Sensitivity and Uncertainty Analysis of Physical Parameterization and Initial Conditions on Meteorological Variables and CO_2 Mole Fractions

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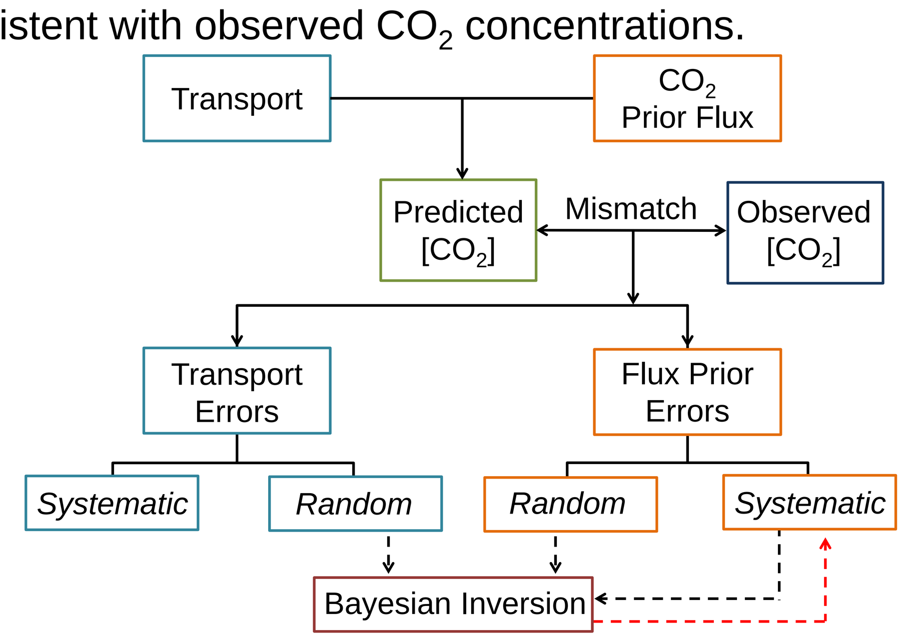
Motivation

- Atmospheric inversions uses atmospheric transport models to estimate carbon fluxes by adjusting these fluxes to be optimally consistent with observed CO_2 concentrations.

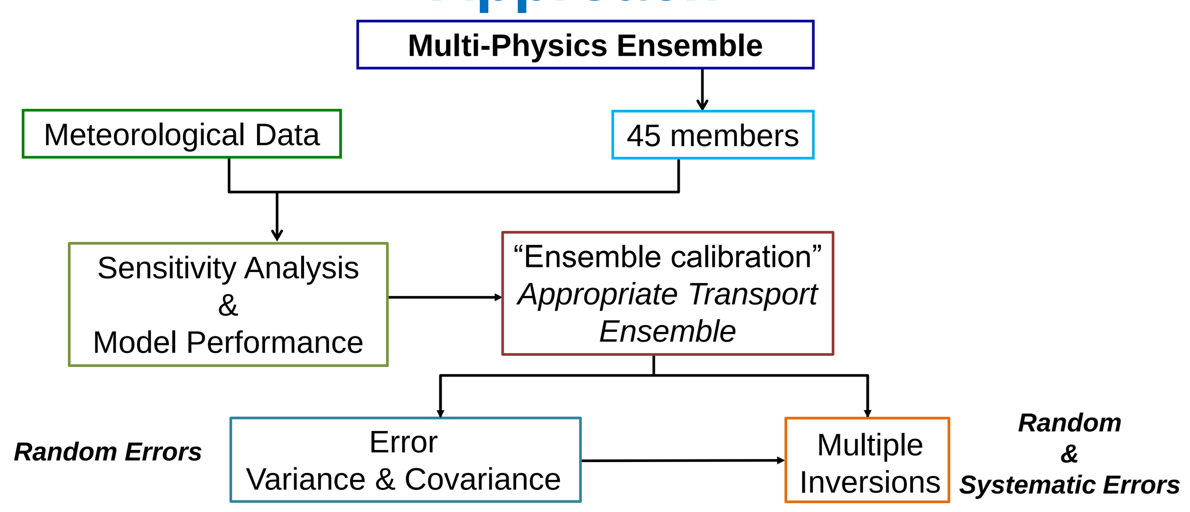


- The inverse system assumes that transport models are only affected by random errors and that systematic errors are unique to prior fluxes.
- This method assumes that the atmospheric transport model uncertainties are known. This leads to model errors that propagate to inverse (or posterior) fluxes, limiting the quality of the optimization.
- The atmospheric inverse system will be more reliable if the atmospheric transport errors are quantified rigorously and if the transport model is unbiased.

Objectives

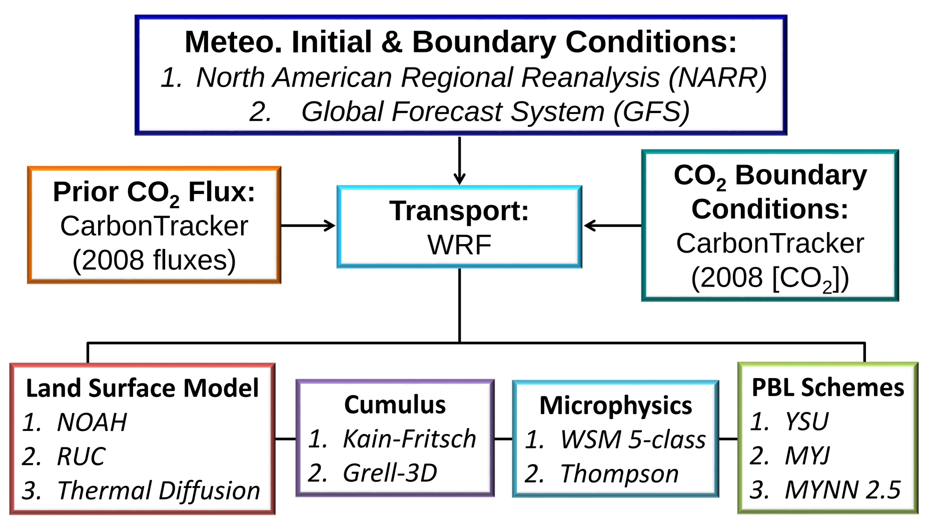
- Quantify the impact of both physics parameterizations and meteorological reanalyses on CO_2 mole fractions.
- Quantify transport errors and explore how sensitive they are to the physics parameterization and reanalysis product.
- Generate a calibrated atmospheric transport ensemble with accuracy and spread that represent systematic and random transport errors.

Approach



Multi-Physics Ensemble

- Our 45-member ensemble is created with the Weather Research and Forecasting (WRF) model that includes the chemistry module (WRF-Chem).
- This ensemble was built using different physical parameterizations and meteorological initial conditions (IC) and lateral boundary conditions (LBC) (see diagram).



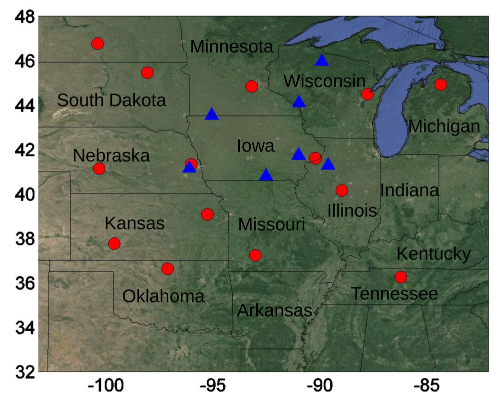
Domain: Centered in Iowa, covering 1600 km × 1600 km, with 10 km grid resolution

CO_2 Flux and LBC: CarbonTracker (CT) data assimilation system developed at NOAA (Peters et al., 2007)

Period: June 17 to July 21 of 2008

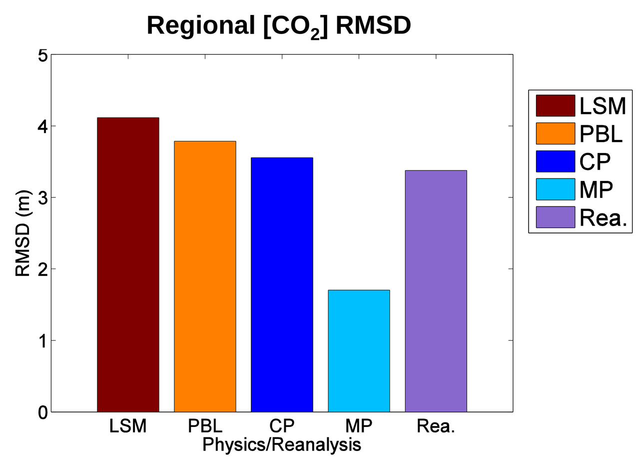
Data

- To evaluate and calibrate the ensemble we use observations from 14 rawinsonde sites (*red circles* in the map).
- Wind speed, wind direction and planetary boundary layer height (PBLH) data was evaluated at 0000 UTC.
- PBL depth was estimated using the virtual potential temperature gradient ($\nabla\theta_v$) ≥ 0.2 K/m.

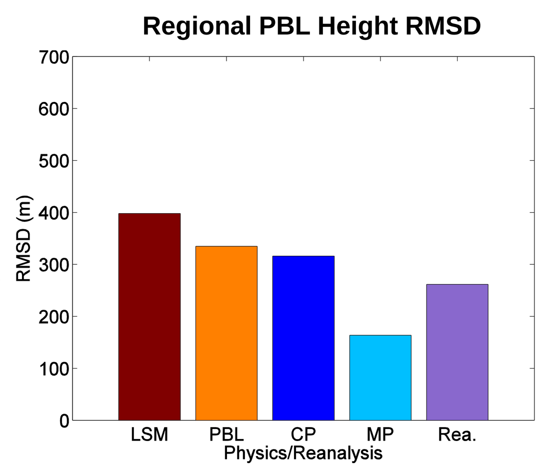


Sensitivity Analysis & Model Performance

Impact of Transport Errors on [CO_2]



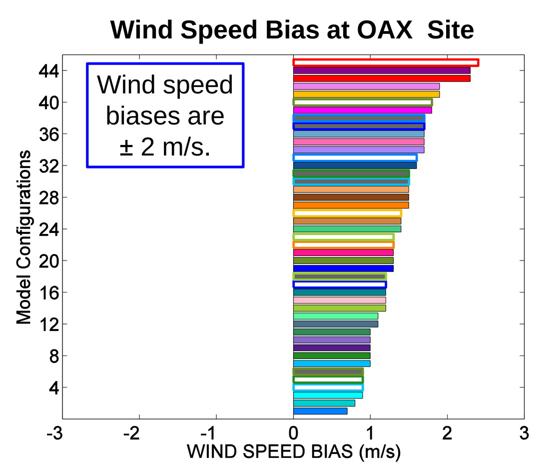
- *Model-Ensemble mean comparison used to isolate transport errors.*
- ***PBL physics is not the only physics parameterization that matters.***

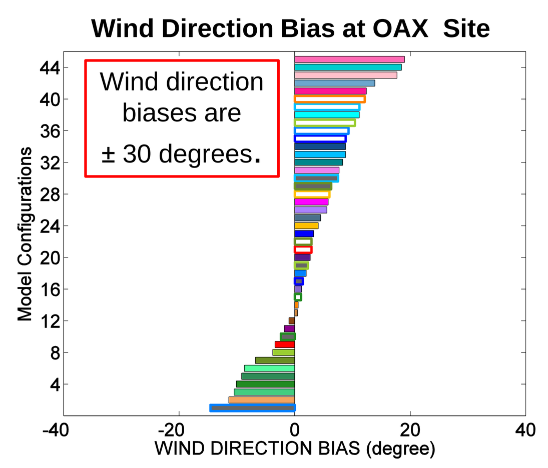


- LSMs, PBL schemes, Cumulus parameterizations (CP) and Reanalysis all have a big impact on wind speed, wind directions and PBL height errors.
- ***The order of impact in PBL height errors is similar to the CO_2 mole fraction errors.***

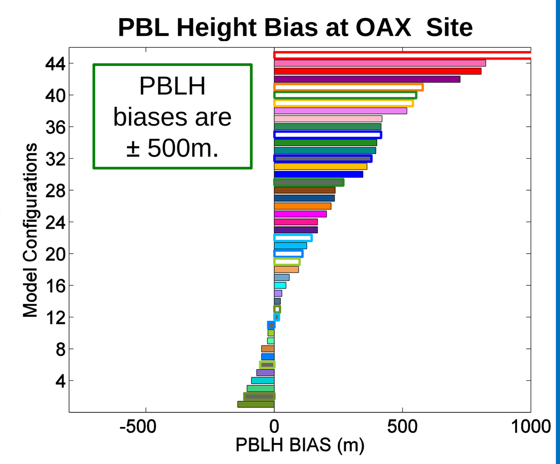
Unbiased Model

- We estimated the bias over a month for each member of the ensemble (represented by the different color bars).





- For wind speed most of the sites shows a *positive* bias, whereas for wind direction most of the sites show both *positive* and *negative* bias.
- ***It is hard to define the best configurations for wind speed and wind direction.***

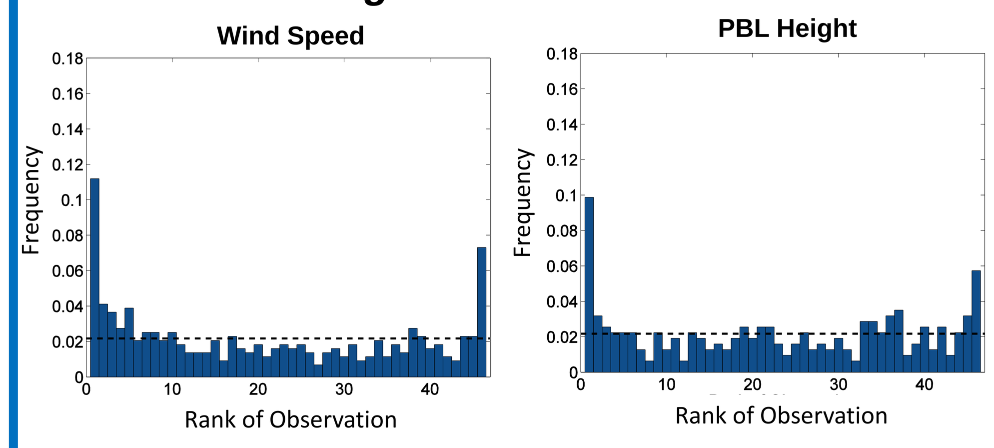


- For PBLH most of the sites shows both *positive* and *negative* bias.
- PBL height bias is controlled by both the LSMs and PBL schemes.
- ***PBL height biases can be sorted by model configuration.***

Ensemble Calibration

Rank Histogram Score & Bias

- **Rank Histogram:** This tool is used to diagnose the bias and the dispersion of the ensemble. ***An ensemble that is not biased and neither underdispersive nor overdispersive will have a flat rank histogram.***



- U-shape rank histogram implies that our ensemble spread is ***too small***.
- ***Flat rank histogram is needed to estimate transport errors.***

- **Rank Histogram Score (RHS):** This metric is used to measure the flatness of the rank histogram and should be close to 1.
- **Bias:** The bias of the residuals (model-data difference) is used as an additional criteria to choose a sub-ensemble that has an equal or lower bias than the full ensemble.

Variable	RHS	Bias
Wind Speed	6.1	0.66 m
Wind Direction	7.2	-0.41 deg.
PBL Height	3.2	98 m

- The RHS of the full ensemble is higher than one for all the variables.
- PBL height shows the lowest RHS.
- Wind speed and PBL height have *positive* bias and wind direction shows a *negative* bias.

Ensemble Calibration Technique

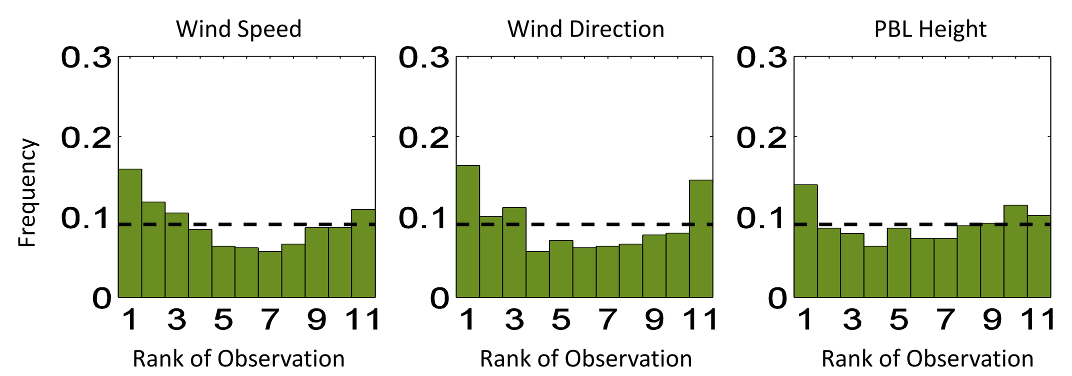
Simulated Annealing (SA):

- General probabilistic local search algorithm proposed by Kirkpatrck et al., (1983).
- This optimization method uses a cost function to find the global minimum or optimal solution, in our case a sub-ensemble with a rank histogram score close to one.

Calibrated Ensemble

- SA technique was applied to calibrate our ensemble for 10, 8 and 5-member sub-ensembles (Garaud and Mallet, 2011).
- The selected sub-ensemble, should have a RHS and bias smaller than the full ensemble.

Calibrated Ensemble 10-members:



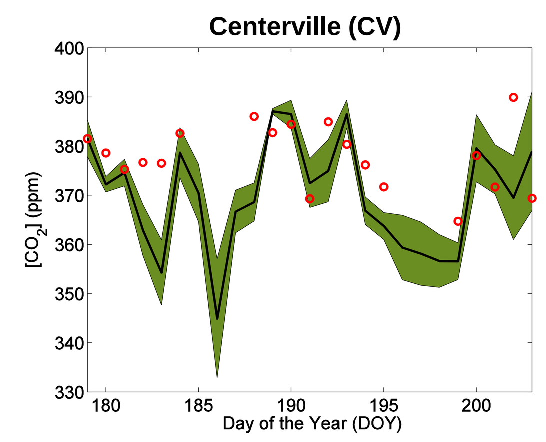
- Wind speed and wind direction still generate a U-shape rank histogram with this calibrated ensemble.
- PBL height has a flat rank histogram and the smallest RHS compare to the rest of the variables.
- Simulated Annealing (green) allows us to find a sub-ensemble that has a smaller bias than the full ensemble (blue – above).

Variable	RHS	Bias
WSPD	4.6	0.53 m/s
WDIR	6.3	-0.21 deg.
PBLH	1.6	78 m

Synthesis

- Not only the PBL schemes have a significant impact in CO_2 mole fractions, other physics schemes such as LSM and Cumulus parameterizations contribute to CO_2 variability.
- The configuration performance varies over the domain, therefore making it hard to select the best configuration.
- PBL depth bias can be reduced, therefore a best configuration (less bias) exists for this factor alone.
- From a 45-members ensemble, we were able to create a sub-ensemble of 10-members that shows an appropriate spread and smaller bias.

Future Work: Evaluate Calibrated Ensemble



- Transport errors show large temporal variability
- Interpretation of hourly ensemble-based error variances:
  - Model-data differences larger than transport errors: *flux signals still present*
  - Observations within transport error bounds*: no flux signal left*