WRF Variational Data Assimilation Development at NCAR

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1. Introduction

In the previous year, data assimilation research and development for the WRF model has gathered pace, with a number of centers designing and testing both variational and ensemble-based algorithms for use with WRF. This abstract focuses on recent efforts to expand the capabilities of the community WRF 3/4D-Var system described in previous MM5/WRF workshops, and built on the research/operational MM5 3D-Var system described in Barker (2004).

2. Release of WRF 3D-Var Version 2.0

Included in version 2.0 (V2.0) of the WRF model, released in May 2004, is an upgraded version of the WRF 3D-Var system. The merging of WRF codes into a single release ensures compatibility between the assimilation and forecast components of WRF, and is a necessary step towards the development of a WRF 4D-Var system, in which model integrations are performed as part of the assimilation algorithm itself.

The major new capabilities of WRF 3D-Var (V2.0) include:

* Vertical velocity analysis increments - introduced as a strong constraint via the "Richardson equation".
* Radar 3D radial velocity assimilation - see Xiao et al (this volume).
* Buoy, and wind-profiler observation types.
* "Outer-loop" - to account for nonlinearities (e.g. in observation operators, balance constraints, etc.), and to permit "adaptive" quality control.
* Conjugate gradient (CG) minimization option - For purely linear "inner-loops", the CG method results in a substantial reduction in CPU time to convergence.
* Improved surface observation operators - In order to provide a more accurate calculation of observation minus first guess difference, vertical "interpolation" is performed using planetary boundary layer physics.
* "i=x, k=1 at bottom" - This time-consuming, but zero-impact change was performed to remove the MM5 "i=y" legacy of the previous code. As a result, WRF 3D-Var V2.0 requires an WRF2MM5 converter to run in MM5 applications,
* Inclusion of multiple background error (BE) covariance models - permits the comparison of alternative BE formulations whilst retaining the same observations.

The latter feature is used in studies of the impact of the BE model on details of the assimilation e.g. convergence, computational cost, analysis increments structure, etc. As a simple example, Fig. 1 shows the horizontal u-wind analysis increment response to a single surface u-wind observation which differs from the first guess forecast by 2m/s.

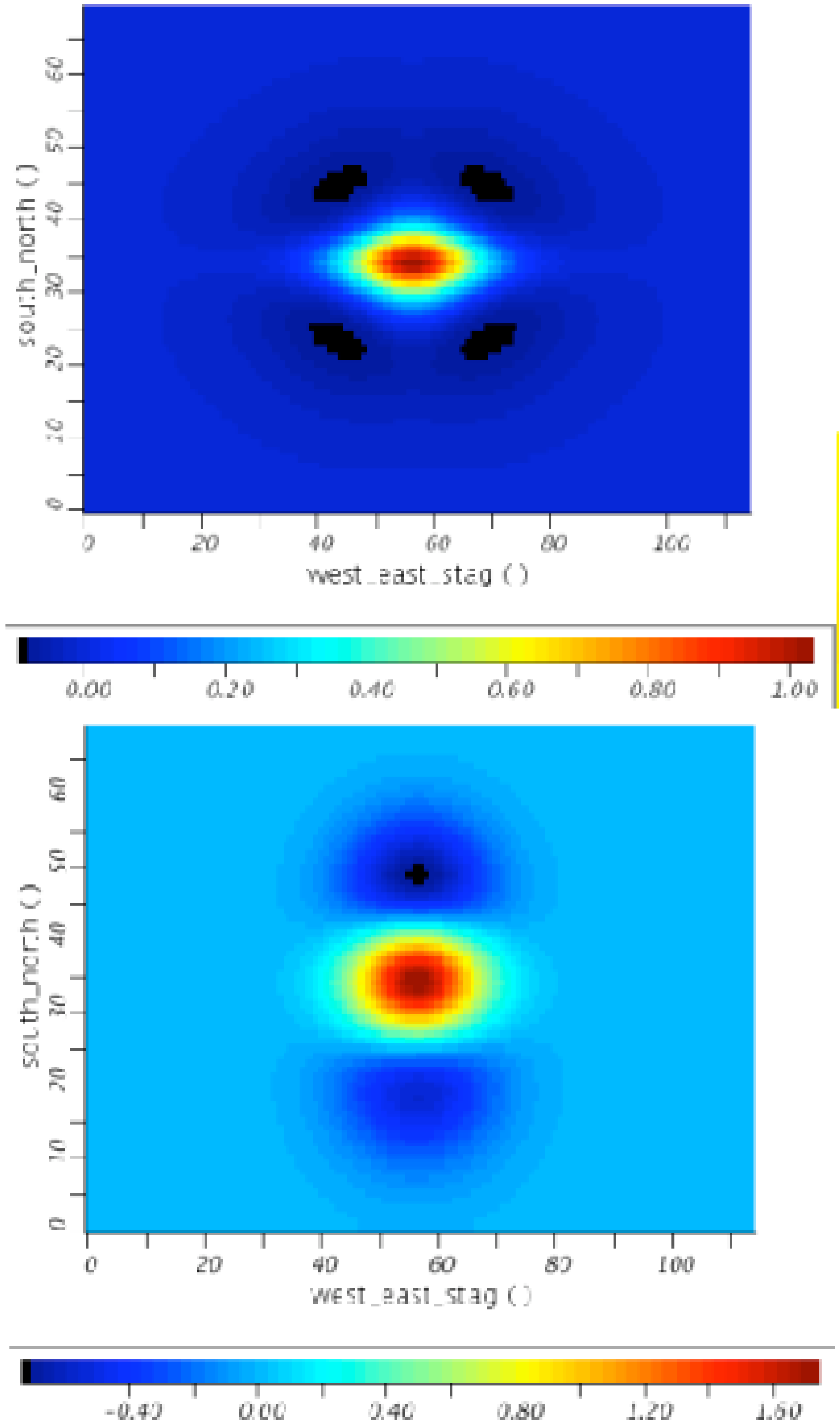

Fig. 1: U-Wind horizontal analysis increment structure due to the assimilation of a single u-wind observation (difference from first-guess = 2m/s). Upper (NCAR/UKMO BE model), lower (NCEP BE model).

The upper panel shows the 3D-Var response using the NCAR/UKMO BE model (recursive filters (RFs) in horizontal, eigenvector decomposition in the vertical, and dynamical balance constraint). The lower panel shows the equivalent analysis increments using the NCEP BE model (RFs in both horizontal and vertical, and statistical balance constraint). Qualitatively, the horizontal increments appear similar. The size of maximum increment, the vertical structure (not shown), and computational cost differ somewhat (the latter due to efficient data compression in the EOF decomposition). Further work is planned to assess the impact of alternate strategies to implement flow-dependent covariances, and also on an ensemble-based calculation of forecast error covariances to replace the "NMC-method" (Parrish and Derber 1992).

3. WRF 3D-Var/WRF Forecast Verification

In order to satify the major design requirements of WRF 3D-Var (accuracy, efficiency, flexibility, portability, robustness, and ease of use), verification of WRF 3D-Var requires a large suite of diagnostics. Many data assimilation diagnostics, e.g. first-guess/analysis fit to observation statistics (mean/rms, probability distribution, etc.), quality control rejection rates, variational cost function diagnostics, computational cost etc. can reveal much information on the performance of the assimilation. To many users however, the ultimate verification is the accuracy of NWP forecasts integrated from the analysis. Building on previous efforts to verify MM5 forecasts initialized with WRF 3D-Var, WRF forecast verification is now being performed in a number of applications in both "cold-start" and full cycling "warm-start" mode.

Fig. 2 shows 12-hour forecast verification against rawinsonde observations in a 40km CONUS application of WRF for a 10-day period in January 2002. Numerous experiments are shown including "SI" (integrate WRF from interpolated NCEP GFS analysis), "C-3DVAR" (cold-start WRF 3D-Var using SI as first guess), and "12h-CYC" (12-hourly cycling of WRF 3D-Var/WRF taking only lateral boundary conditions from the GFS). For temperature, there is a positive impact of the C-3DVAR reanalysis compared to the SI control, whereas ther is a neutral impact on wind verification scores. Although not a clean experiment (first guess and observation errors are correlated, and some observations may be assimilated twice) this is a promising result for mesoscale applications that feed off the global analysis, but do not have details of the observations contained therein. It also gives confidence that the WRF 3D-Var system is performing satisfactorily.

The 12-hourly cycling experiment "12h-CYC" verifies less well than the cold-starting application (mean deterioration ~0.25K, 0.5m/s). This is not completely unexpected, given that only those conventional observations available to NCAR's MM5 real-time datafeed have been assimilated in these experiments - significant omissions include automated aircraft observations (AMDARS/ACARS), particular mesonets, and satellite radiance data. A second limitation of the cycling experiment is that observations are only available every 12 hours in contrast to the 6 hourly updating of the NCEP GFS. Both these limitations contribute towards the deterioration of the cycling forecast relative to the cold-starting application. These results highlight the importance of complete, qualitycontrolled observation datasets to permit testing of the full capabilities of the WRF 3D-Var system. Future work will concentrate on producing these datesets, and testing sensitivity of WRF forecast scores to details of the assimilation (e.g. observation impact studies, alternative BE formulations, etc.)

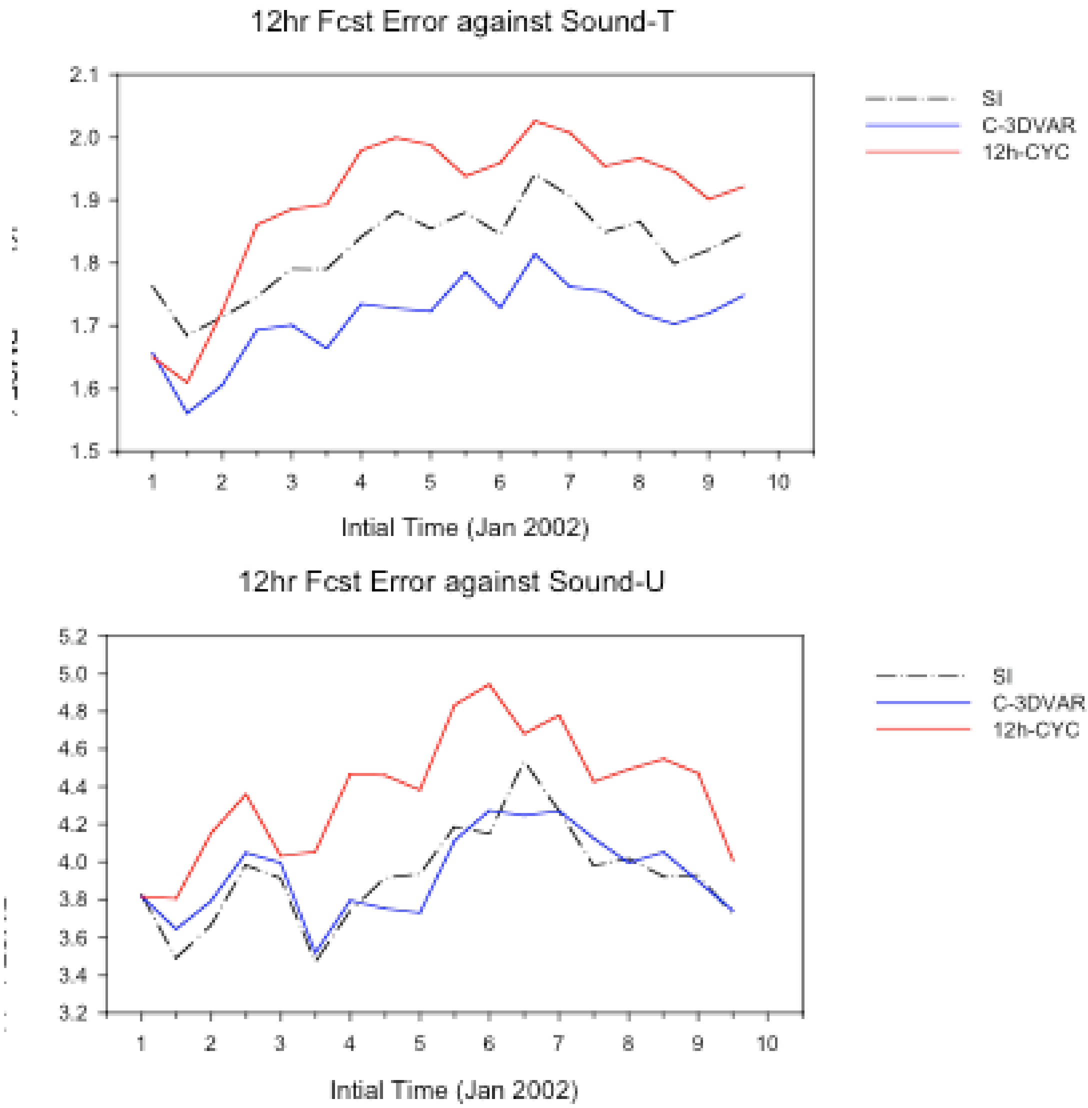

Fig. 2: 12-hour forecast verification against CONUS radiosondes for the various WRF 3D-Var/WRF experiments described in the text: temperature (above - K), and u-wind (below - m/s).

4. Summary and Conclusions

The recently released WRF 3D-Var (V2.0) contains a number of significant improvements, and has been tested in a variety of domains (e.g. CONUS, middle-east, Asia, and Antarctica). Initial forecast verification is promising but highlights the need for concerted efforts to produce comprehensive observation datasets to permit detailed intercomparison of data assimilation algorithms. The production of this dataset, and defining details of the experiments to be performed (domain, verification metrics, etc) are of the highest importance to WRF data assimilation efforts. The WRF Developmental Testbed Center should play a key role in this work. In parallel, NCAR efforts will concentrate on improved BE models, the development of WRF 4D-Var, and comparison between variational and ensemble-based data assimilation strategies.

References

Barker, D. M., W. Huang, Y.-R. Guo, and Q. N. Xiao, 2004: A Three-Dimensional (3DVAR) Data Assimilation System For Use With MM5: Implementation and Initial Results. *Mon. Wea. Rev.*, **132**, 897-914.

Parrish, D. F., and J. C. Derber, 1992: The National Meteorological Center's Spectral Statistical Interpolation analysis system. *Mon. Wea. Rev.*, **120**, 1747-1763.