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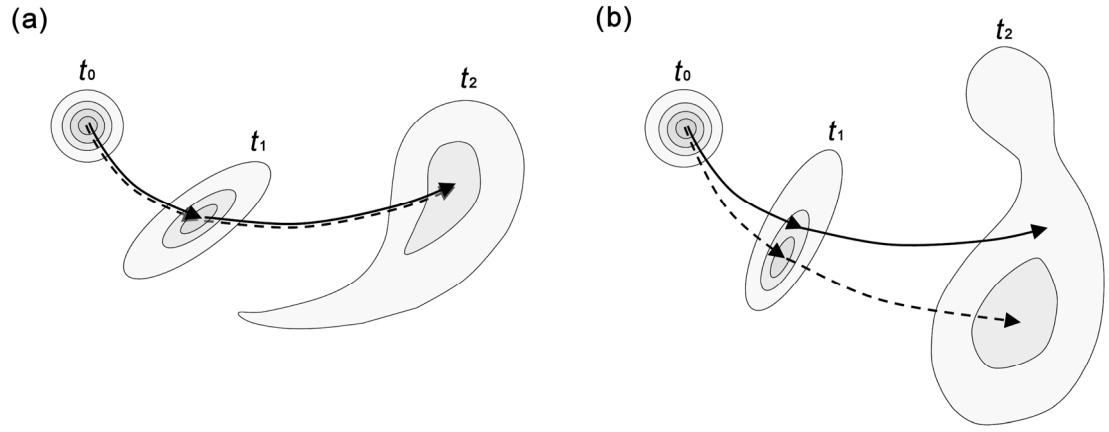

Fig. 1. Evolution of PDFs in phase space for (a) a deterministic nonlinear system that satisfies the divergence condition and (b) a deterministic nonlinear system that does not. Thick solid lines are the trajectories of deterministic prediction starting from the modes of the PDFs.

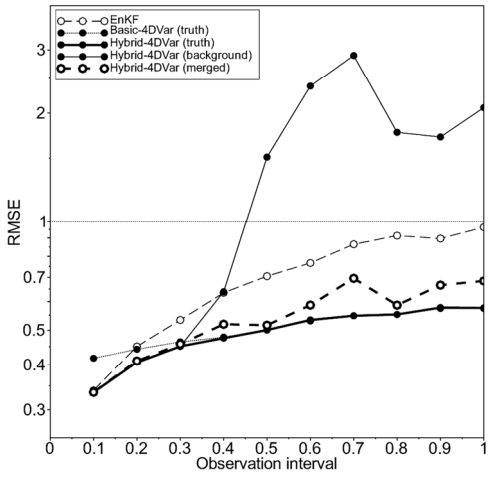

Fig. 2. RMSEs of analyses by EnKF, basic-4DVar of the truth cycle, hybrid-4DVar of the truth cycle, background cycle, and merged cycle for the Lorenz-63 model. The horizontal line is the standard deviation of observation error, and the abscissa is the time interval of observational data.

- Conditions for the forecast state starting from the mode of a PDF of the state variables to remain sufficiently close to the mode of the PDF at forecast time are derived under assumption of a small forecast error.
- A new formulation of 4DVar is presented, which reveals that a non-Gaussian prior PDF which evolves according to the Liouville equation is implicitly used in 4DVar.
- Results from data assimilation experiments with toy models demonstrate that 4DVar cycles with some modifications outperform EnKF cycles in terms of the accuracy of analysis in strong nonlinearity as well as in weak nonlinearity.