

Tsuyuki, T., F. Kawasaki, and S. Kotsuki, 2025: Four-dimensional variational data assimilation using the second-order incremental approach and quantum annealing. *J. Meteor. Soc. Japan*, **103**, <http://doi.org/10.2151/jmsj.2025-032>.

Plain Language Summary: Unlike ensemble Kalman filters (EnKFs), four-dimensional variational data assimilation (4DVar) can be applied to strongly nonlinear regimes in data assimilation. A problem with 4DVar is that the cost function may have multiple minima, and that it can be difficult to find the global minimum using a gradient descent (GD) method. This study proposes a method of searching for the global minimum through combining a second-order incremental approach and quantum annealing (QA); when GD has failed to reach the global minimum, QA provides guidance on where to explore in state space by minimizing an approximated cost function.

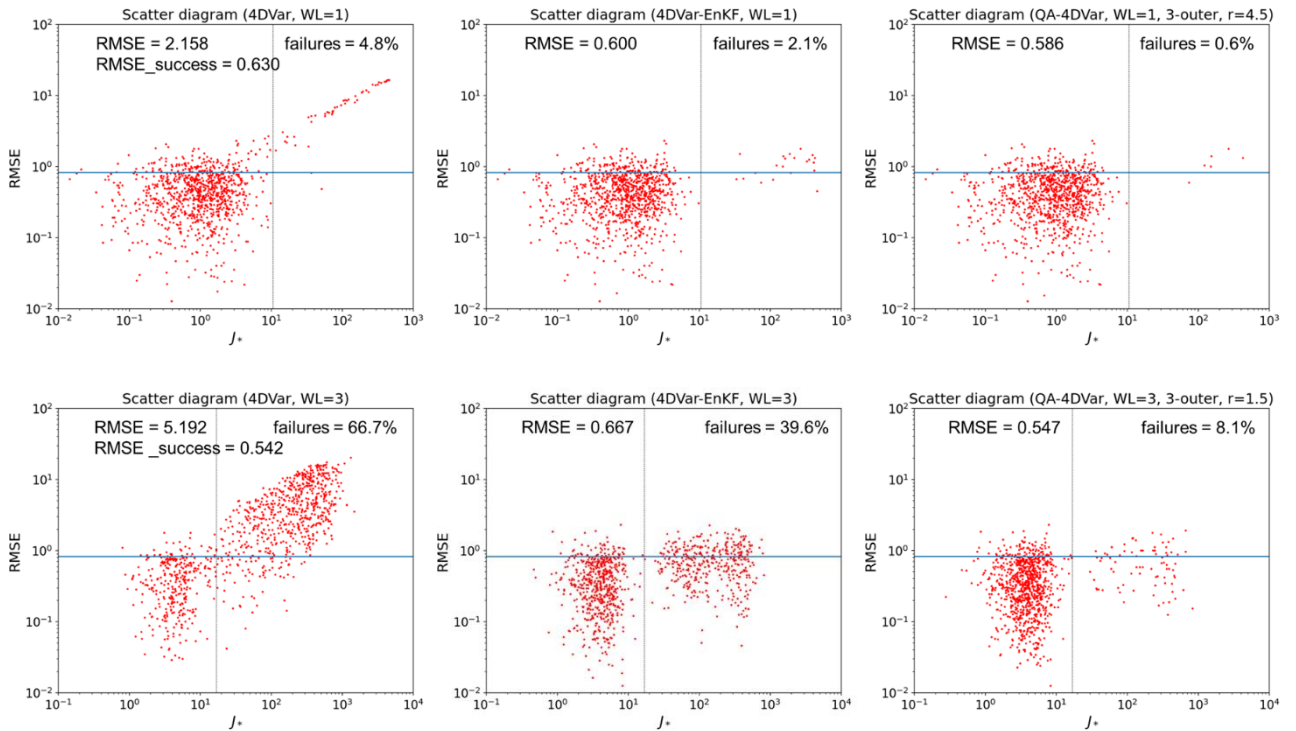


Fig. 1. Scatter diagrams of the convergence value of the cost function J_* and analysis RMSE in data assimilation experiments using the Lorenz-63 model. Upper and lower panels are for a window length of 1 and 3, respectively, for 4DVar (left), 4DVar with EnKF replacement (middle), and 4DVar with EnKF replacement and QA (proposed method, right). The time interval of observations is set to 1. Blue line indicates mean analysis RMSE of EnKF. When J_* exceeds the dotted line, GD is assumed to have failed to reach the global minimum.

- The proposed method significantly reduced the frequency of falling into local minima.
- The benefit of extending the length of the assimilation window was realized by the proposed method even in strongly nonlinear regimes.
- Data assimilation experiments in which simulated annealing (SA) was adopted instead of QA showed that QA exhibited comparable or better performance compared to SA.