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SYNOPTIC INTERPRETATION OF ADJOINT-DERIVED FORECAST SENSITIVITIES

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1. INTRODUCTION

A sensitivity study involves calculating how a particular function of a numerical weather prediction (NWP) model forecast state (called the response function, *R*) changes with respect to changes in the model control variables (i.e., initial or boundary conditions). This calculation allows one to evaluate how changes in the initial model state will affect the response function at the final time, provided the assumption of linear dynamics is valid. The adjoint of a NWP model is a tool used to calculate these sensitivities. Adjoint-derived sensitivities have also been used for targeted and adaptive observing strategies, in which the sensitivity fields define those portions of the atmosphere in which modifications to the model initial state from the assimilation of additional observations would have maximum effect on the subsequent forecast. For a response function defined as a measure of the forecast error, adjoint-based sensitivity fields can be useful for investigating the possible causes of a poor numerical forecast provided that the model error is small. Recently, it has been proposed that adjoint-derived sensitivities may also be used with differences between operational analyses to generate an ensemble of forecasts for a particular forecast aspect (Kleist et al., 2001).

In spite of the many uses for adjoint-derived sensitivities, there are few published synoptic interpretations of sensitivity fields. There are no extant studies that establish the relationship between the sensitivity gradients to the larger scale flow regime, nor the dependence and/or relationship between sensitivity fields calculated from response functions which might be expected to be related synoptically. The objectives of this presentation are to:

- interpret forecast sensitivities calculated for basic states derived from NWP forward integrations initialized from different, yet nearly identical analyses;
- compare sensitivities calculated from a set of response functions, some of which may be related synoptically; and
- suggest relevant response functions for adjoint-based adaptive targeting strategies

Section 2 of this preprint contains a brief discussion of the modeling system used. Section 3 contains an example and brief interpretation of a sensitivity calculation for a particular synoptic case. A summary of the basic questions to be addressed in this and future work can be found in section 4.

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2. MODEL CONFIGURATION

Sensitivity calculations were performed using the MM5 Adjoint Modeling System (Zou et al., 1997). The Tangent Linear Model and the corresponding adjoint of the MM5 include simple physical parameterizations:

- Horizontal and vertical diffusion
- Dry convective adjustment
- Bulk aerodynamic surface flux parameterization
- Kuo and Grell cumulus parameterization schemes

All of the sensitivities to be described were calculated with this system by integrating the adjoint model "backwards in time" (without considering moisture) about a moist basic state derived from an MM5 non-linear forecast which utilizes more sophisticated physics.

3. CASE STUDY

An example of an event in which forecast sensitivity calculations may be useful is the 24-25 January 2000 East Coast Cyclone. The event was noteworthy as operational NWP model guidance was particularly poor. With this event, forecasts of the cyclone and its associated precipitation were too far to the east. However, as lead times decreased, the forecasted cyclone intensity and location improved, while forecast guidance of precipitation remained poor.

For this case, we are particularly interested in understanding why improvements in the forecasted cyclone (position and intensity) were not necessarily associated with improvements in the precipitation/vertical motion forecast. We consider four relevant response functions for this case:

- R_1: Energy-weighted forecast error (in a region encompassing the cyclone at verification time).
- R_2: Circulation about a box (the same region as the energy-weighted error calculation)
- R_3: 700 hPa frontogenesis (in a region extending from central North Carolina to New Jersey)
- R_4: Upward vertical motion in a region similar to that defined for response function R_3.

Response functions R_1 and R_2 were chosen because they are measures of cyclone intensity, while R_3 and R_4 were chosen as they are related to the dynamics governing the precipitation. Synoptically, we anticipate that the response function for frontogenesis should be related to that for the vertical motion, as frontogenesis and vertical motion are related through the Sawyer-Eliassen equation. The gradients of these response functions with respect to initial conditions for a 36h forecast (valid at 1200 UTC 25 January 2000) were calculated.

The sensitivity gradients for the four response functions are all maximized in the lower troposphere in a region of large baroclinity (Fig. 1), downstream of an

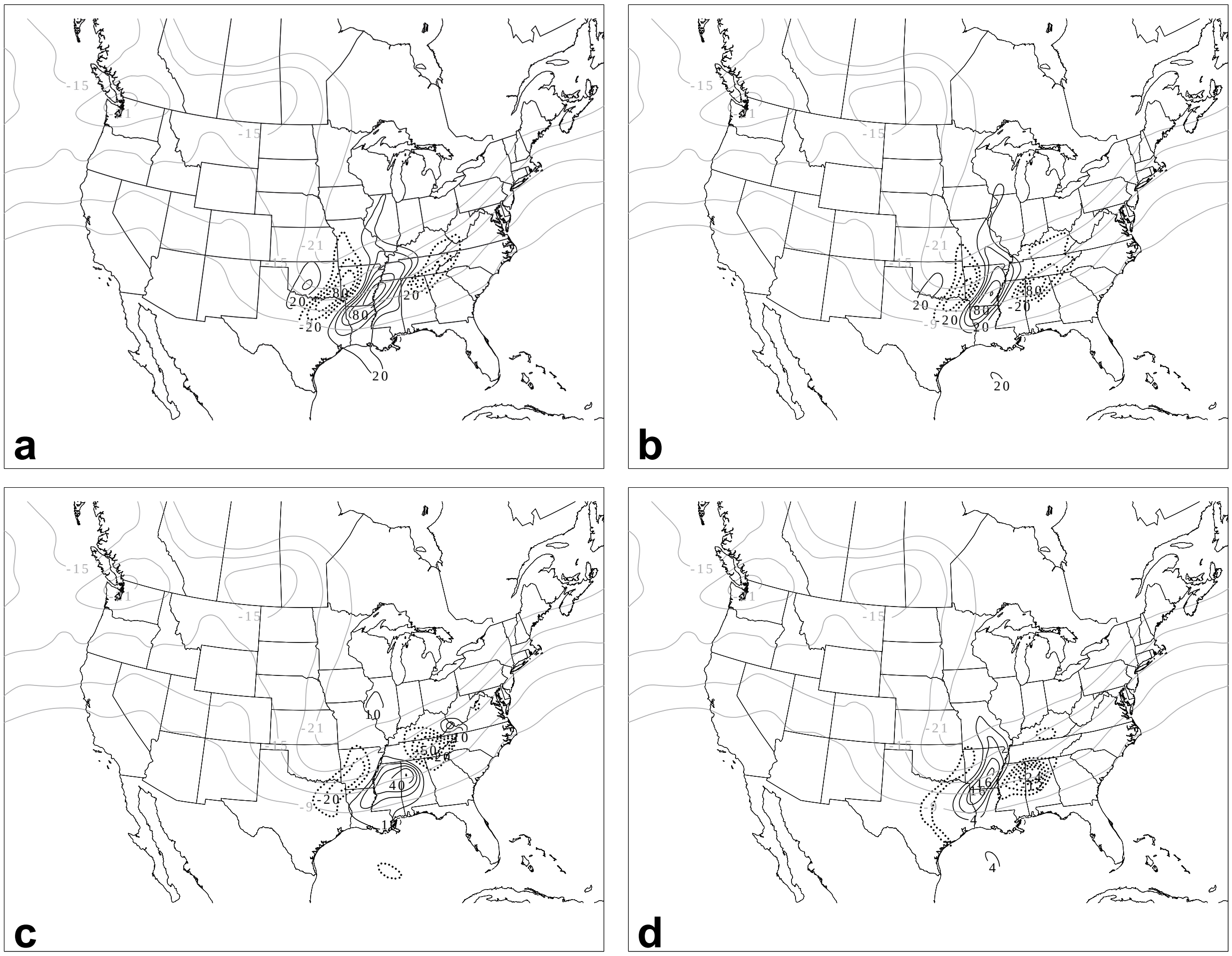

Figure 1. Sensitivity gradients (36h) valid at 0000 UTC 24 January 2000 for the initial distribution of temperature at 600 hPa for (a) -$\boldsymbol{R_1}$ (cint =20x10^{-1} Jkg^{-1}K^{-1}), (b) $\boldsymbol{R_2}$ (cint =20x10^{2} s^{-1}K^{-1}), (c) $\boldsymbol{R_3}$ (cint =10x10^{-16} Km^{-2}s^{-1}), and (d) $\boldsymbol{R_4}$ (cint =4x10^{-3} ms^{-1}K^{-1}). For the sensitivity gradients, the zero line has been omitted, positive values are solid and negative values are dashed. Also contoured in all four panels is the initial distribution of temperature (0000 UTC 24 January 2000) at 600 hPa (cint=3^{o}C, between -21 ^{o}C and -9 ^{o}C).

upper trough (not shown). Of the four sensitivity gradients, gradients of R_1 and R_2 (Figs. 1a and b) are most similar: both indicate that perturbations in temperature in the sensitive regions will lead to a reduction of the forecast error and a more intense vortical circulation (Note, that for this interpretation and for a direct comparison, the gradient in Fig. 1a has been multiplied by negative one). This is consistent with the facts that both R_1 and R_2 are measures of the cyclone intensity and that much of the forecast error in the region selected is due to the poor forecast of the cyclone. However, there are significant differences, with these gradients, when the response functions for frontogenesis and vertical motion are considered. One obvious difference is the large positive (negative) extrema over Mississippi/Alabama for the R_3 (R_4) gradients. It is counterintuitive that placing a positive temperature perturbation at 600 hPa in this location will lead to an increase in the forecasted frontogenesis, but a decrease in the forecasted vertical velocities (in the domain defined for the response functions). This is just one example of inconsistencies that may be observed when considering a variety of response functions.

4. FUTURE WORK

This work is part of a larger project aimed at understanding the characteristics and sensitivity to initial conditions of short-range NWP errors. More sensitivity studies will be performed to better understand the characteristics of forecast sensitivity, including further research and interpretation of the January 2000 case as well as the investigation of other cases of interest. In addition, near real-time forecast sensitivity calculations are found at http://helios.aos.wisc.edu.

5. REFERENCES

Kleist, D., M. Morgan, and G. Postel, 2001: Use of adjoint-derived sensitivities in constructing an ensemble of forecasts, this volume.

Zou, X., F. Vandenberghe, M. Pondeca, and Y.-H. Kuo, 1997: Introduction to adjoint techniques and the MM5 adjoint modeling system. NCAR Technical Note, NCAR/TN-435+STR, 117 pp.

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