Quantify transport errors in CO_2 mixing ratios using a small-size ensemble

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1. Generate a calibrated ensemble which represents the characteristics of transport errors using a minimum number of members

PhD of ***Liza Diaz-Isaac (now at Scripps, UC San Diego)***

2. Remove the sampling noise due to the limited number of members

in collaboration with ***Marc Bocquet (CEREA, Paris)*** *and* ***Nicolas Bousserez (U. of Colorado)***

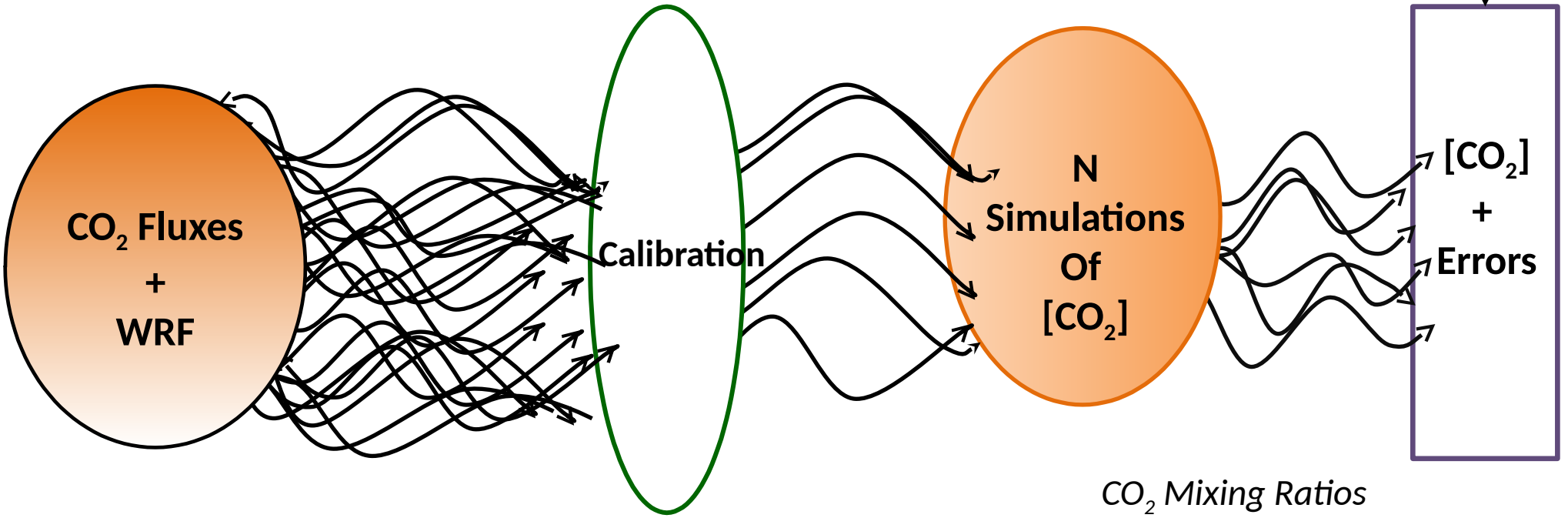
PSU-UMD Data Assimilation Workshop, 26-27 June 2017, College Park, MD

Physics-based ensemble of atmospheric simulations

Objective 1
Generate an ensemble of simulations using an atmospheric modeling system

Objective 2
Evaluate if the Ensemble Spread Represents the Transport Errors

Assess Transport Errors in the Atmospheric Inversion.

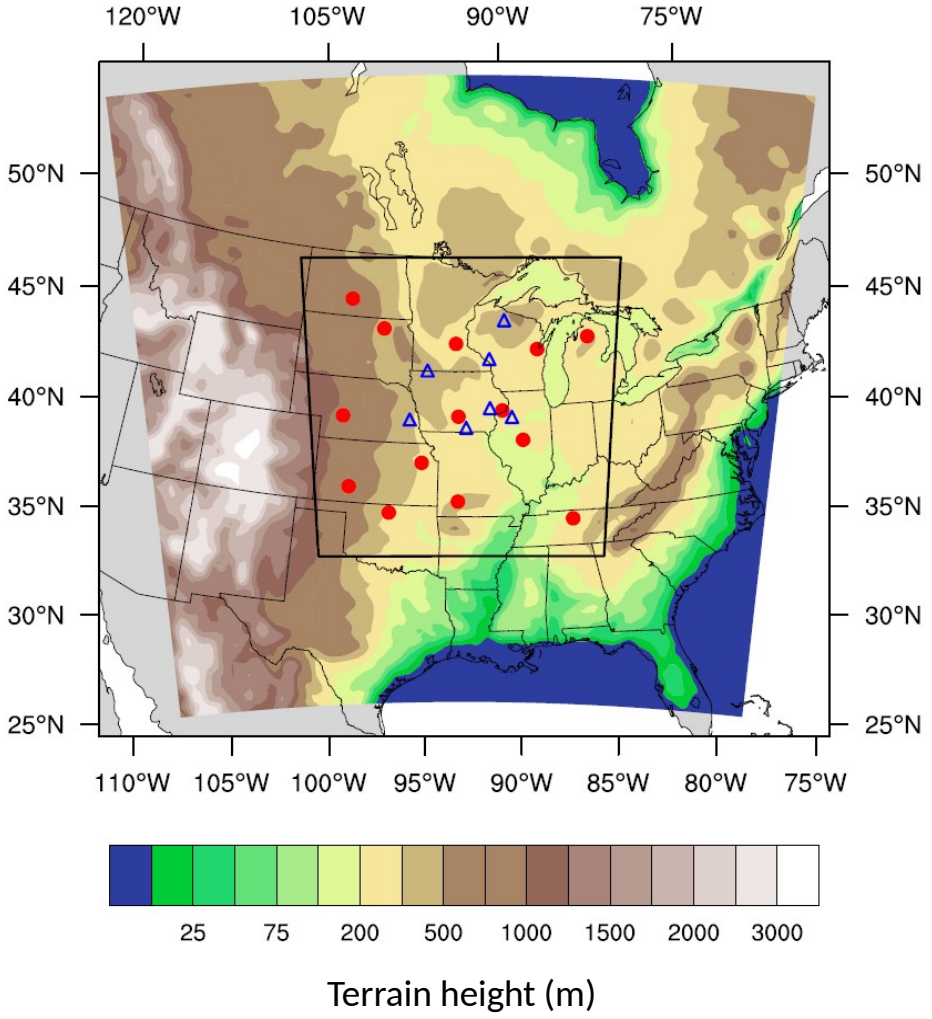


Meteorological Variables

CO_2 Mixing Ratios

from Diaz-Isaac et al. (in prep.)

Description of the WRF simulation domain



Period: June 18-July 21, 2008

Grid Resolution:

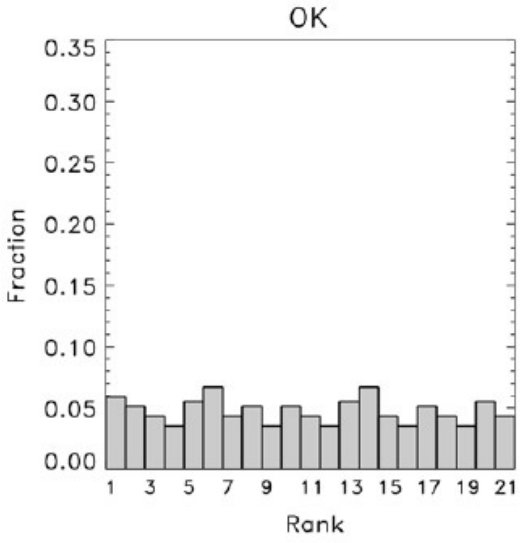
Parent Domain (d01): 30-km

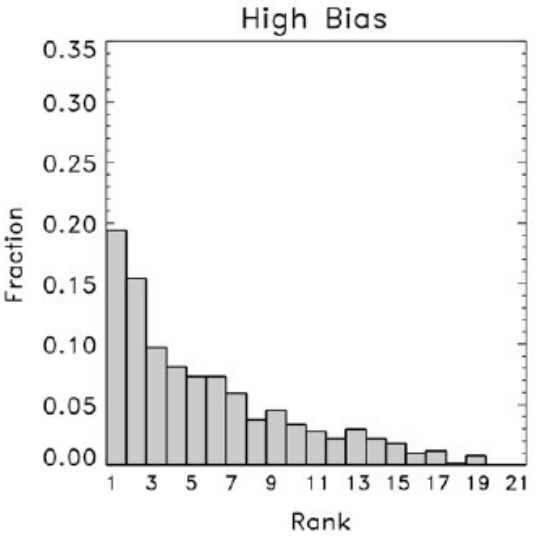
Inner Domain (d02): 10-km

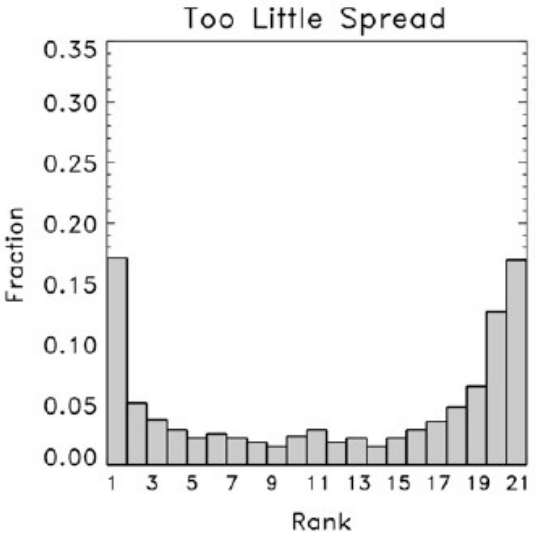
- Re-initialization every five days.
- A multi-physics and multi-analysis ensemble will be used instead of a randomly perturbed ensemble.
- The multi-physics and multi-analysis configurations allows us to select different model configurations for multiple atmospheric inversions.

from Diaz-Isaac et al. (in prep.)

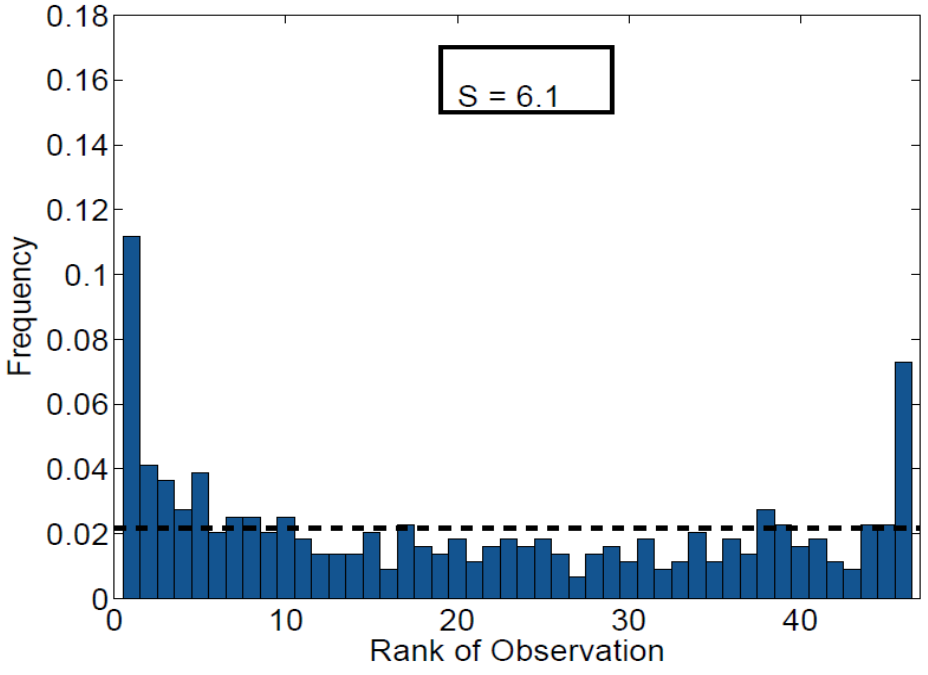
Rank Histograms & Score







If the ensemble is under-dispersive
Than the score will be greater than 1



How to improve the score of the ensemble, i.e. increase the dispersion?

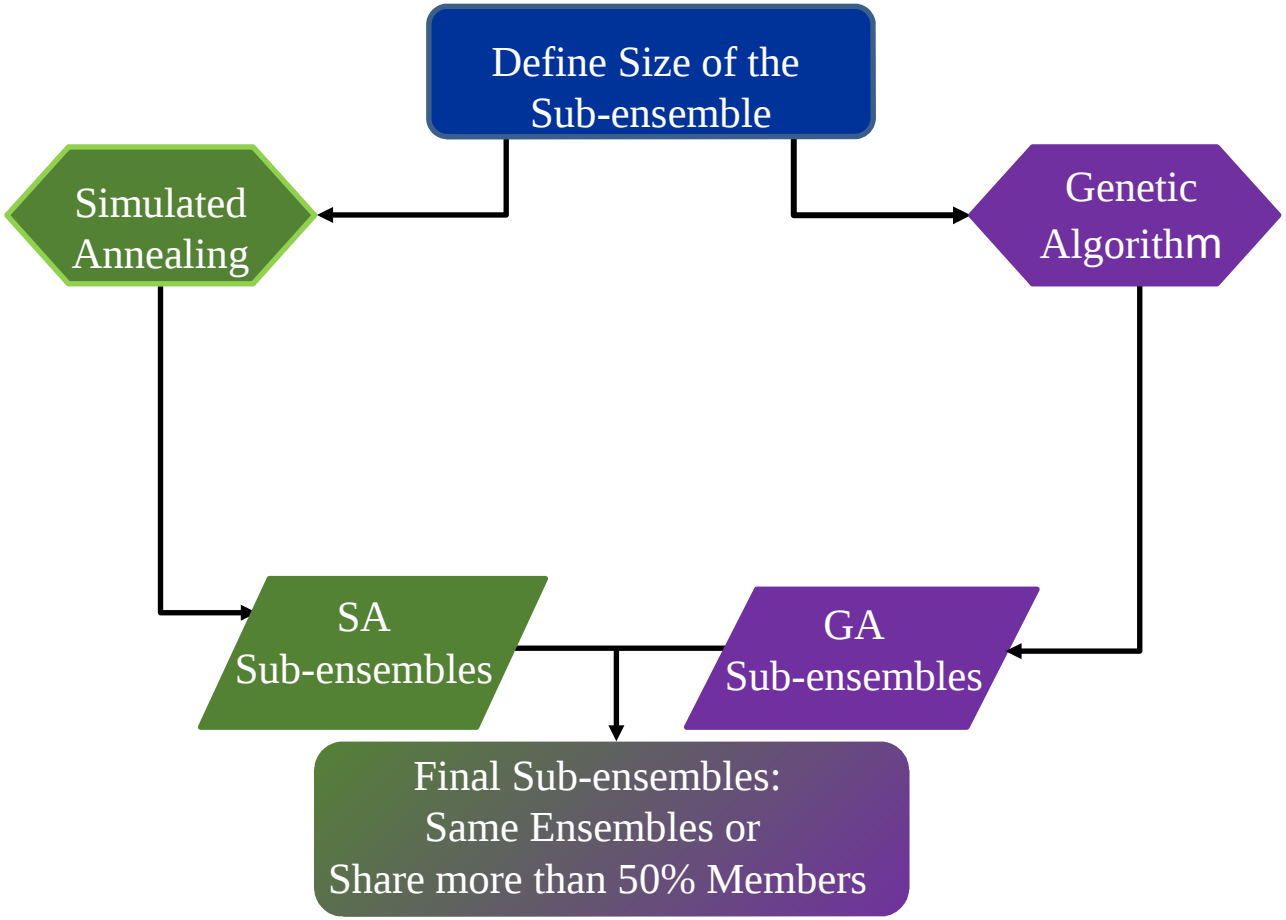
Hamill, 2001

Calibration of the ensemble

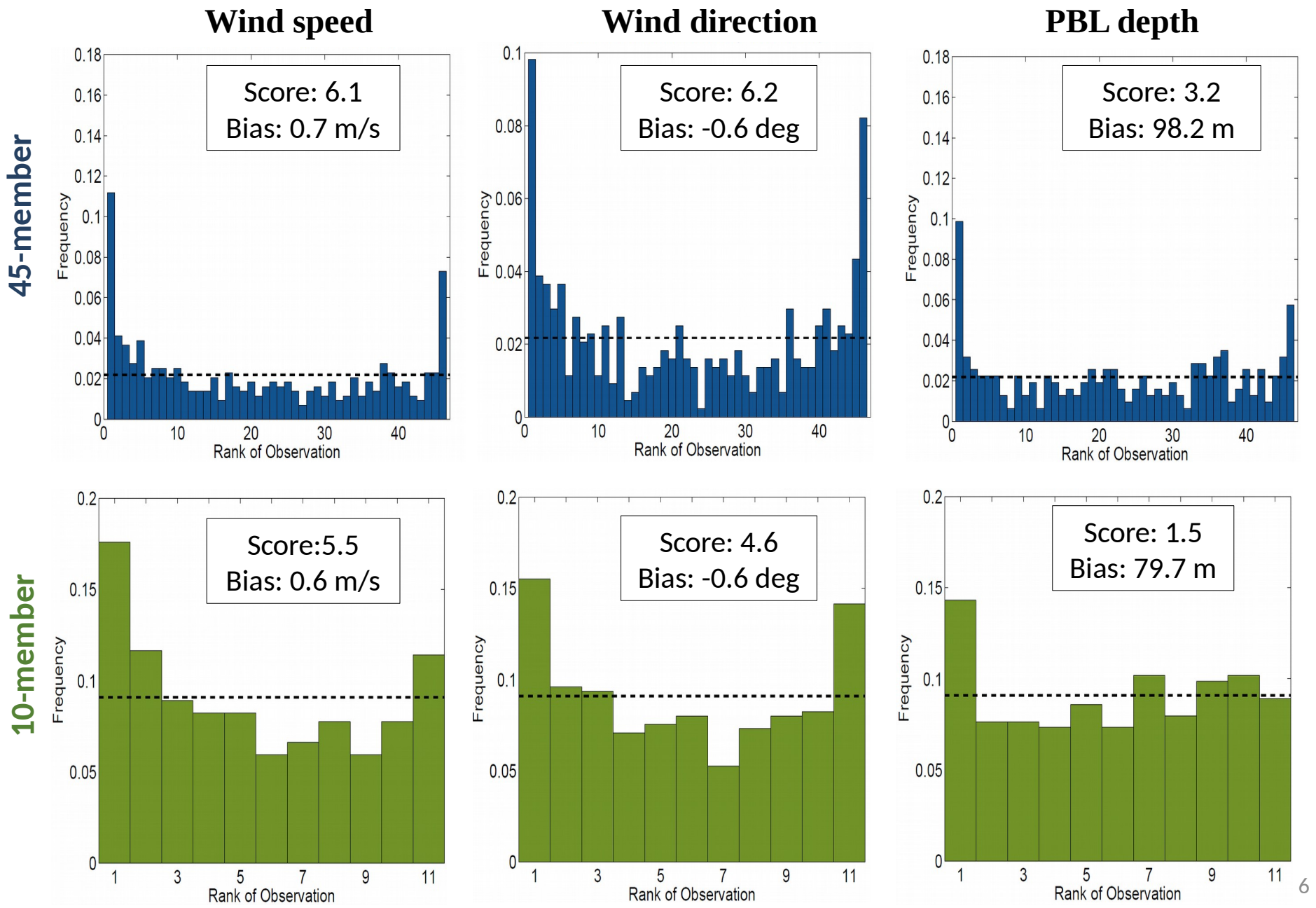
Optimization
Simulated Annealing &
Genetic Algorithm

An automatic selection of a sub-ensemble is used to minimize the score.

$$S = (S_{wsp})^2 + (S_{wdi})^2 + (S_{pbl})^2$$



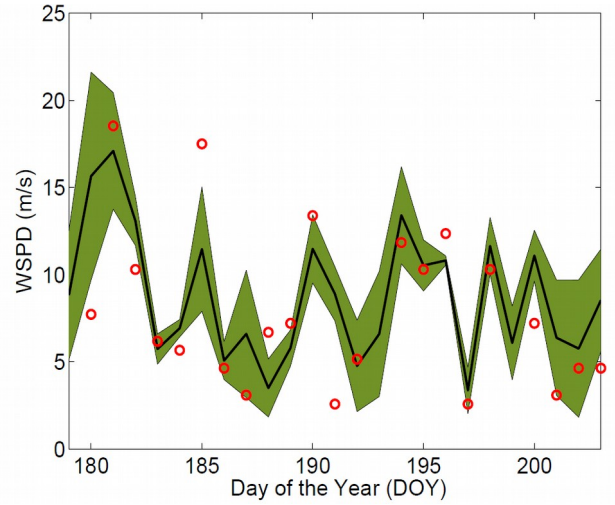
Simulated Annealing 10-member Sub-Ensemble



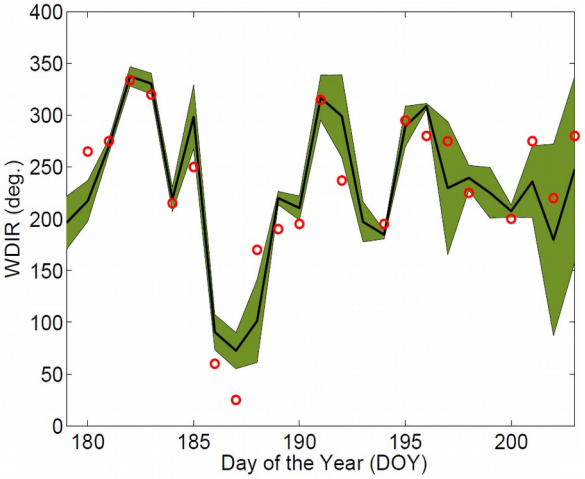
from Diaz-Isaac et al. (in prep.)

Ensemble-based CO_2 Variance

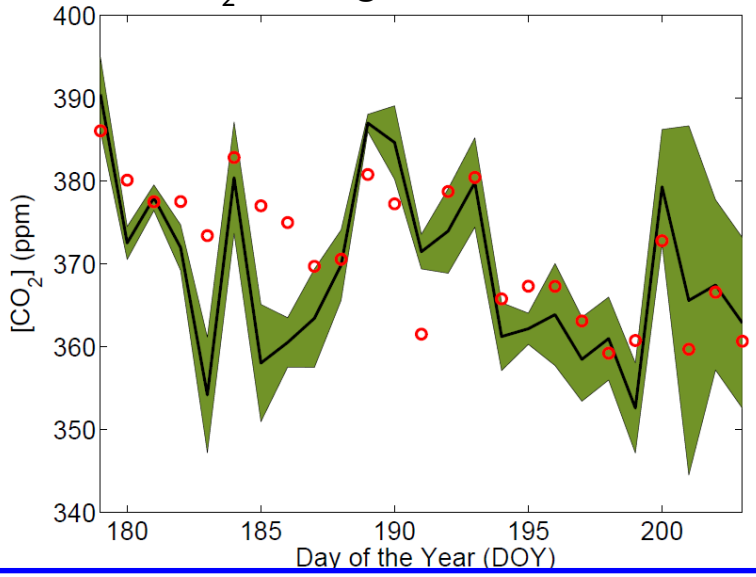
Wind Speed at DVN



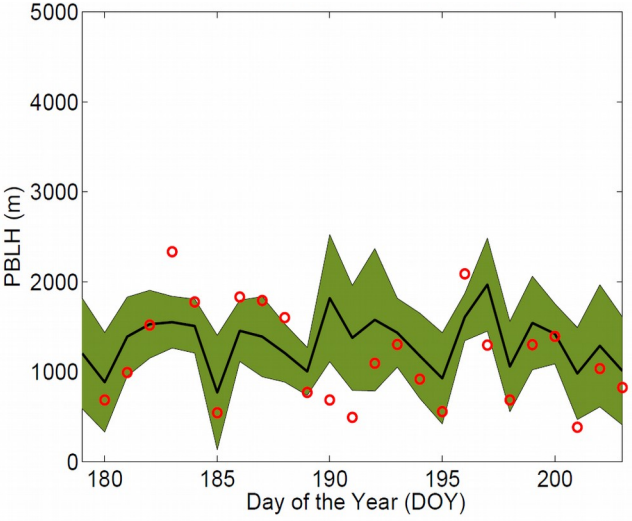
Wind Direction at DVN



CO_2 Mixing Ratio at WBI



PBL Height at DVN



from Diaz-Isaac et al. (in prep.)

Quantify transport errors in CO_2 mixing ratios with a small-size ensemble

2. Remove the sampling noise due to the limited number of members

Work based on recent developments in NWP for noise filtering using an objective filter

Sub-question: How to define the reference (best ensemble)?

Note: 45-member ensemble is not calibrated

Quantify transport errors in CO2 mixing ratios with a small-size ensemble

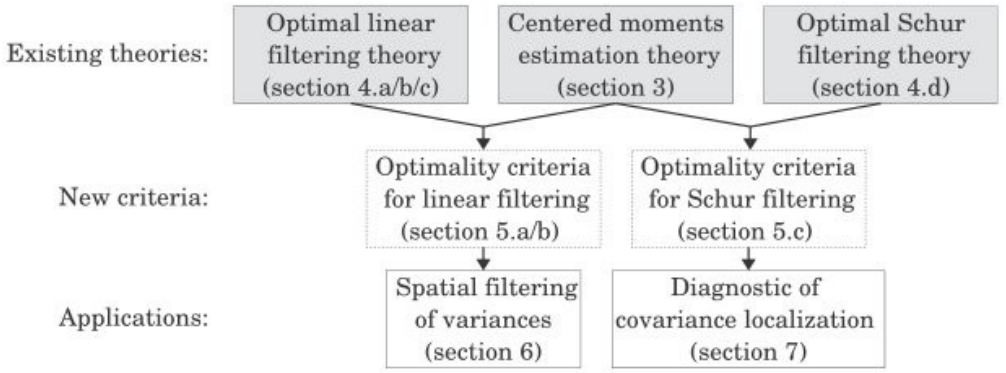


FIG. 1. Outline of the paper, from original theories to applications, via new optimality criteria definition.

	Non-Gaussian	***Gaussian***
Variance (filter)	$\mathfrak{C}_i = \mathbb{E}[\widetilde{v}_i^2] - \frac{N(N-2)(N-3)}{(N-1)(N^2-3N+3)}\mathbb{E}[\widetilde{v}_i\widehat{v}_i] - \frac{N^2}{(N-1)(N^2-3N+3)}\mathbb{E}[\widetilde{\xi}_i],$	$\mathfrak{C}_i^G = \mathbb{E}[\widetilde{v}_i^2] - \frac{N+1}{N-1}\mathbb{E}[\widetilde{v}_i\widehat{v}_i].$
Covariance (schur product)	$L_{ij} = \frac{(N-1)^2}{N(N-3)} - \frac{N}{(N-2)(N-3)}\frac{\mathbb{E}[\widetilde{\Xi}_{ijij}]}{\mathbb{E}[\widetilde{B}_{ij}^2]} + \frac{N-1}{N(N-2)(N-3)}\frac{\mathbb{E}[\widetilde{v}_i\widetilde{v}_j]}{\mathbb{E}[\widetilde{B}_{ij}^2]}.$	$\mathfrak{C}_i = \mathbb{E}[\widetilde{v}_i^2] - \frac{N(N-2)(N-3)}{(N-1)(N^2-3N+3)}\mathbb{E}[\widetilde{v}_i\widehat{v}_i] - \frac{N^2}{(N-1)(N^2-3N+3)}\mathbb{E}[\widetilde{\xi}_i],$

from Menetrier et al. (2015), Monthly Weather Review

Impact of the calibration on Filtered CO_2 Variances and Covariances using calibrated and random ensembles of 5 and 8members

Monthly averages of the filtered hourly results

27 June to 20 July, 2008

1. "Random ensembles" were generated with randomly selected members

- Random ensembles ("random X-member") do not share any members with calibrated ensembles ("calibrated X-member") = members never selected by calibration procedure

- Random ensembles of different sizes (i.e. 5-member and 8-member) share only one member (I didn't do that on purpose, it just turned out to be that way)

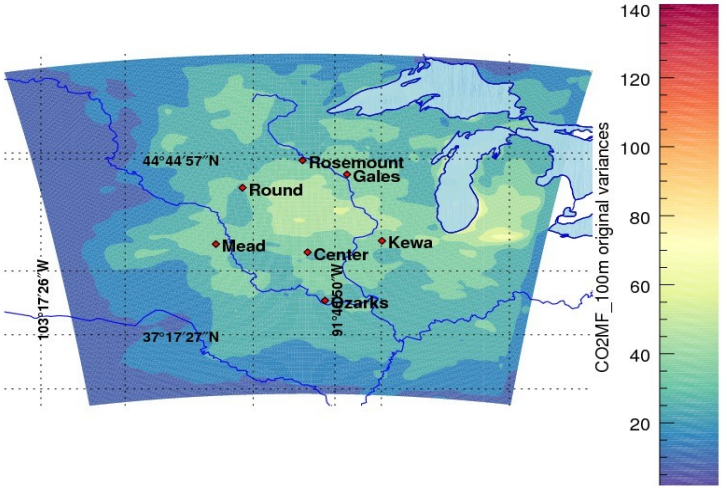
2. "Calibrated ensembles" were generated with two methods:

- Simulated Annealing (SA): best option AND best option most similar to GA

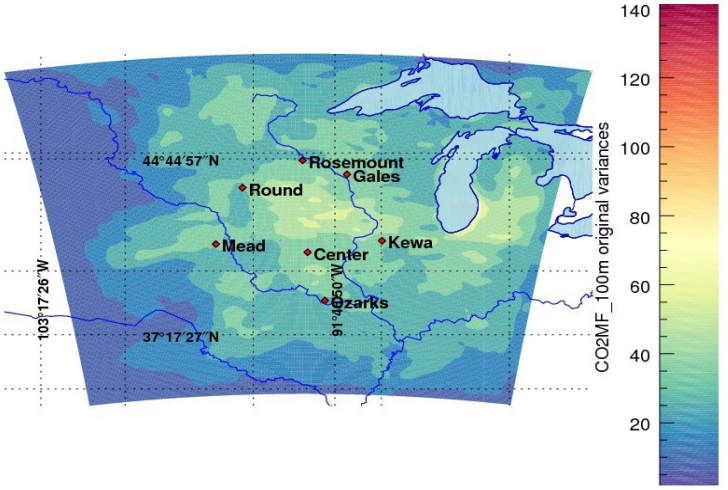
- Genetic Algorithm (GA):best option AND best option most similar to SA

Note: before, I was only using "SA ensembles most similar to GA" (and not "best option")

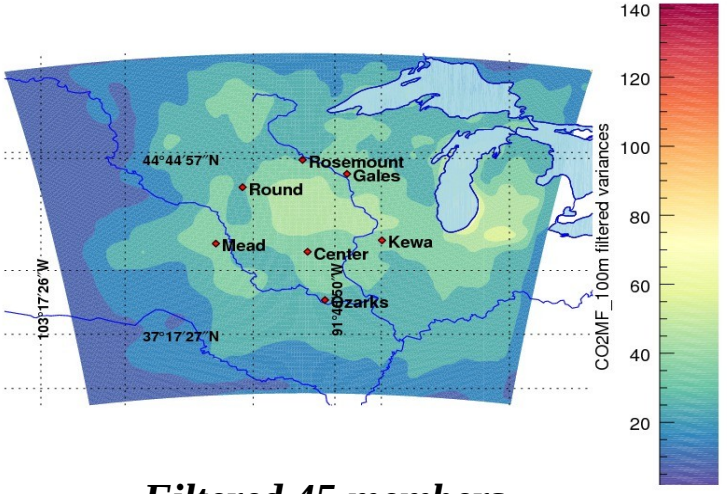
Quantify transport errors in CO_2 mixing ratios with a small-size ensemble



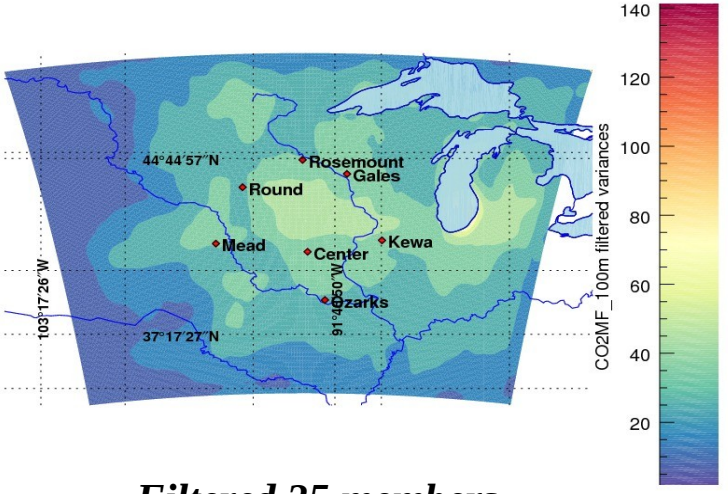
Raw 45 members



Raw 25 members



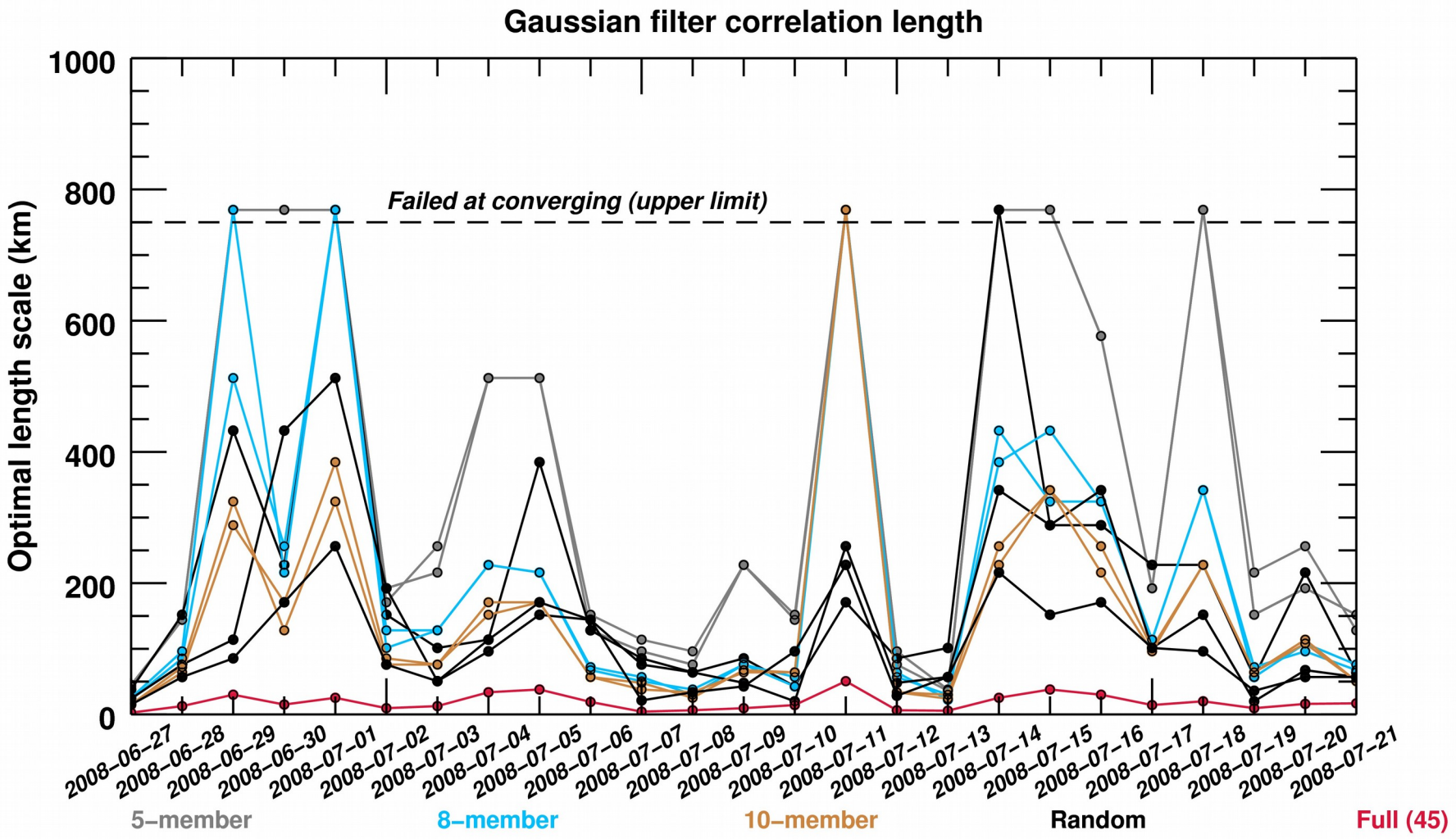
Filtered 45 members

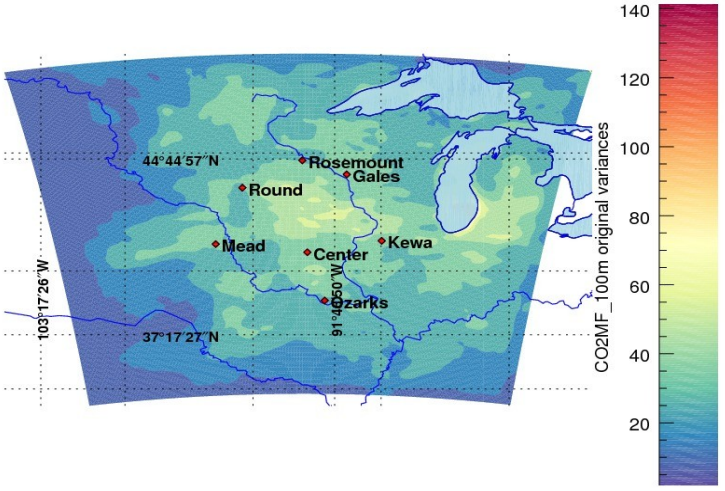


Filtered 25 members

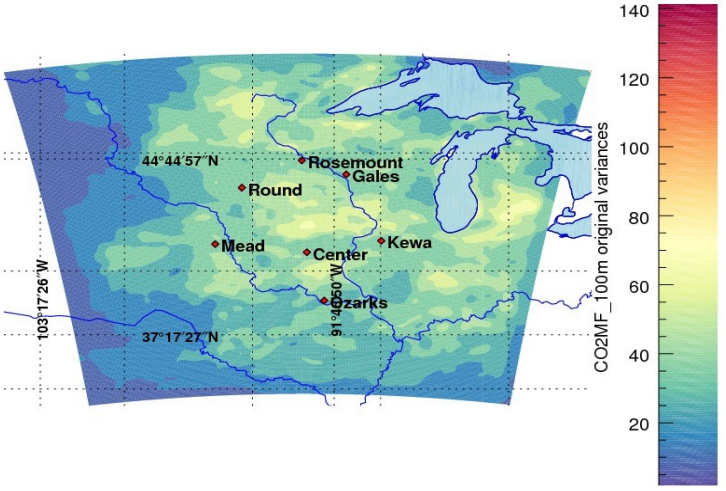
Optimal sub-ensemble = sufficient number of members (here 25 members) and calibration of the ensemble

Convergence of the filter for variances

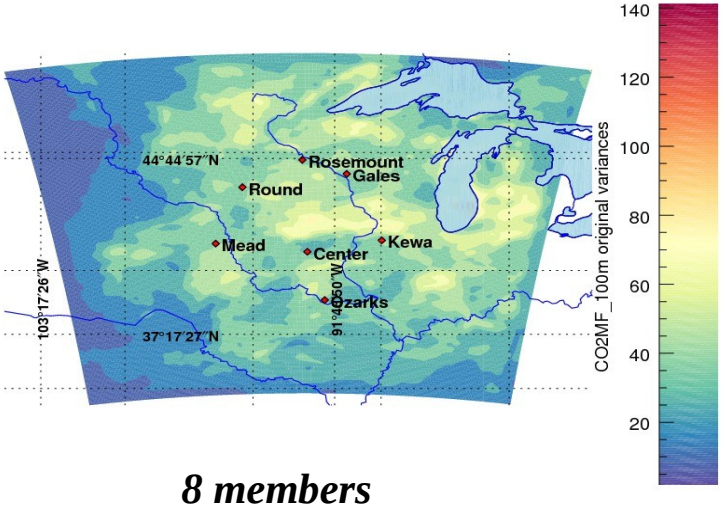




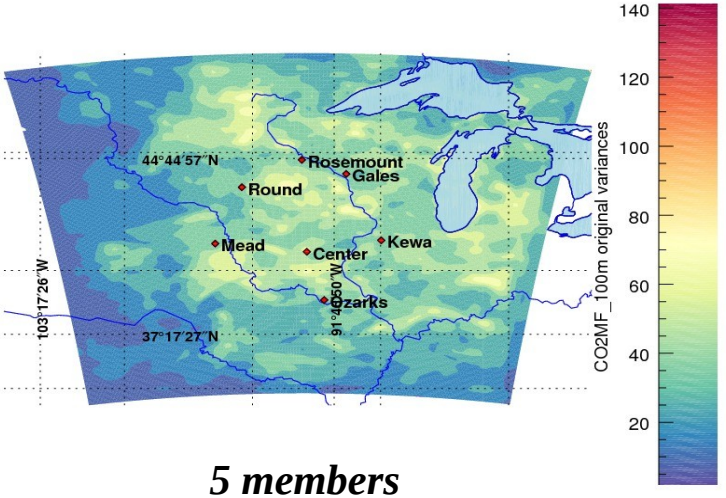
25 members



10 members

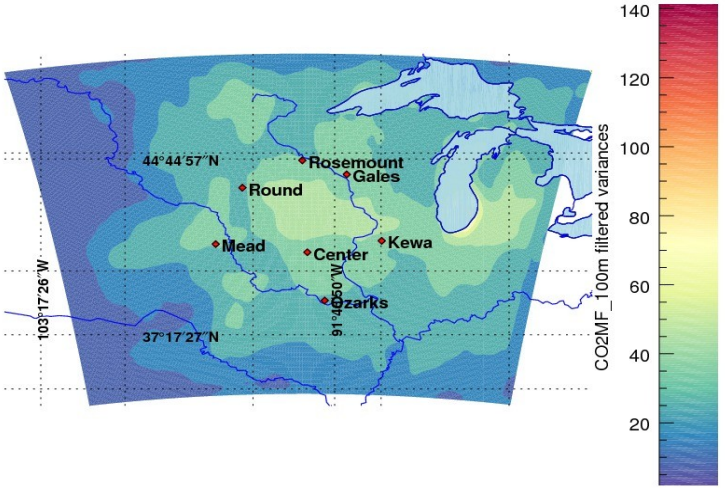


8 members

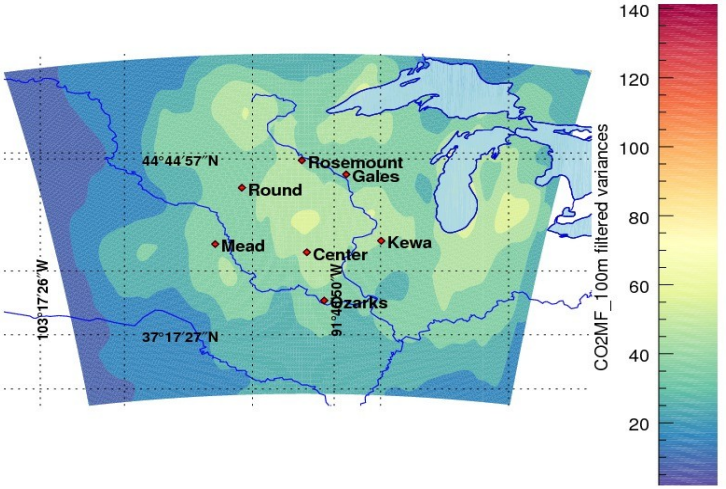


5 members

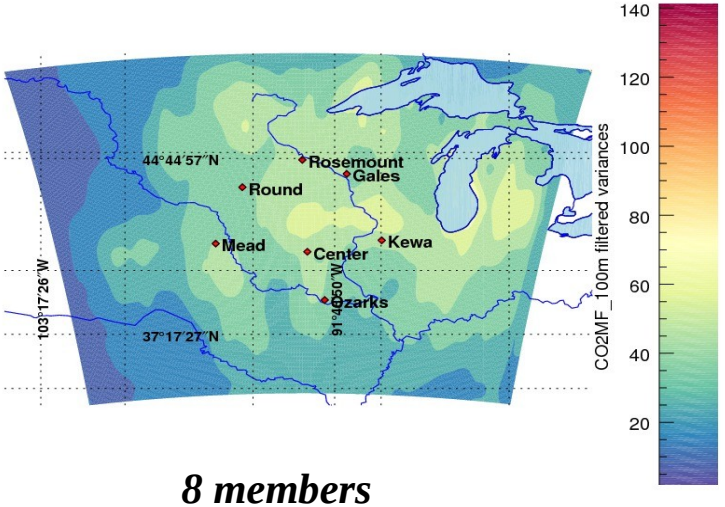
Unfiltered variances averaged over one month (in ppm^2)



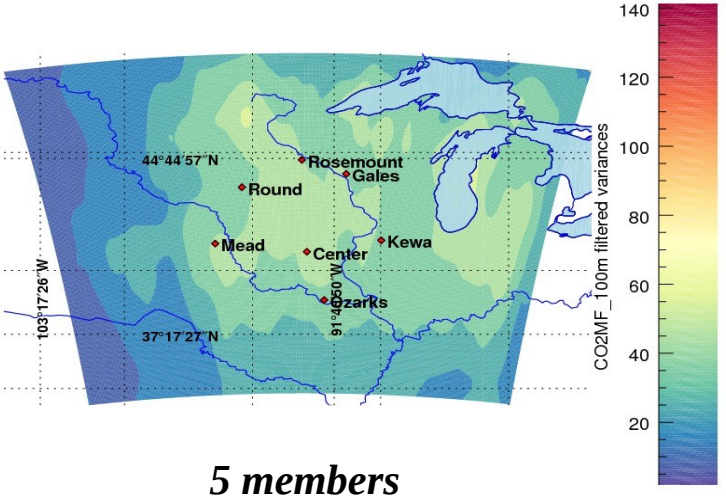
25 members



10 members



8 members



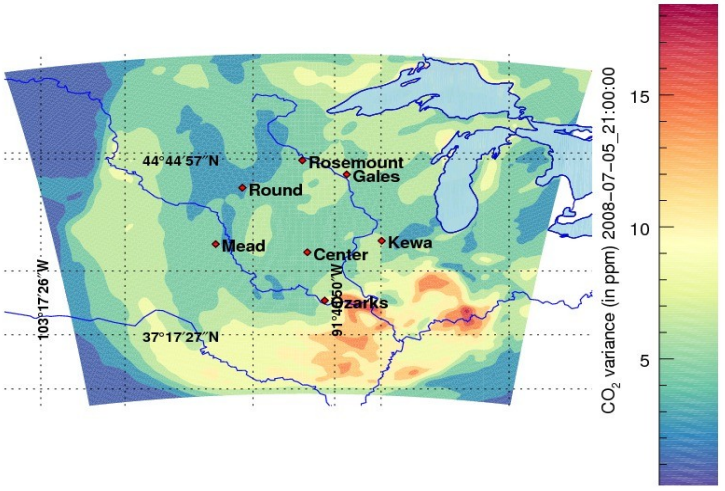
5 members

Filtered variances averaged over one month (in ppm^2)

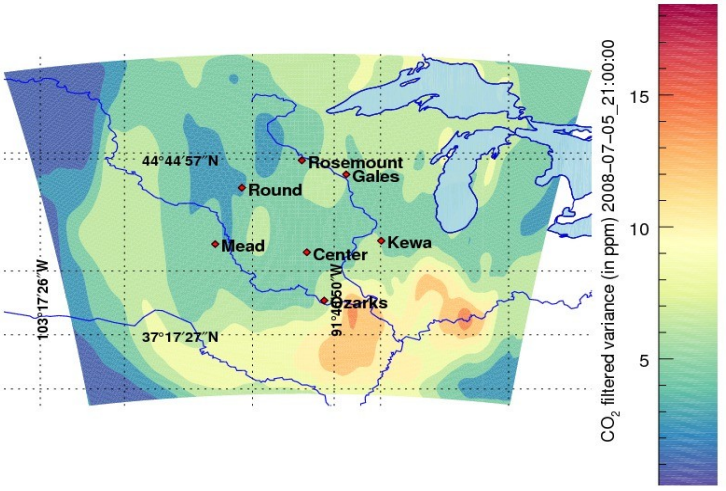
An example

I show here an example of hourly variances for July 5 and July 20 of 2008

5 July

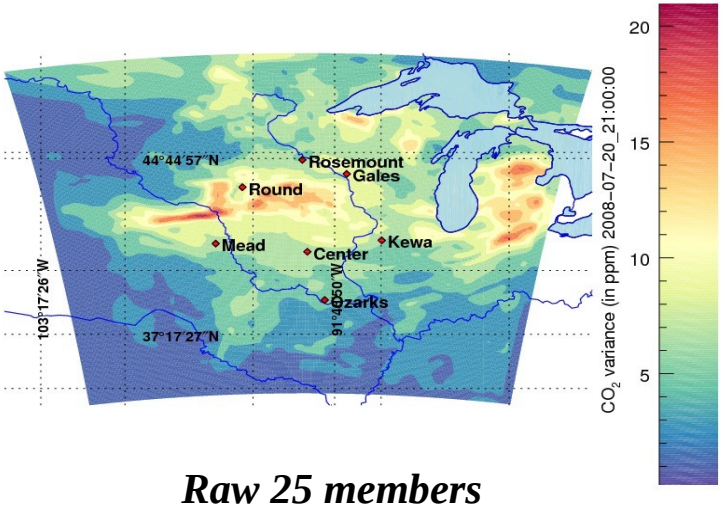


Raw 25 members

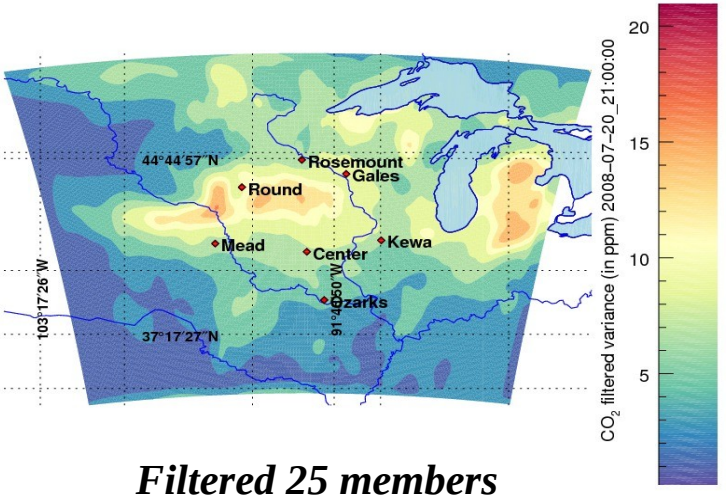


Filtered 25 members

20 July



Raw 25 members



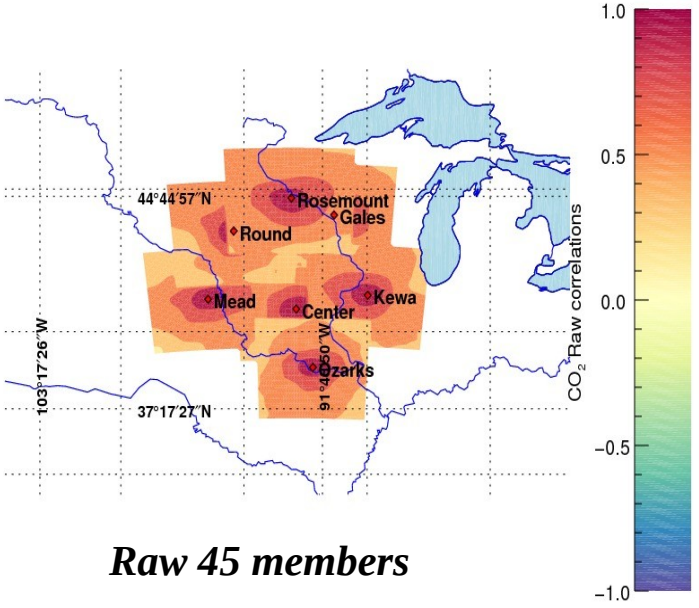
Filtered 25 members

25-member variances averaged over one month (in ppm^2)

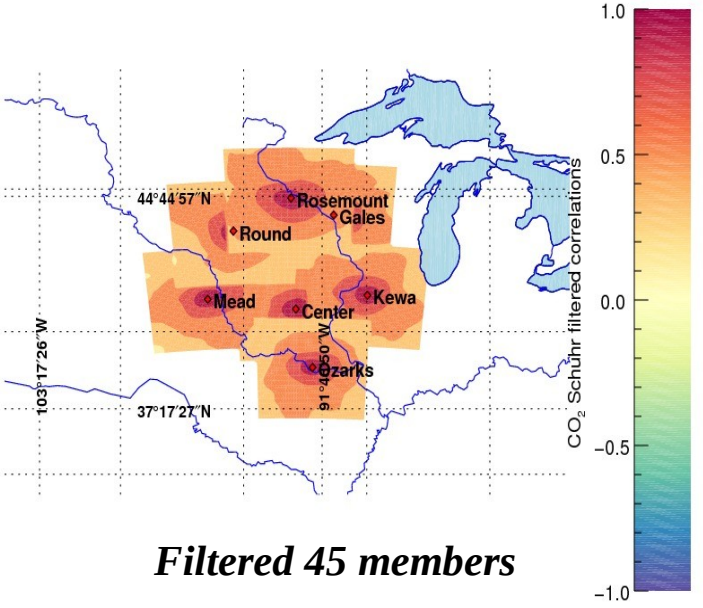
And the error covariances

Here is the monthly averaged error correlations after using Menetrier's filter (Schur product here)

Filtering covariances (Schur product) of calibrated ensembles



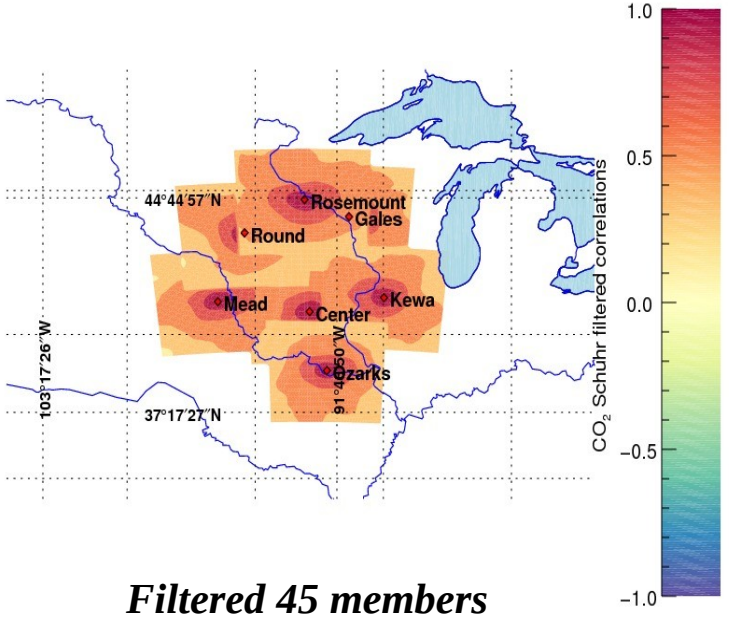
Raw 45 members



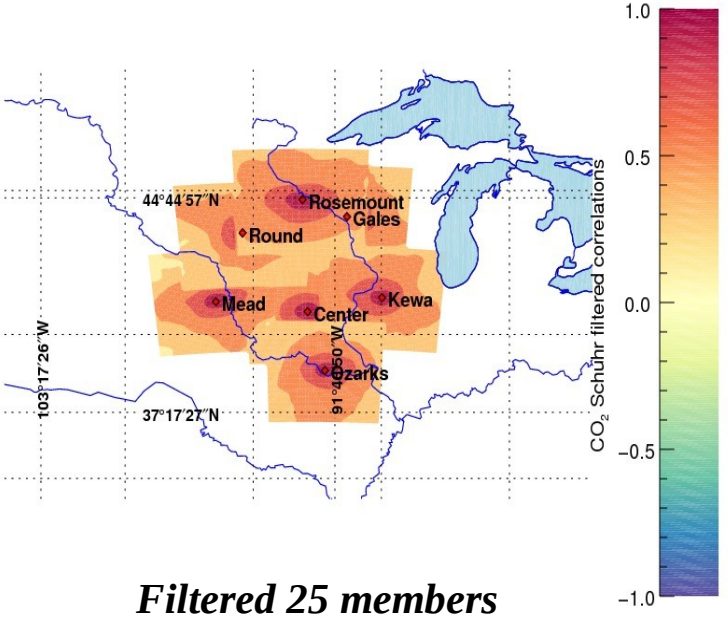
Filtered 45 members

Full (=45-member) ensemble error correlations averaged over one month

Filtering covariances (Schur product) of calibrated ensembles



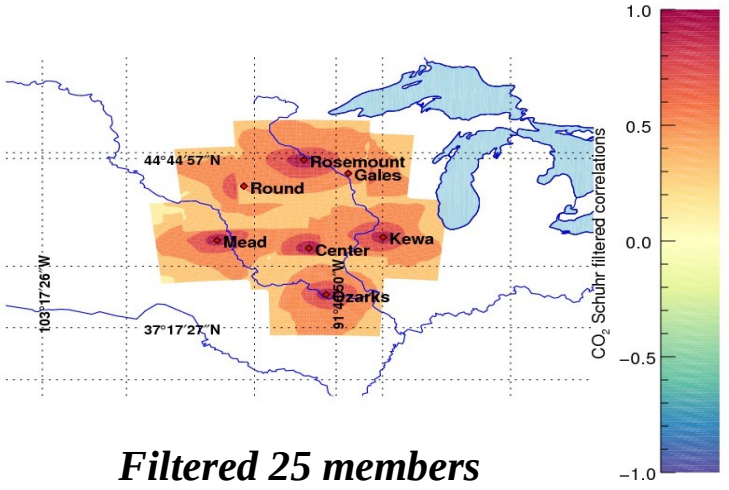
Filtered 45 members



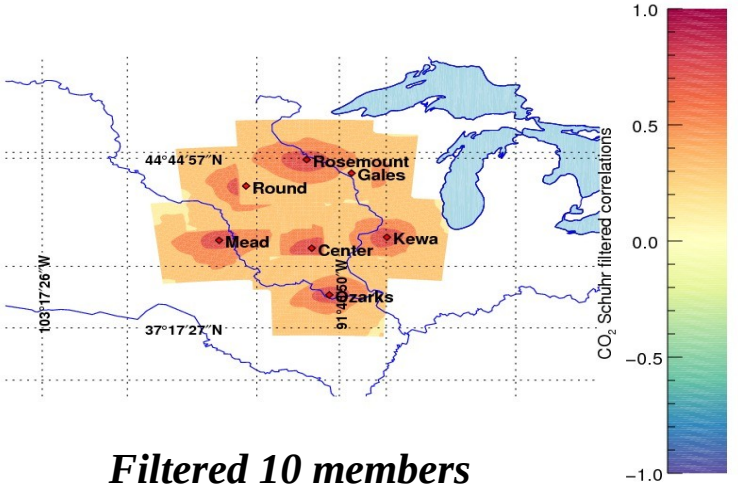
Filtered 25 members

Full (=45) and 25-member error correlations averaged over one month

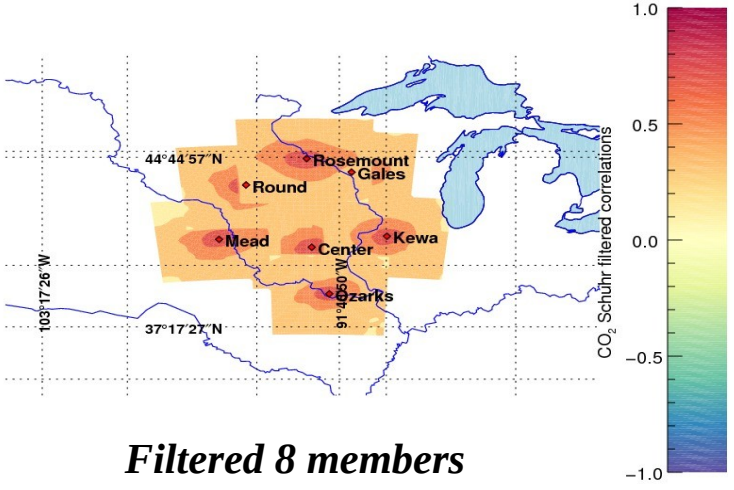
Filtering covariances (Schur product) of calibrated ensembles



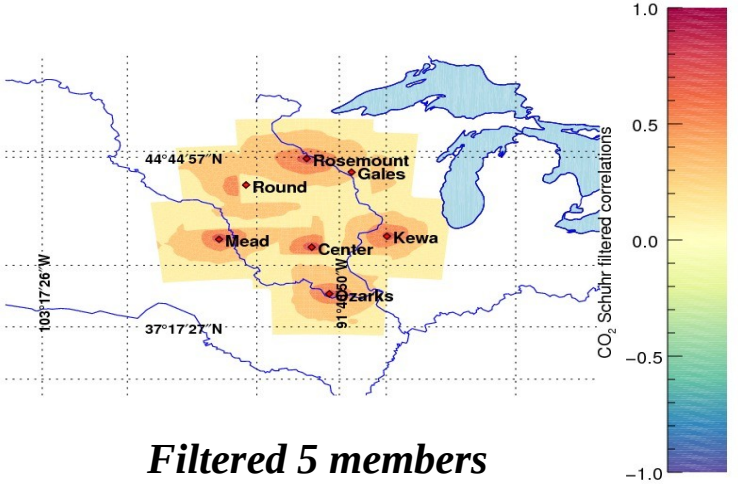
Filtered 25 members



Filtered 10 members



Filtered 8 members



Filtered 5 members

Conclusions and Perspectives

1. Generate a calibrated ensemble which represents the characteristics of transport errors using a minimum number of members

Starting from 45 members, small-size ensembles of 8 and 10 members are able to represent the observed CO_2 variances

Initial dispersion was small which limits our ability to match exactly the model errors

→ ***Generate perturbed ensembles to increase the dispersion***

2. Remove the sampling noise due to the limited number of members

Calibrated sub-ensembles show specific error structures not visible in the original ensemble and in random sub-ensembles

→ Need to create error covariance matrices for the CO_2 atmospheric inversion