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Plain Language Summary: As an alternative to the particle filter for high-dimensional systems, a nonlinear data assimilation method based on deep learning is proposed, in which deep neural networks (DNNs) are locally embedded in the ensemble Kalman filter (EnKF). This method is named the deep learning-ensemble Kalman filter (DL-EnKF). Results of data assimilation experiments using three versions of the Lorenz 96 model and an EnKF with a small ensemble show that the DL-EnKF is superior to the EnKF in terms of accuracy in strongly nonlinear regimes.

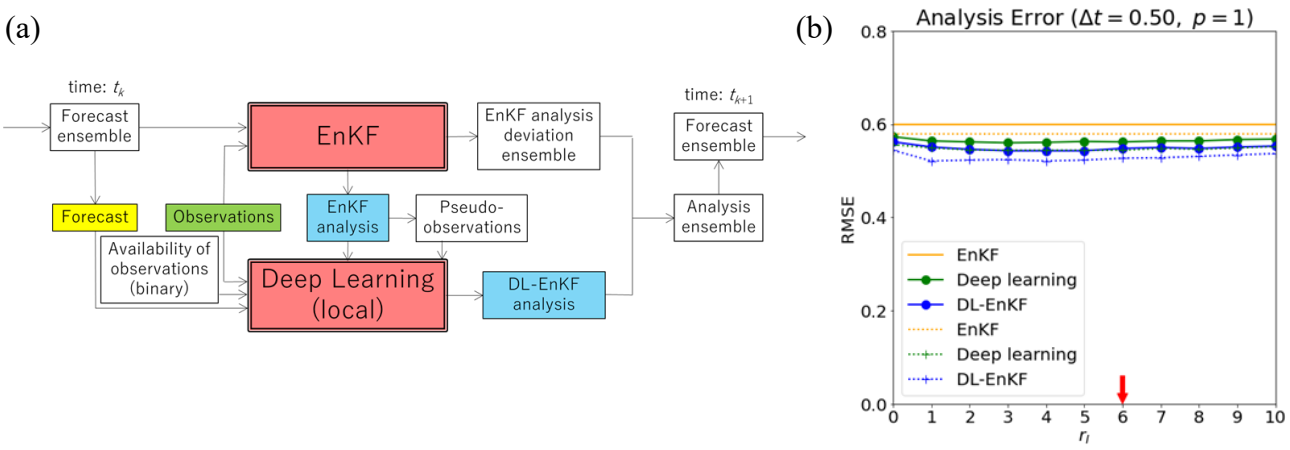

Figure 1. (a) Workflow of the DL-EnKF. Observational data for which the input nodes are absent in DNNs are assimilated by the EnKF part and their information is provided to the deep learning part through the EnKF analysis. (b) Comparison of the RMSEs of EnKF (orange lines), deep learning (green lines), and DL-EnKF (blue lines) for an imperfect model scenario (solid lines) and a perfect model scenario (broken lines). The RMSEs are plotted against the input radius of DNNs, and a red arrow indicates the optimal localization radius of EnKF (unit: grid intervals). The standard deviation of observation error, time interval between observations, and probability of observations are 1, 0.50, and 1, respectively.

- The DL-EnKF analysis is more accurate than the output of deep learning because of positive feedback in assimilation cycles.
- Even if the target of training is an EnKF analysis with a large ensemble or a simulation by an imperfect model, the improvement introduced by the DL-EnKF is not very different from the case where the target of training is the true state.
- The inclusion of EnKF analysis in the inputs of DNNs not only improves the accuracy of deep learning but also reduces the optimal number of nodes per hidden layer and the dependence of the accuracy on the input radius.