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Interactive comment on “Structure of the transport uncertainty in mesoscale inversions of CO₂ sources and sinks using ensemble model simulations” by T. Lauvaux et al.

T. Lauvaux et al.

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We thank the referee for his comments. The different sentences we included in the corrected version of the paper are indicated with the answers. We especially emphasized on other techniques to estimate transport error covariances, and explained more clearly the technical choices for our diffusion model and the atmospheric coupling. Here are the specific answers to the 6 different questions raised by the reviewer.

1. The direct comparisons with real data remain the best quantification of the uncertainty in the model. You address here an objective way to quantify and characterize it. Nevertheless, number of observations at the mesoscale, and more specifically in our domain, remains limited to few stations. In general, 7 radisoundings are operated

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daily at 12am and 0am in France. During the CERES campaigns, extra radiosoundings were done during the day at La Cape Sud and Toulouse. These two stations would help verifying the uncertainty (variances) and vertical error correlations at the two station locations, but would be too limited to characterize its structure over the domain. Our study allows the estimation of the temporal correlations and spatial correlation structures over the entire simulation domain as an independent method for any type of campaign, considering that the density of observations available during the CERES campaign is not often reached. The comparison to such dataset with our results would be interesting, but we already noticed the consistency between our values (correlation lengths) and similar studies using data comparison. We included in the introduction the following sentence in the Introduction: "Such direct comparison using radiosoundings was previously done at larger scale (gerbig et al., 2008) but requires a sufficiently large number of observations over the domain."

2. These technical details were not pointed out as they were previously validated and published for MesoNH (Redelsperger and Lafore (1988), Klemp and Wilhelmson (1978), Davies (1976)) and commonly used in mesoscale modeling. Each simulation ran in this ensemble has nothing different than classic non-perturbed coupling between ARPEGE and MesoNH, that is used in several papers. We added the following sentence to precise the actual parametrization in our simulations using classical opened lateral boundary condition treatment: "The boundary conditions from the ARPEGE ensemble simulations are coupled each 3 hours to constrain the meso scale model, following the Sommerfield equation for the normal wind velocity components at the boundaries with a constant phase speed (relaxation term) of 20 m.s⁻¹."

3. The fast growth rate of the ensemble dispersion is surely affecting the first 48 hours of simulation, corresponding to the period of initial perturbation of ARPEGE. The fastest growth rate appears at the early stage of the simulation (SV method especially, Magnusson et al., (2008)). Concerning the structure of the transport error, we estimated the four daily error structures (correlation lengths especially) and noticed the similarity

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of the estimates during the 4 days of simulation. The spatial structures correspond to daily meteorological conditions, averaged by using the four days as one single period. We reinforced our first hypothesis that transport error structures are driven by the model resolution and not by the resolution of the perturbations as long as they are larger than the model one. For example, perturbing synoptic conditions will affect local structures, so their spatial dimensions will correspond to local dynamics rather than initial perturbation dimensions. If the simulation period was affected by different situations or an important change in the dynamics, the final estimation could be affected and not realistic for any single day. But we observed similar features during our period with high surface temperatures and midday sea breeze circulation. The "cut-off" is due to the numerical dispersion of the mesoscale model itself that can't run continuously for more than 4 days without being affected by its own dynamical divergence. In more, the perturbation method was optimized for 4 day long simulation, including the perturbations during the first 48 hours for an optimal solution during the next 48 hours.

4. The diffusion operator can smooth the retrieved length-scales compared with the raw length-scale field. However, according to previous studies, this appears as beneficial as shown by Pannekoucke et al. (2008). Several tests show in this study the impact of the diffusion model using pseudo-data experiment where known length-scale fields were perturbed and estimated with the diffusion equation. The retrieved length-scales are slightly overestimated but the final result shows clearly the benefits from the diffusion model compared to the raw field. The gaussian diffusion operator remains local, and allows non-symmetric structures (anisotropic). One way to test whether a given structure is related to the dynamics or is just noise, is to run a larger ensemble, what we tried to avoid with the presented method. The manuscript has been modified as follows to take into account the review: "The estimation is slightly biased with an over-estimation of the truth (Pannekoucke et al., 2008). The sampling distribution has an heavy tail with a positive skewness. It results that, in average, the sampling noise leads to an estimation larger than the truth (see e.g. Pannekoucke et al 2008, Fig. 7). That is, the smooth of the raw length-scales modeled with the diffusion operator appeared as

beneficial revealing clearly the initial true correlation structures."

5. We agree completely to this point. We added in the abstract the following sentence: "Variances are based on model-data mismatch to avoid under-estimation of the absolute transport error due to model bias that affects the ensemble of simulations, whereas spatial and temporal covariances are estimated with our method."

6. Systematic errors in the models affecting the nighttime build-up are due to different problems. First of all, the vertical resolution should be the first limitation to investigate. The first vertical layer is situated at 20m high, too low to represent the vertical structure close to the surface. Second, nocturnal boundary layer conditions usually neutral are not well parameterized. An ensemble of simulations considering this issue could study its sensitivity. Third, the surface conditions are also affecting the energy budget that drives the dynamics, especially in our case where the surface model is coupled online to the atmospheric model. Water content and vegetation description errors induce an important part of the nocturnal transport error. As we pointed out in the paper, modifying the parametrization leads to consider different models, and makes the interpretation of the results harder. Parameters were estimated thanks to several dynamical tests and changing one of them could induce some inconsistencies in different situations. We are now trying to increase the vertical resolution and to use different description of the surface layer dynamics to improve the surface flux estimates.

Minor comments:

Introduction: We added three papers: Gerbig et al. (2003), Stephens et al. (2007), and Law et al. (2008).

Section 2.1: The singular vectors are combined linearly to generate the 10 perturbed simulations. Number of singular vectors is important to explore the complete structure of the model sensitivity, but they are not directly associated to one simulation. Number of simulations determine the spread of the ensemble, whereas the number of singular vectors determines the final representativity of the variance structures.

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Section 2.2: We explained the different terms of the equation.

Conclusions: We thank the referee. The period of the day was changed.

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