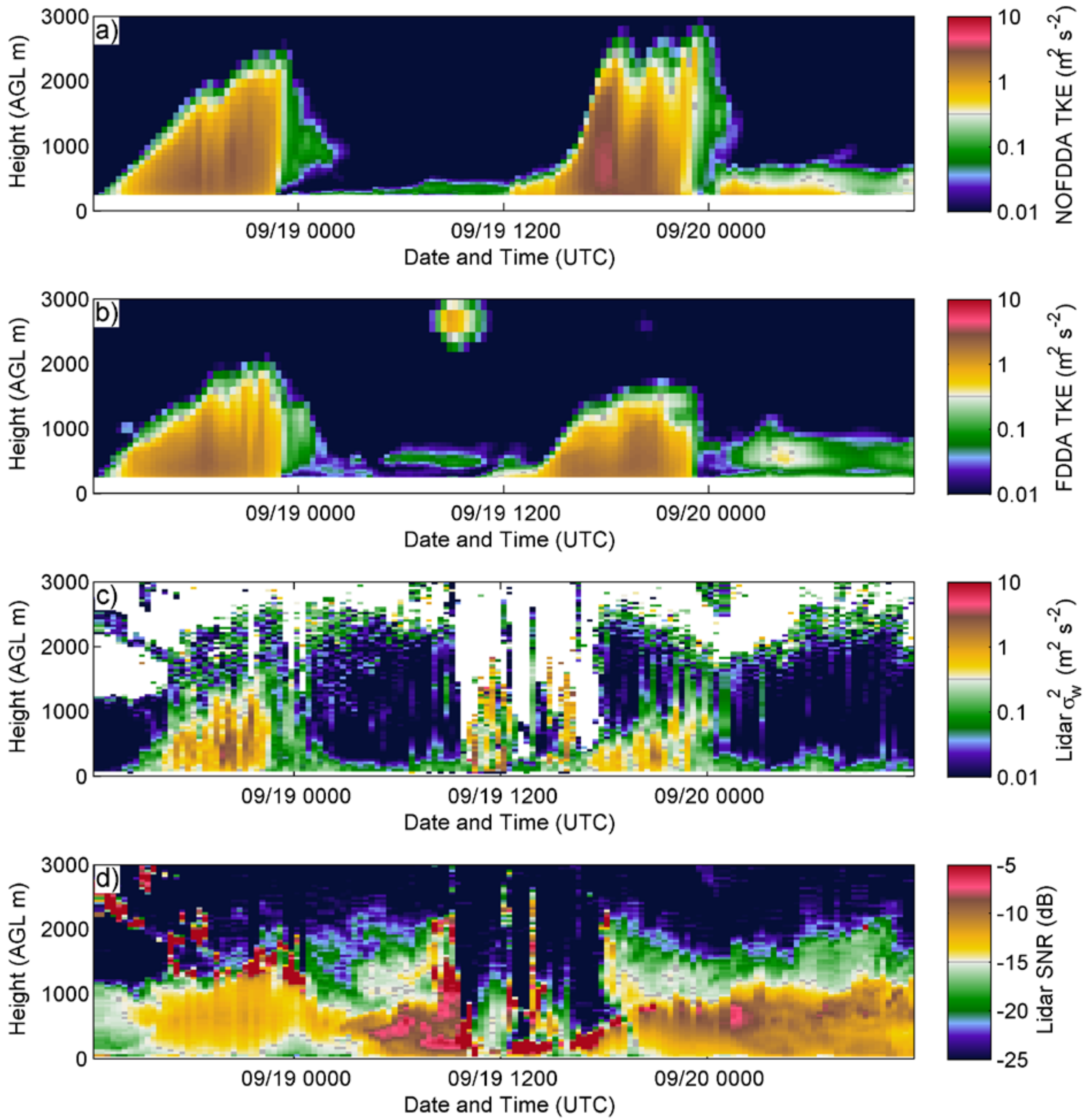
INFLUX Model-data Comparison for PBL Depth for 19-20 Sep. 2013

TKE in Standard WRF

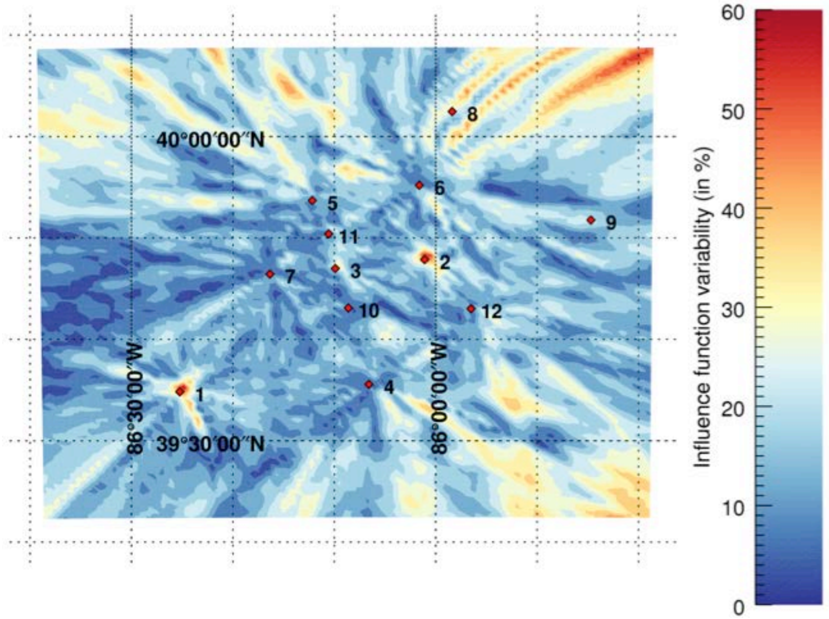
TKE in WRF with Data Assimilation (Expt. FDDA_WMO_Lidar_ACARS)

Lidar Vertical Velocity Variance

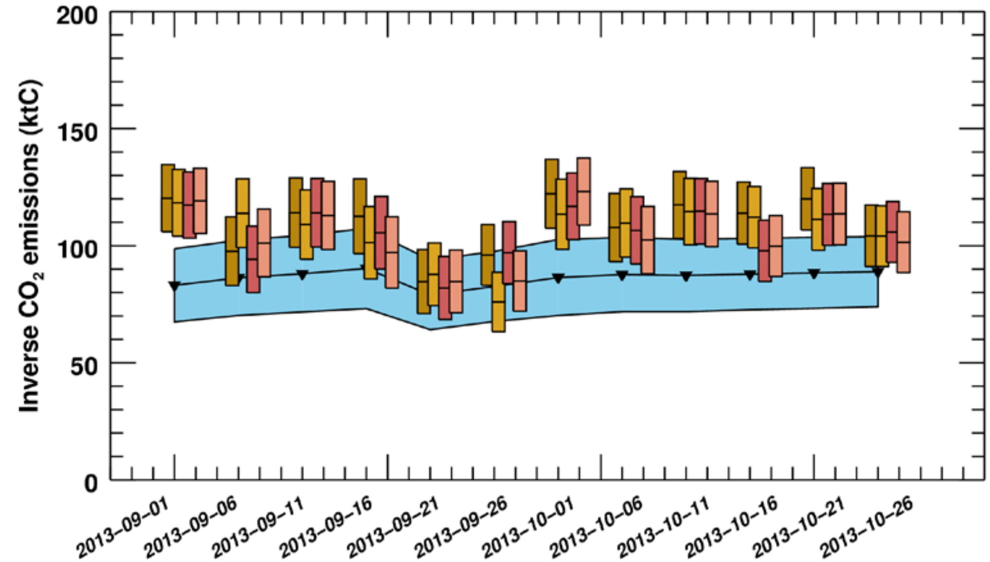
Lidar Signal-to-Noise Ratio (SNR)



Propagation of WRF-FDDA runs into inverse CO_2 emissions



Relative impact of the transport differences on the tower footprints at 1km resolution (RMS over the two-month period)



Total inverse emissions (5-day time step) for Sept-Oct 2013 over Indianapolis using the 4 different FDDA configurations

Conclusions and Perspectives

Meteorological measurements remain the most valuable and direct source of observations to understand the transport model errors

CO2 aircraft profiles have shown additional values to understand the contribution from the large scale inflow (CO_2 boundary conditions)

PBL height is critical for regional inversions but wind direction and speed is the first limitation in urban inversions

Propagation of these errors into the flux space remains challenging