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Very short range forecasting of precipitation: Comparing NWP and extrapolation techniques

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1. INTRODUCTION

Presently, the state-of-the-science technique for very short range forecasts of convection involves spatial extrapolation of existing radar echoes (sometimes called Nowcasting). These techniques are computationally inexpensive, however, their forecast skill rapidly decrease due to the fact that system evolution is typically not accounted for. An alternative technique is to assimilate stormscale data into a nonlinear Numerical Weather Prediction (NWP) model. In contrast to Nowcasting techniques, stormscale assimilation is computationally expensive and often difficult to code. However, since NWP models have the ability (in theory) to forecast system evolution, the technique has the potential to improve over Nowcasting methods.

At the National Center for Atmospheric Research we have been examining, over the last decade, the ability of NWP models to explicitly forecast convective storms in the very short range (typically 0-2 hours). The technique we have been using is four-dimensional variational assimilation (4DVar) of radar data into a cloudscale model. The goal of the present study is to perform a systematic comparison of stormscale NWP and Nowcasting methods for a number of convective cases from the midwest of the USA as part of the Regional Convective Weather Forecast (RCWF) program supported by the FAA.

2. 4DVAR TECHNIQUE

The system used to produce very short range convective forecasts is the Variational Doppler Radar Analysis System (VDRAS). Here, we briefly describe the method. The objective is to find an initial state that upon model integration produces output fields that fit the observations as well as a background field as closely as possible. The background field is typically valid at the initial time, whereas the observations can be spaced at any time throughout a specified time window.

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A cost function measuring the misfit between the model forecast and both the background field and observations of radial velocity, v_r^{obs} and rainwater q_r^{obs} (converted from reflectivity) is defined. Assuming that the observational errors are uncorrelated in space and time, the cost function, *J*, is given by:

$$J = \sum_{\sigma,\tau} \left[\ \eta_v (v_r - v_r^{obs})^2 + \eta_{q_r} (q_r - q_r^{obs})^2 \ \right] + J_b + J_p \qquad (1.1)$$

where σ represents the spatial domain and τ represents the temporal domain. The quantities η_v and η_{q_r} are weighting coefficients that represent the inverse of the observational error (squared) of the radial velocity and rainwater data, respectively. The radial velocity v_r is calculated from the Cartesian velocity components (*u, v, w*) through:

$$v_r = u\frac{x - x_r}{r} + v\frac{y - y_r}{r} + (w - w_t)\frac{z - z_r}{r} \qquad (1.2)$$

where w_t is the fallspeed of precipitation.

The term J_b in (1.1) represents the fit to the background field. In this work, the background field is given by a previous, short-term, forecast (typically 20 minutes) valid at the initial time. The term J_p represents a penalty term that seeks to minimize excessive temporal and spatial variations.

The numerical model that is used in the 4DVar technique is an anelastic, nonhydrostatic, storm-scale model. The prognostic variables include the three velocity components, the perturbation liquid-water potential temperature, rainwater mixing ratio, and total water mixing ratio.

The system was run over the RCWF domain and assimilated data from 5 WSR-88D Doppler radars (KLOT, KIWX, KILX, KIND, and KILN). The gridspacing of the analysis is 5 km in the horizontal and 500 m in the vertical. A 12 minute assimilation window was used, which meant that 3 volumes of data were assimilated for a radar in storm mode and 2 volumes in "clear-air" mode. Because of computational constraints, only a one-hour forecast was produced during realtime operations. (The analysis plus forecast cycle took on average 35 minutes.) After the experiment, we selected a number of cases of strong convection and produced a series of 2-hour forecasts for each case.

3. RESULTS

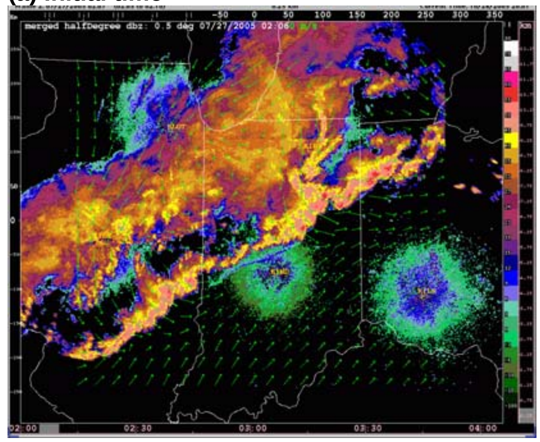
Here, we present results from three case studies of strong convection in the RCWF domain (July 27, August 4, and August 12, 2005). Figures 1 through 3 show the reflectivity field at (a) initial time (b) t = 1 hour, and (c) t= 2 hours for the three case studies. (The initial time for each case is given in the figure caption). The VDRAS forecast of reflectivity (at z = 250 meters, reflectivity threshold of 20 dBZ) at t = 1 and 2 hours is shown by the white contour on panels (b) and (c), respectively. Finally, the VDRAS forecast wind fields at z = 250 meters are shown by the green vectors.

We are currently performing a systematic verification of the one and two hour forecasts from VDRAS and comparing against extrapolation forecasts. Results will be presented at the Conference. As an initial test, we plan to first use traditional verification scores (r.m.s, threat score, etc.) on the rainwater forecasts. Recently, a number of new "object-based" methods for verifying forecasts of discrete fields, such as precipitation, have been developed and tested. These methods have shown a lot of promise for verifying forecasts in which precipitation develops during the forecast as they can account for spatial, and sometimes temporal, phase errors. However, in the present case, where the initial conditions of the forecast contain the correctly-located precipitation field, the traditional scores may still have some value.

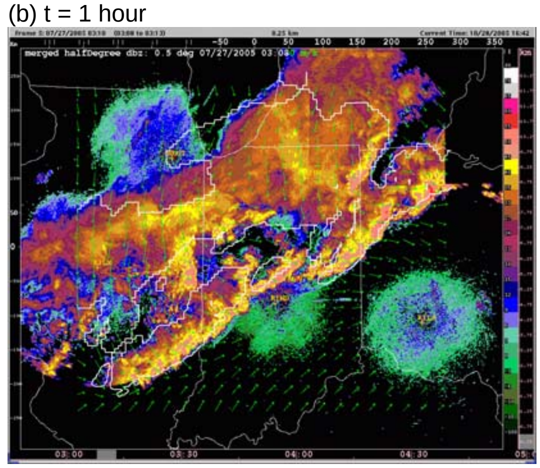
Qualitatively, it appears that the VDRAS forecasts capture system propagation quite well. It also forecasts the position of the leading-edge convergence very well (see in particular, Fig. 1(c)). However, to improve over extrapolation, the VDRAS forecasts need to capture some of the system evolution. There are indications that some of this evolution is being captured. For example, in the August 12th case, VDRAS correctly forecasts the decay of the cells ahead of the main line, as well as the solidification and strengthening of the cells in the center of the line. Finally, it should be noted that the benefit of VDRAS should become apparent in cases like August 12th, which exhibit significant cell growth and decay as well as variable cell-motion vectors, rather than cases of steady propagation where extrapolation forecasts do quite well.

July 27, 2005.

(a) Initial time



(b) t = 1 hour



(c) t = 2 hours

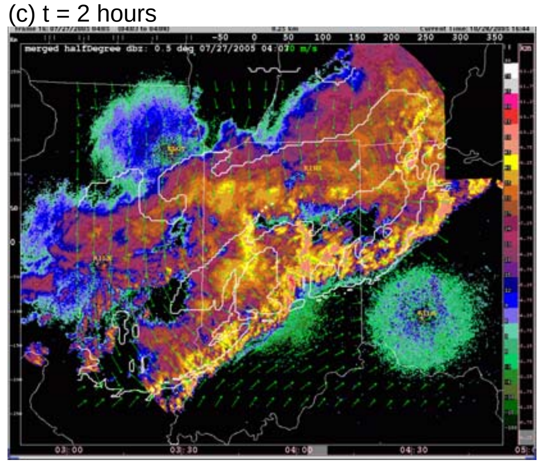


Figure 1. Mosaic reflectivity at (a) initial time = 0205 UTC, July 27th, 2005, (b) one hour later, and (c) two hours later. The VDRAS one and two hour forecasts are shown in (b) and (c), respectively, by the white contour at a threshold of 20 dBZ. VDRAS wind forecasts (z = 250m) are shown by the green vectors.

August 4, 2005

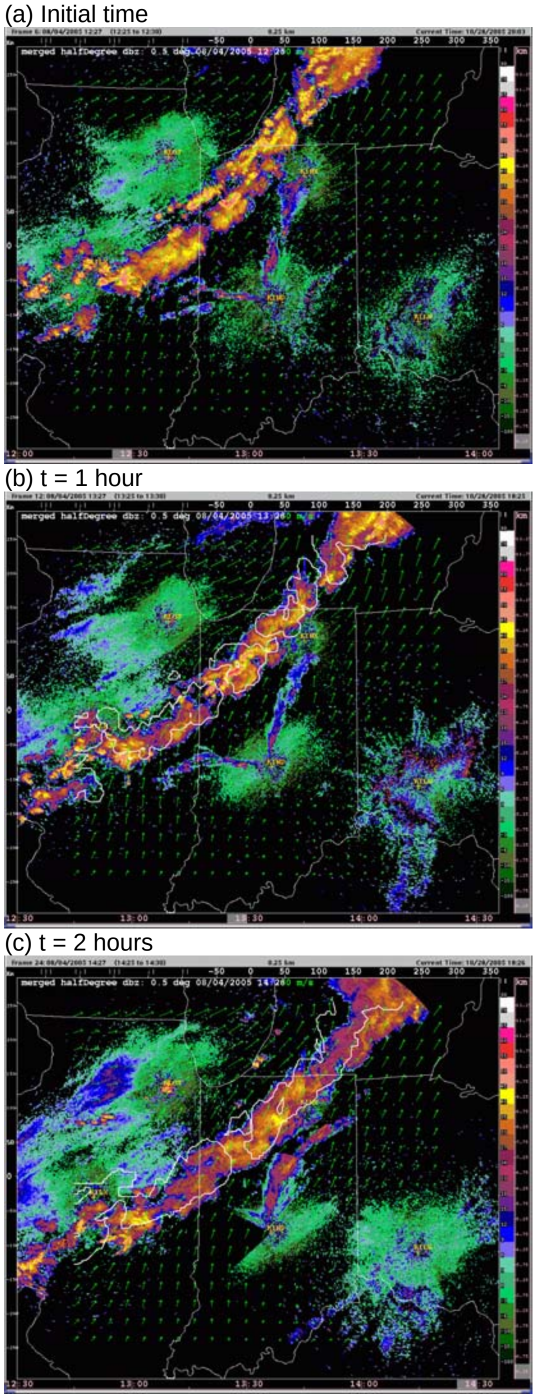


Figure 2. Same as Fig. 1 except at an initial time of 1225 UTC, August 4th, 2005.

August 12, 2005

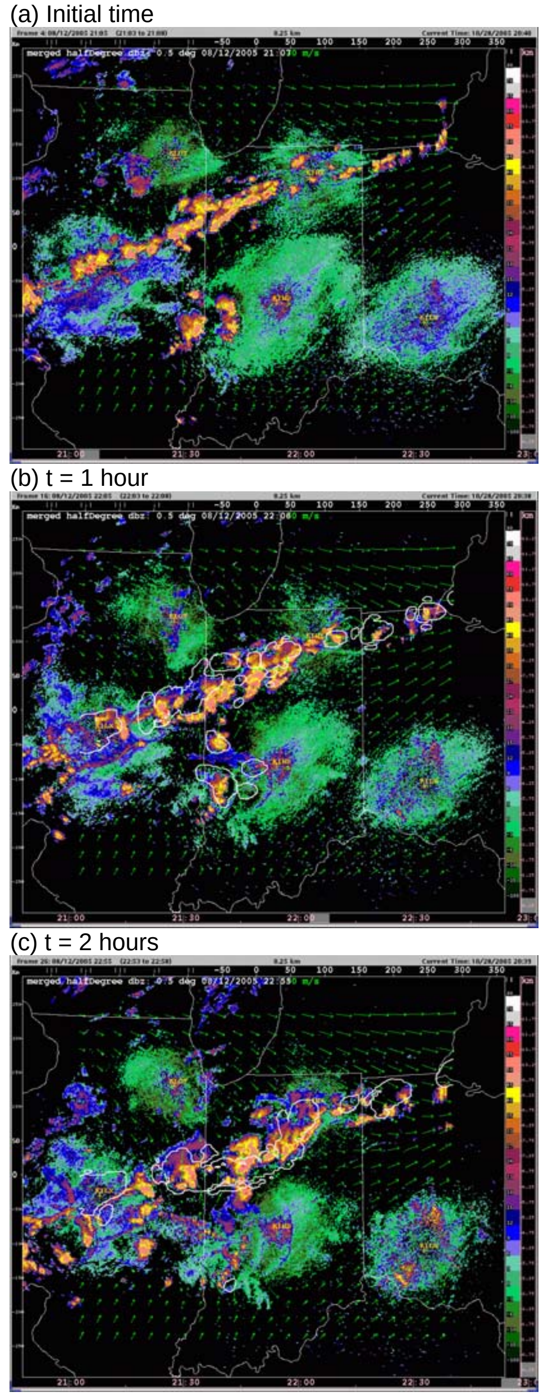


Figure 3. Same as Fig. 1 except at an initial time of 2105 UTC, August 12th, 2005.