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ERROR GROWTH AND ADAPTIVE OBSERVATIONS

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1. INTRODUCTION

The goal of adaptive observations is to decrease the forecast error by placing observations in regions where additional observations are expected to improve a forecast of interest. These regions may be considered "sensitive" in the sense that changes to the initial conditions in these regions are expected to have a larger effect on a particular measure of forecast skill than changes in other regions.

Gradient sensitivity and singular vectors (SVs) are the tools that have been proposed as adaptive observation strategies. Because both gradient sensitivities and SVs are calculated using the adjoint of the tangent linear propagator of the model, gradient sensitivities and SVs are called "*adjoint-based sensitivities*". Most of the studies that have used adjoint-based sensitivities to identify sensitive regions for adaptive observations have assumed that the actual error which projects onto the adjoint-based sensitivities contributes to a significant fraction of the forecast error (Gelaro et al. 1999). Since the structure and evolution of the actual analysis error is not known in real situations, it is not clear how valid this assumption is. In this study, the structure and evolution of both analysis error and adjoint-based sensitivities are compared following a typical synoptic event under the perfect model assumption.

The results show that the projection of the evolving SV onto the forecast error increases during the SV's evolution, which suggests the possibility of using the evolved SV for adaptive observations. In order to test the feasibility of the evolved SV strategy for adaptive observations, the evolved SV strategy along with several other strategies is implemented in observation system simulation experiments (OSSEs). The average reduction in forecast error produced by each of the strategies is evaluated and compared. The OSSEs are run using the National Center for Atmospheric Research (NCAR) quasigeostrophic (QG) model. The adjoint model developed by Kim (2002) is used to calculate the adjoint-based sensitivities.

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2. GENERATION OF EXPERIMENTAL STATES

A case is selected from a set of states generated from nonlinear integrations of the QG model. We identify this arbitrary state as the *true state*. During the spin-up time, a *model state* is initially generated by modifying the true state with random noise and subsequently assimilating simulated rawinsonde observations every 12 hours using the three-dimensional variational data assimilation scheme developed by Morss (1999). Once the truth and model states are generated at the beginning time of each experiment, the states at subsequent times are generated by integrating both states forward for 48 hours using the QG model. The *analysis error* (*forecast error*) is calculated by the difference between true state and model state at the beginning time (at subsequent times). Details of the experimental overview is shown in Kim et al. (2002).

3. COMPARISON OF ERROR AND ADJOINT-BASED SENSITIVITIES

In order to quantify the degree of similarity between the error and adjoint-based sensitivities, the projections of each of these fields onto the others is calculated. The evolutions of the projection of the analysis error onto the adjoint-based sensitivities are shown in Fig. 1. That the projection of the analysis error onto the adjoint-based sensitivities at t = 0h is small, implies that only a small fraction of the analysis error contributes to a significant fraction of the forecast error at t = 48h. The evolution of the normalized projection of the error onto the SV suggests the "evolved SV" as an adaptive observation strategy.

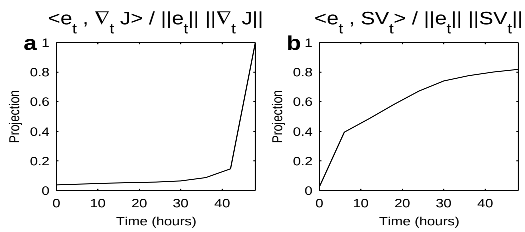

FIG. 1. Time evolution of the normalized projection of the analysis error onto (a) the gradient sensitivity and (b) the SV for the entire domain. All the normalized projections are obtained by averaging over 25 cases.

4. IMPACT OF ADAPTIVE OBSERVATIONS

Figure 2a shows the RMS forecast errors associated with 16 fixed (adaptive) observation locations at the indicated times for the nonadaptive and four adaptive strategies. The forecast errors of the various adaptive strategies are less than that of the fixed observation strategy. The forecast errors produced by the evolved SV strategies are smaller than those produced by the adjoint-based strategies. Figure 2b shows the RMS forecast errors for 32 fixed (adaptive) observation locations. In contrast to the sparse observation case, the adaptive strategies do not reduce error significantly more than the fixed observation strategy. Even in this case, the evolved SV strategies perform better than the adjoint-based strategies.

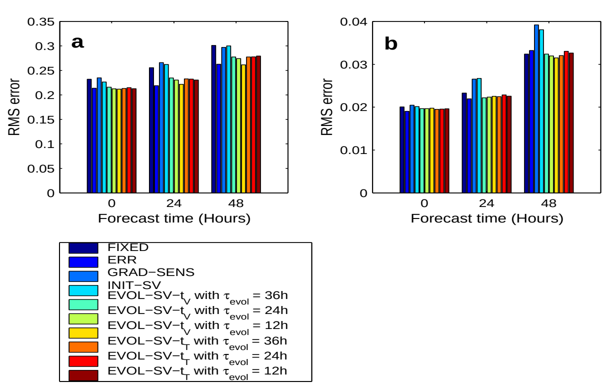

FIG. 2. RMS forecast errors produced by fixed observations and by adaptive strategies based on the error, the gradient sensitivity, the initial SV, and the evolved SV, for the following observing networks: (a) 16 fixed (adaptive) observations and (b) 32 fixed (adaptive) observations. The order of the legend corresponds to the order of bars in each plot.

5. SUMMARY AND DISCUSSION

The impact of adaptive strategies varies with the observation density. For a small number of observations, several of the adaptive strategies tested reduce forecast error more than the nonadaptive strategy. For a large number of observations, it is more difficult to reduce forecast errors using adaptive observations. The evolved SV strategies perform as well as or better than the adjoint-based strategies for both observation densities.

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