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Nonlinear Processes in Geophysics
Discussions
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Interactive comment on "Improving the ensemble transform Kalman filter using a second-order Taylor approximation of the nonlinear observation operator" *by* G. Wu et al.

Anonymous Referee #2

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General comments

This paper addresses some issues associated with Ensemble Transform Kalman Filter (ETKF) in applications to nonlinear observation operators. In particular, the paper proposes the use of second-order Taylor expansion in approximation of nonlinear observation operator to improve error covariance inflation in ETKF. The proposed methodology is applied to the Lorenz 40-variable model.

Overall, the paper clearly describes the improvements and demonstrates the benefit of introducing the second order information. Most of the mathematical description is focused on the improvements of the error covariance inflation methodology for the

ETKF.

Specific comments

1) Introduction: Although the title of the paper indicates it is focusing on the ETKF applications and improvements, it would be beneficial to describe the treatment of nonlinearity in general ensemble data assimilation outside of ETKF, including the Maximum Likelihood Ensemble Filter (Zupanski 2005) and the particle filters (van Leeuwen 2009). Also, the proposed methodology implicitly assumes the use of incremental minimization (e.g. a form of truncated Newton method), with outer and inner loops. This should be clearly stated, since this is only one possible approach to iterative minimization, with many more efficient methods available in mathematical optimization and control theory.

2) Impact of higher order nonlinear Taylor approximation: The utility of the nonlinear difference between observation operators (e.g., Eq.(7)) is not adequately presented. For general nonlinear or even non-smooth radiative transfer operators (Steward et al. 2012), the utility of higher-order elements in Taylor expansion may be questionable. Also, the development of the second order term may be time consuming and difficult in case of complex observation operators, and this aspect should also be discussed. I believe that the paper would benefit if these issues are also addressed in discussion.

3) Realistic applications: Since the ultimate goal of data assimilation is to be applied with realistic high-dimensional systems and observations, the conclusion should include some discussion of the outlooks into the applicability of the proposed improvements of ETKF in realistic situations.

References:

van Leeuwen, P. J., 2009: Particle Filtering in Geophysical Systems. Mon. Wea. Rev., 137, 4089–4114.

Steward, J. L., I. M. Navon, M. Zupanski, and N. Karmitsa, 2012: Impact of Non-Smooth Observation Operators on Variational and Sequential Data Assimilation for a

Limited-Area Shallow-Water Equation Model. Quart. J. Roy. Meteorol. Soc., 138, 323-339.

Zupanski, M., 2005: Maximum Likelihood Ensemble Filter: Theoretical Aspects. Mon. Wea. Rev., 133, 1710–1726.

Technical corrections

4) Abstract, line 8: This statement is not correct. Iterative minimization with advanced Hessian preconditioning would require very few minimization iterations (1-2).

5) Introduction, p.544, L.24: "... satellite radiance data . . ."

6) Introduction, p.546, L.3-5: Not clear what the sentence wants to say. Given that degrees of freedom of the ensemble forecast error covariance are governed by the number of ensembles, it is only natural to define the minimization space in the ensemble domain. The way to deal with insufficient degrees of freedom is to consider hybrid variational-ensemble error covariance, which is outside of the paper's considerations.

7) Introduction, p.547, L.7-10: Linearization typically doubles the number of operations, and thus increases the computational cost (e.g. del(x*y)=x*del(y)+y*del(x)). This should also be taken into account when discussing the cost.

8) Section 2.2.2: Mathematical derivation should be followed by a brief verbal description of the meaning and implications of equations, as this is the main novelty of this paper.

9) p. 562, L.13: Although it is true that most observation operators are localized, there are some that are not. How would this impact the computation of the second order term?

Interactive comment on Nonlin. Processes Geophys. Discuss., 1, 543, 2014.