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Interactive comment on "Applying a new integrated mass-flux adjustment filter in rapid update cycling of convective-scale data assimilation for the COSMO-model (v5.07)" *by* Yuefei Zeng et al.

Yuefei Zeng et al.

yuefei.zeng@lmu.de

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To Reviewer 1

The paper introduced a new integrated mass-flux adjustment filter in Ensemble Kalman Filter (EnKF) to correct the analyzed wind field and suppress the unphysical increase of the surface pressure tendency in the analysis. An idealized supercell storm was used to examine the performance of the new filter. The root-mean-square error, ensemble spread, cool pool, surface pressure tendency, and supercell detection index were investigated. The results show that the new filter slightly degrades the analysis accuracy, which is still acceptable, but this filter alleviates the imbalance problem caused by the data assimilation. The forecast skill in terms of fractions skill scores (FSSs) of reflectiv- ity composite and the number of spurious convection is improved after using the new filter. This paper is interesting and well-written. I recommend that the paper should be accepted with Minor revisions and I include my few comments below.

Answer: Thank you very much for your kind acknowledgment of our work.

Specific comments L5-6: Readers who are not familiar with dynamic problems associated with data assimilation may be confused with the words: "suppress the increase of the surface pressure tendency in the analysis". Please spend a bit more words on why the increase of the surface pressure tendency in the analysis should be suppressed.

Answer: We rephrased the sentence as "it considerably diminishes spurious mass-flux divergence as well as the high the surface pressure tendency and thus results in more dynamically balanced analysis states".

L63-66: Why exclude the vertical mass flux?

Answer: We are not sure if we understand the question exactly. The use of the integrated mass flux for the filter is valid due to the analogy of the integrated mass-flux divergence to the surface pressure tendency as shown in Eq. 2, and the vertical mass flux does not appear in Eq. 2. Furthermore, as mentioned in the outlook, we will extend the filter to the vertical, i.e., correcting the wind field by analyzed mass-flux from level to level, which may be more accurate and more balanced but computationally more expensive.

L76-78: How to understand the words: "a realistic integrated mass-flux divergence if this variable is directly updated?" Do authors mean that using the cross-variable covariance between observations (e.g., HX of Vr and HX of Z) and the integrated mass-flux divergence to update? If so, please directly tell readers how to update the integrated mass-flux divergence and think about whether the word "realistic" is suitable here, because an accurate analysis depends on the accuracy of covariance which is not also reliable in EnKF especially in the first few cycles.

Answer: Note that the integrated mass-flux divergence filter does not correct the wind field via the cross covariance and it is a post-processing method. Eqs. 1-3 are equations of LETKF Hunt et al. (2007). It can be seen that, adding variables such as integrated mass-flux divergence which do not go to the observation forward operator does not change $\tilde{\mathbf{P}}_k^a$ and does not change $\overline{\mathbf{w}}_k^a$, therefore, it has no influence on the other variables of $\overline{\mathbf{x}}_k^a$. But on the other hand, the changes in variables like u that go to the observation forward operator will change the integrated mass-flux divergence through cross correlations. Moreover, the wording of "realistic" is correct because the integrated mass-flux divergence derived from the wind field of the analysis is usually significantly larger than that derived from background. But if treating integrated mass-flux divergence as a variable and using the LETKF to update it, the resulted integrated mass-flux divergence of the analysis is slightly larger than that of the background as seen in Fig. 5. We rephrased as "we use the fact that we can soundly estimate integrated mass-flux divergence via LETKF directly through cross correlations".

$$\overline{\mathbf{x}}_k^a = \overline{\mathbf{x}}_k^f + \mathbf{X}_k^f \overline{\mathbf{w}}_k^a \tag{1}$$

$$\overline{\mathbf{w}}_k^a = \tilde{\mathbf{P}}_k^a \mathbf{Y}_k^f \mathbf{R}_k^{-1} \left(\mathbf{y}_k^o - \overline{\mathbf{y}}_k^f \right) \quad (2)$$

$$\tilde{\mathbf{P}}_k^a = \left[(N-1)\mathbf{I} + \mathbf{Y}_k^{f^T} \mathbf{R}_k^{-1} \mathbf{Y}_k^f \right]^{-1} \quad (3)$$

L91-92: Please tell the physical meaning of this function. Why design the function in the form of Eq. (5).

Answer: The function f should distribute the integrated adjustment over the column to correct the wind field. We assume the corrections should be larger at places where the analysis increments of the wind field are larger. We rephrased the sentence.

L105: Please briefly list some key points of configurations in Zeng et al (2020b)

Answer: We added "the analytical profile is defined by two parameters u_infty and q_v_max. u_infty is the upper wind in the troposphere, which determines the entire wind profile and scales the wind shear, and q_v_max determines the humidity profile and a higher q_v_max results in stronger instability of the atmosphere".

L115: If possible, add a plot of radar locations or list the radar locations. I am not sure whether radars observed the entire storm, especially at low levels. Without low level airflow information, the analysis of integration mass-flux divergence may not be accurate as expected.

Answer: The plot of radar locations is added (see Figure 1). As seen, it covers the propagation path of storms within the study period.

L124: Environment errors were introduced? A brief description of the difference between profiles will be appreciated.

Answer: Done

L126: Why is 0.75?

Answer: The coefficient is tuned to 0.75 for KENDA system (Schrafff et. al 2016). We rephrased it.

Figure 3: It seems that the imbalance mass flux mainly affects the first few cycles. The amplitudes of surface pressure tendency in E_VrZ_6m are not much larger than those in E_VrZ_6m_f after the first few cycles, except for those after 14:30 UTC. If stop using the mass-flux filter after the first several cycles, what will happen? In addition, please adjust the position of the legend in Figure 3b (the right one).

Answer: High frequency convective-scale data assimilation continually accumulates noises and imbalances through cycling, stoping using the filter will certainly lead to larger increase in surface pressure tendency. We changed the layout of the legend.

Figure 4: The loss of accuracy is OK, but it is better to concern the relatively rapid increase of forecast error in u just after 14 UTC. Reducing mass-flux error does not certainly ensure a lower forecast error? Additionally, in some analyses after 14 UTC, the RMSE of qr becomes larger after analysis. It seems that the cross-variable error covariance is not so reliable after using the mass-flux filter. A bit more discussion on the potential negative impact of using the new filter will be helpful for others who would like to adopt the filter.

Answer: The filter is a post-processing approach that does not consider the accuracy of model states while reducing the imbalance. An idea that takes those both regards into account is to impose the filter as a weak constraint to the cost function of EnKF algorithms. We added texts for this in the outlook.

Figure 5: It is a good result, but what is the physical relationship between the mass-flux filter and this better cold pool? Is it valid in most cases or is case dependent?

Answer: Strongly rotating updraft (i.e., mesocyclone) and cold pool are important features of supercells. The application of the filter could possibly deteriorate those features as it causes some accuracy loss to model states. However, Figure 6 shows that the filter generates a comparable cold pool as without using the filter.

L180-181: Please directly point out what is better. The areas of spurious convection are smaller? The environment perturbation may also introduce spurious convections. How to extract the contribution of the new mass-flux filter from the final forecast results?

Answer: We added "Results indicate that the application of the filter reduces the dynamical imbalance of analyses, which slows down the error growth of model states in free forecasts and thus improves the forecast skills. This is in line with Zeng and Janjic (2016); Zeng et al. (2017)".

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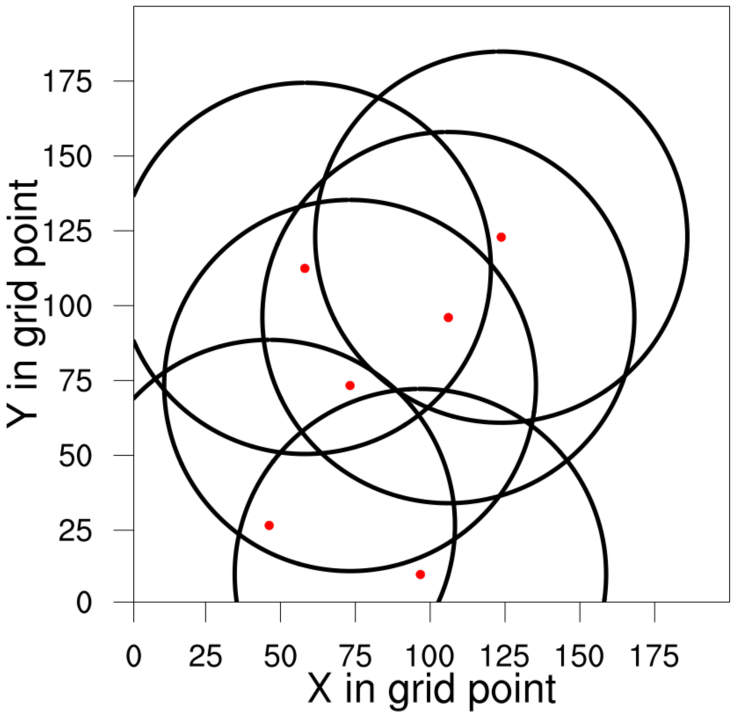

Fig. 1. Distribution of radar network (six radars), expressed by the range of PPI (Plan Position Indicator) scan at the elevation $0.5ˆ{\circ}$

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Discussion paper