Development of an ensemble Kalman filter-based regional ocean data assimilation system

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With enhanced observations by satellites and Argo profiling floats, various ocean data assimilation systems based on the optimal interpolation (OI), three- and four-dimensional variational methods (3D- and 4D-Var), and Kalman filter-based methods have been developed, providing high-quality analysis datasets assimilating the observations. So far, a reanalysis dataset was produced with the ensemble Kalman filter (EnKF) (Sakov et al. 2012), and three EnKF-based ocean data assimilation systems have been developed (Miyazawa et al. 2012; Penny et al. 2013; Baduru et al. 2019).
A geostationary satellite Himawari-8 has been observing sea surface temperatures at short time intervals of 10 minutes since July 2015 (Bessho et al. 2016; Kurihara et al. 2016). Assimilating such high-frequency observations would be a challenge because initial shocks by high-frequency gravity waves might result in a degradation of the analysis. To mitigate the problem, the existing EnKF-based systems inflate observation errors and assimilate observations with long intervals of several days. It is important to explore how to use frequent observations with an EnKF.
The following two methods have been proposed to reduce the initial shocks: (i) an incremental analysis update (IAU; Bloom et al. 1996) to apply the analysis increments gradually during the model integration, and (ii) relaxation-to-prior methods (Zhang et al. 2004; Whitaker and Hamill 2012) to inflate the underdispersive ensemble by relaxing the reduction of the ensemble spread at the analysis step. In this study, we investigate the importance of the IAU and relaxation methods for an EnKF-based ocean data assimilation system.
We developed an ocean data assimilation system consisting of the Stony Brook Parallel Ocean Model (sbPOM; Jordi and Wang 2012) and the local ensemble transform Kalman filter (LETKF; Hunt et al. 2007). The sbPOM covers the northwest Pacific region [118°–180°E, 10°–50°N] with a horizontal resolution of 0.25° and 50 sigma layers. Using the LETKF, we assimilate satellite sea surface temperature, salinity, and height, and in-situ temperature and salinity at a 1-day interval. We perform six sensitivity experiments from July 2015 to December 2016 with combinations of three covariance inflation schemes [multiplicative inflation (MULT), relaxation to prior perturbations (RTPP), and relaxation to prior spread (RTPS)] with/without the IAU. The analysis is evaluated using a nonlinear balance equation to estimate dynamical imbalance (Zhang et al. 2001; Shibuya et al. 2015), and spatial correlation coefficients and root mean square deviation relative to observed sea surface height (Ducet et al. 2000).
The results show that the combination of RTPP/RTPS with the IAU demonstrates the best performance. Experiments with RTPP/RTPS without the IAU show less dynamical balance and reproducibility. MULT experiments are unstable regardless of the use of the IAU because of numerical instability. Therefore, the combination of RTPP/RTPS and the IAU plays an important role in maintaining dynamical balance and providing high-quality analysis. The results imply further possibilities to improve atmospheric data assimilation systems with MULT and to implement the EnKF into other models in which gravity waves have substantial contributions.

Keywords: Ocean data assimilation, Ensemble Kalman filter, Relaxation to prior, Incremental analysis update, Himawari-8, Dynamical balance

