Investigating Sources of Error in Numerical Weather Forecasting with an Observing System Simulation Experiment

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It is difficult to evaluate the quality of background, analysis, and short-range forecast errors in numerical weather prediction models due to a lack of independent data for verification. A tool that can potentially be used for examination of these errors is an Observing System Simulation Experiment (OSSE), where the real atmosphere is replaced by a simulation in which the true state of the entire atmosphere is known. In the OSSE framework, errors in the data assimilation process and forecasts can be explicitly calculated, allowing examination of sources of error in a sophisticated modeling system.

An OSSE framework has been developed at the National Aeronautics and Space Administration Global Modeling and Assimilation Office (NASA/GMAO). The performance of the GMAO OSSE has been extensively validated against real observational data to ensure that the behavior of the OSSE is similar to reality in terms of the statistics of observation innovations, analysis increments, forecast skill, and adjoint-estimated observation impacts.

In the simulated reality of the OSSE, aspects of the data assimilation and modeling systems that are hard to modify in the real world may be easily altered in highly controlled or idealized scenarios. A series of experiments is performed in order to examine the relative impacts of observation error, model error, and initial condition error on the evolution of forecast error and on the effectiveness of the data assimilation system. The magnitude of observation errors is varied from low to high, and the global observing network is tested both in a standard realistic configuration and in an idealized global network of high-quality sounding observations. An ‘identical twin’ case employing a perfect model scenario was also developed to explore the case of no model error.

Observation errors are found to have significant impact on the variance of analysis increments, and can contribute to a degradation of the analysis quality in comparison to the background state if there is a mismatch between the actual error variances and those assumed by the data assimilation system. The smallest analysis errors are achieved in the case of the idealized observing network. The case of the idealized observing network also features the largest total amount of ‘work’ done by observations during cycling of the data assimilation system.

It is found that model error is a major contributor to the evolution of forecast skill. The forecast skill in cases with no model error showed an improvement in skill compared to cases with model error equivalent to a decrease in forecast lead time of two days in the extratropics and four days in the tropics. In comparison, when the initial condition error is greatly reduced but with model error included, the forecast error increases rapidly during the first 24-36 hours of integration, and the improvement in forecast skill is only equivalent to a reduction in forecast lead time of one day in the extratropics and two days in the tropics.