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Improved ensemble-mean forecast skills of ENSO events by a zero-mean stochastic model-error model of an intermediate coupled model

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To perform an ensemble-based ENSO probabilistic forecast, the crucial issue is to design a reliable ensemble prediction strategy that should include the major uncertainties of a forecast system. In this study, we developed a new general ensemble perturbation technique to improve the ensemble-mean predictive skill of forecasting El Niño Southern Oscillation (ENSO) using an intermediate coupled model (ICM). The model uncertainties are first estimated and analyzed from the ensemble Kalman filter (EnKF) analysis results through assimilating observed sea surface temperature (SST; which is the dominate model variable in the ICM). Then, based on the pre-analyzed properties (i.e. the spatial patterns, the temporal lagged correlations, the long-term averages) of the model errors, a zero-mean stochastic model-error model is developed to mainly represent the model uncertainties induced by some important physical processes missed in the coupled model (i.e. explicit air-sea heat interactions, stochastic atmospheric forcing/MJO, extra-tropical cooling and warming, Indian Ocean Dipole mode, the feedback of cloud and the salinity effect, etc.). Each member of an ensemble forecast is perturbed by the stochastic model-error model at each step during the 12-month forecast process, and the stochastical perturbations are added into the modeled physical fields to mimic the presence of these high-frequency stochastic noises and model biases and their effect on the predictability of the coupled system.

The impacts of stochastic model-error perturbations on ENSO deterministic predictions are examined by performing two sets of 18-yr retrospective forecast experiments. The two forecast schemes are differentiated by whether they considered the model stochastic perturbations, with both initialized by the ensemble-mean analysis states from EnKF. The comparison results suggest that the stochastic model-error perturbations have significant and positive impacts on improving the ensemble-mean prediction skills during the entire 12-month forecast process. Because the nonlinear feature of the coupled model can induce the nonlinear growth of the added stochastic model errors with model integration, especially through amending the forecasted horizontal advection and the vertical temperature gradient, the positive effects of model-error perturbations can increase for longer lead time.