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ON THE DYNAMICAL BASIS OF TARGETING WEATHER OBSERVATIONS

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1 MOTIVATION

The National Centers for Environmental Prediction/National Weather Service (NCEP/NWS) implemented an operational targeted weather observation program with the aim of reducing the risk of forecast failures in the prediction of severe winter storms with potentially large impact on society (Toth et al. 2002). At NCEP the Ensemble Transform Kalman-Filter (ETKF, Bishop et al. 2001; Majumdar et al. 2001) is used to determine the future observational time, t_o, and observational region from where extra observations taken at t_o are most likely to considerably reduce the error in the prediction of the selected storm at a future verification time, t_v ($t_v > t_o$).

While the forecast verification results (Szunyogh et al. 1999, 2000, 2002; Toth et al. 2000, 2002) have provided convincing evidence that the ETKF technique, and its predecessor the Ensemble Transform (ET) technique (Bishop and Toth 1999), are reliable practical tools to target observations, the underlying assumptions of these algorithms have not been rigorously tested. These assumptions are that (i) the analysis error covariance matrix can be well approximated by linearly combining a small ensemble of short-term forecasts valid at the future observational time, t_o, and (ii) the forecast error covariance matrix for the grid points within the verification region can be reasonably approximated by applying the same weights to the ensemble of forecasts valid at t_v. Given these assumptions, the ETKF technique provides an estimate of the forecast error variance reduction (formally, the reduction in the trace of the forecast error covariance matrix) due to the hypothetical extra observations. The main goal of this paper is to explore whether a small ensemble can represent the uncertainty in the dynamical evolution of the atmospheric flow both at observational and verification times. In other words, we ask: Does the atmosphere show finite-time local low-dimensional chaotic behavior in the targeted and the verification regions?

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2 BACKGROUND

To answer the question above we compute the Bred Vector (BV) dimension (Patil et al. 2001, 2002) for an experimental ensemble. This ensemble is a replica of the NCEP operational global ensemble, except that 15 pairs of independent bred vectors are generated instead of the operationally attainable five pairs. The BV-dimension measures the linear independence of the bred perturbations in a rectangular neighborhood (with about 1100 km edges) of each point. We note that the size of this region is comparable to the 1000 km radius disc used to define the potential targeting and verification regions at NCEP.

In this paper, the BV-dimension is computed based on the two components of the wind vector at the 300 hPa pressure level. This choice was made based on the results of Szunyogh (2000, 2002) et al., who argued that the impact of the targeted data was propagated from the Pacific to the Atlantic region by packets of short upper tropospheric Rossby waves, and that strong impact at the surface was observed where the wave packets reached regions of strong low level baroclinicity. More precisely, the influence of the targeted data propagated in a similar manner to an upper tropsopheric wave packet even if such wave packets were not present, but the atmospheric wave packet apparently helped the ETKF to find the dynamical relationship between two distant regions of the atmosphere. This process is demonstrated by Figures 1 and 2, in which the small crosses mark the dropsonde locations (panel a) and the circle marks the verification region (panel e) for a targeting case from the 2000 Winter Storm Reconnaissance program. In Figure 1 the packet envelope function, $A_{total}(x)$, is shown, where

$$A_{total}(x) = \sqrt{\frac{1}{2}\sum_{j} |A_{k_j}(x)|^2} \tag{1}$$

and the packet envelopes, $A_{k_j}(x)$, of the energetically dominant wavenumbers, (k_j; $4 \leq k_j \leq 9$), along the latitudes were demodulated by the Multiple Wavenumber Packet Identification (MWPI) algorithm (Zimin et al. 2002) assuming that the meridional wind component, $v(x)$, can be expressed as

$$v(x) \cong \sum_{k_j} A_{k_j}(x)\cos(k_j x + \phi_{k_j}). \tag{2}$$

This figure shows that the dropsonde observations targeted the tail of a strong atmospheric wave packet at observational time and that the verification region was also located at the tail of the eastward propagating wave packet at verification time, t_v. In order to show that the dropsonde signal propagated as a wave packet, the signal, $s(x)$, was also demodulated by substituting $s(x)$ for $v(x)$ in Equation 2. The signal, $s(x)$, is formally defined by the difference between a forecast that was initiated by assimilating all targeted and standard observations and a forecast that was initiated by assimilating only the standard observations. The results demonstrate that after an initial transient, which is not longer than 12 hours, the leading edge of the targeted data impact propagated with the speed of the atmospheric wave packet.

3 RESULTS

The BV-dimension shown in Figure 3 was computed based on the initial perturbations of the experimental ensemble. This figure shows that the the targeted observations were taken in a region where the BV dimension is about 2.5, which is extremely low considering that the largest possible value of the BV dimension for the given ensemble is 15. The region of local low-dimensionality propagates eastward and by the time it reaches the verification region it increases to 4-5. This example implies that there may be a close relationship between the success of the targeting programs (Toth et al., 2002) and the discovery that in localized geographical regions at the synoptic scales the atmosphere can behave as a local low-dimensional chaotic system (Patil et al., 2001). Furthermore, we conjecture that in the case of winter storms (intense extra-tropical cyclones) the low-dimensional behavior of the atmospheric dynamics is closely related to packets of short (wavenumber 4-9) Rossby waves and the energy conversion processes that generate these wave packets.

4 CONCLUDING REMARKS

The one example shown in this abstract is indicative, but not conclusive evidence that a close relationship exists between local low-dimensional behavior, short Rossby waves, and the propagation of targeted data impact. In our presentation we will show further results including a comprehensive analysis of all targeting cases from the WSR00 field program, and a statistical evaluation of the relationship between low-dimensional dynamics, Rossby waves, and local energy conversion processes.

ACKNOWLEDGEMENTS

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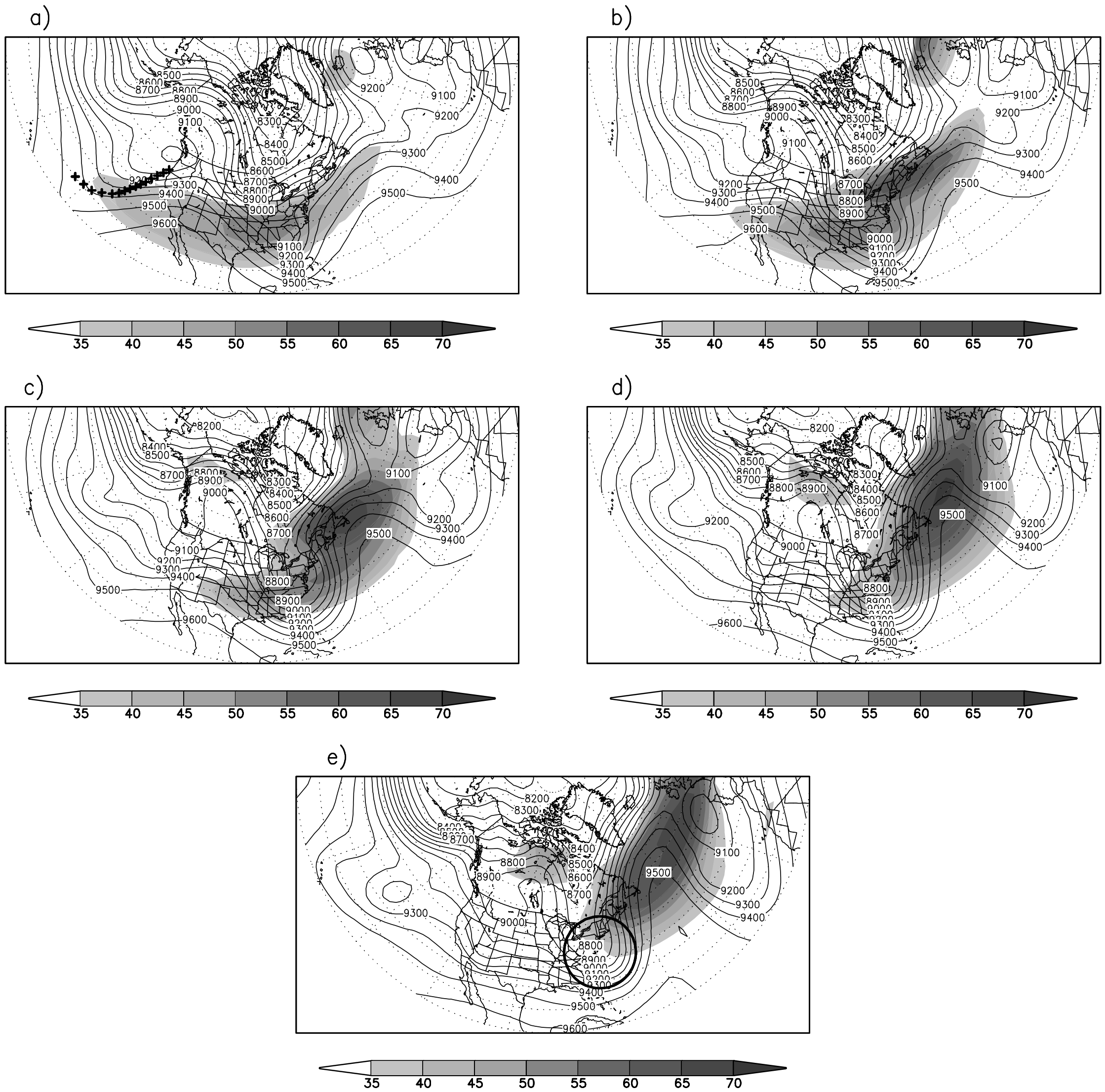

Figure 1: Shown by shades is the wave packet envelope function for the meridional component of the wind at 25 January 0000 UTC (a), at 25 January 1200 UTC (b), at 26 January 0000 UTC (c), at 26 January 1200 UTC (d), at 27 January 0000 UTC (e). Contour lines show the proper lead time analysis of the 300-hPa geopotential height. Crosses show the dropsonde locations and the ellipse in panel (e) shows the verification region for the targeting mission on 25 January 0000 UTC.

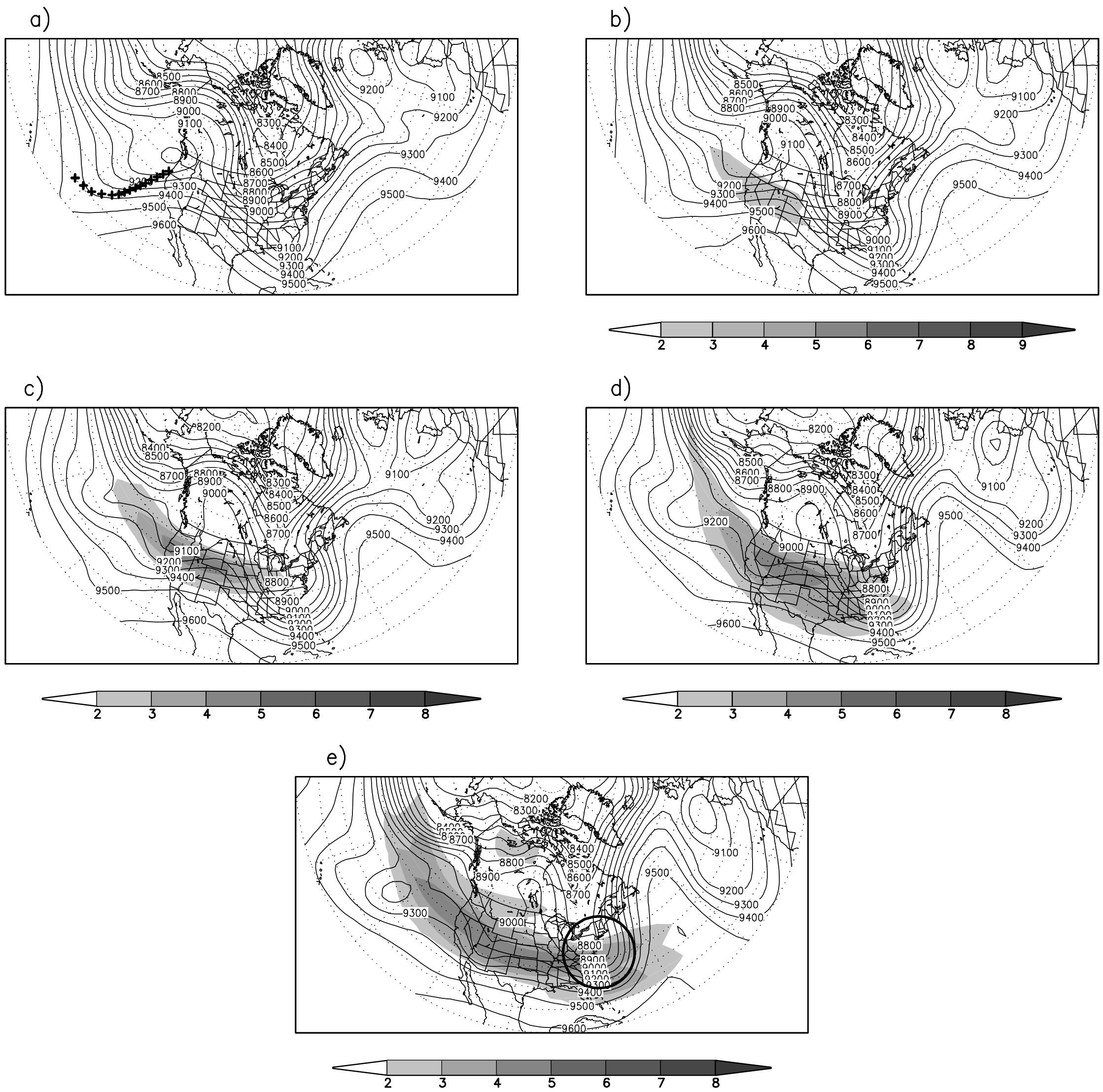

Figure 2: Same as Figure 1, except shown by shades is the packet envelope function for the signal.

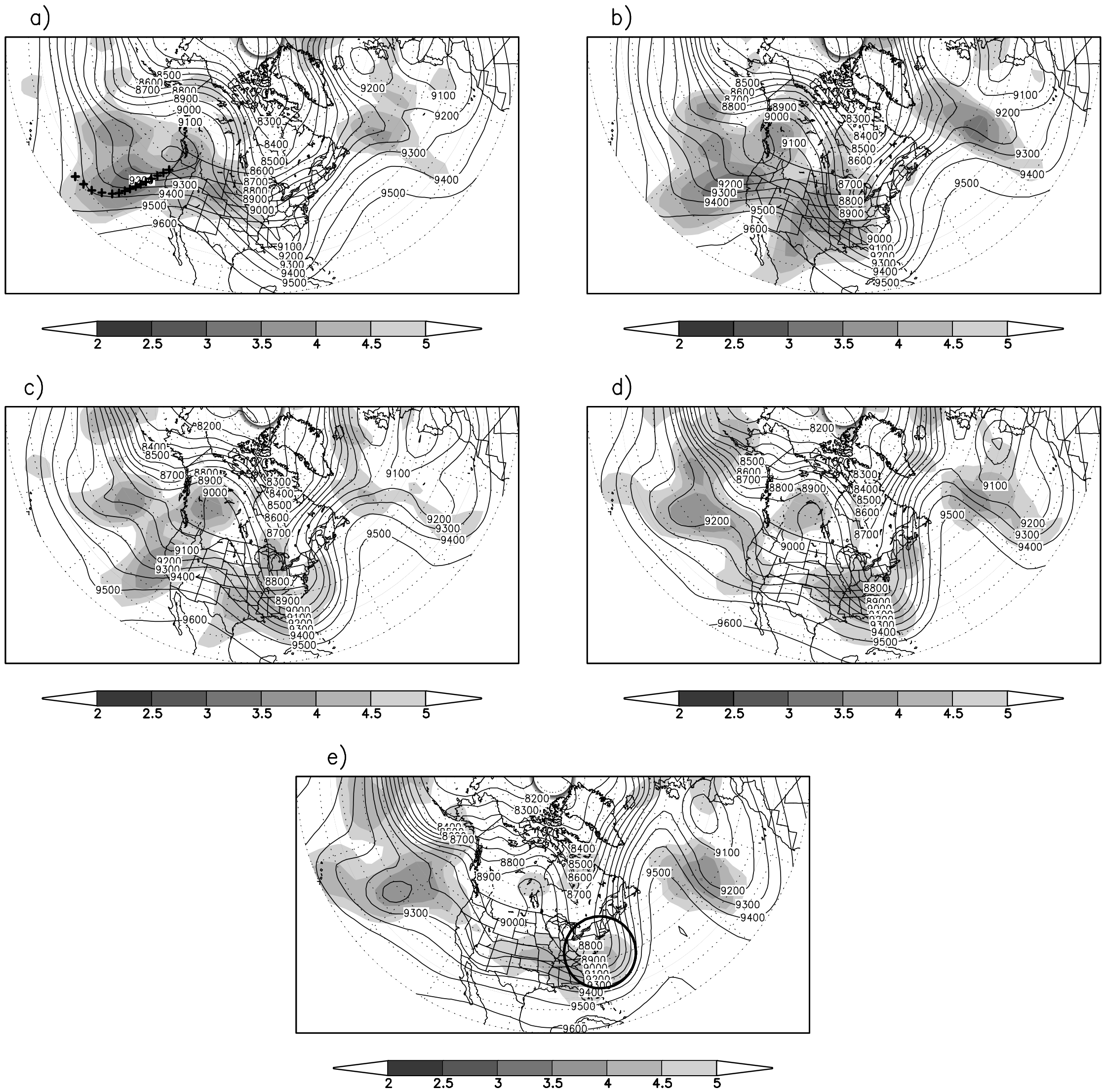

Figure 3: Shown by shades is the BV dimension based on the 15-pair experimental ensemble at 25 January 0000 UTC (a), at 25 January 1200 UTC (b), at 26 January 0000 UTC (c), at 26 January 1200 UTC (d), at 27 January 0000 UTC (e). Contour lines show the proper lead time analysis of the 300-hPa geopotential height. Crosses show the dropsonde locations and the ellipse in panel (e) shows the verification region for the targeting mission on 25 January 0000 UTC.

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