The MM5 Implementation Of 3DVAR

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1. Introduction

The previous year has seen a number of new capabilities added to the threevariational dimensional (3DVAR) data assimilation system built at NCAR for use with both the MM5 (Barker et al 2003a, b) and, more recently, WRF models. Additional observation types tested include buoy, GPS radio occultation retrievals of refractivity, Quikscat oceanic surface winds, wind profiler (a collaboration with Forecast Systems and radar radial Laboratory, Boulder), velocity (Xiao et al, this volume). The 3DVAR system has been used to initialize real-time MM5 forecasts run at NCAR (see http://rain.mmm.ucar.edu/mm5) assimilating conventional and some non-conventional e.g. GPS precipitable total water (TPW) observations. A new project to implement 3DVAR in the real-time Antarctic Mesoscale Prediction System (AMPS http://www.mmm.ucar.edu/rt/mm5/amps) is underway. This paper presents results from a few of the developments completed over the previous year.

2. Operational Implementation in Taiwan

In May 2002, the 3DVAR system replaced the previously used "LITTLE_R" objective analysis package in the Taiwanese Civil Aeronautics Administration's (CAA)'s real-time MM5-based Advanced Operational Aviation Weather System (AOAWS) forecasting system (Barker et al, 2003b). This event followed over a year of pre-operational testing in the triple (135/45/15km resolution) two-way nesting AOAWS domains. The 3DVAR system is set up to "cold-start" from global analyses of the Taiwan Central Weather Bureau (CWB) at the main synoptic hours (00 and 12 UTC) and to "3-hour cycle" at other times i.e. the first guess at 03, 06, 09, 15, 18 and 21 UTC is a previously run 3-hour MM5 forecast.

The use of 3DVAR provides improved forecasts relative to those initialized using the LITTLE R system. Forecast verification scores for the u-wind component are shown in Figure 1 for AOAWS 45/15km domains. Verification is radiosonde against observations. Data use here is valid from 00 UTC 2 to 00 UTC 9 September 2002 using forecasts initialized at 00Z and 12Z. Similar results have been seen in other test periods. To see the improvement due to the change in assimilation technique, only those observations available to LITTLE R in the AOAWS system are included in this test. The "NOOBS" run is an MM5 forecast run from the interpolated CWB analysis - the 3DVAR improvement relative to "NOOBS" is a measure of the "added value" of the MM5 3DVAR reanalysis.

In Figure 1, the analysis (T+00) fit to observations is closer for LITTLE R than for 3DVAR. This does not necessarily indicate a better analysis as is seen by the improved verification 3DVAR wind of versus LITTLE R at all forecast ranges. The improvement in wind forecast is particularly good for the higher resolution (15km) domain Temperature and humidity forecast 3. verification (not shown) does not yet indicate a statistically significant improvement relative forecasts from LITTLE R. Possible to reasons include a) 12-hourly cold-starts - the system does not get a chance to "break free" of the low resolution CWB global analysis,

and b) Current background errors (climatological, estimated via the "NMC-method") are poor approximations to the true error. Future work (full cycling and ensemblebased, flow-dependent background error statistics) will investigate these limitations of the current AOAWS system. In addition, the inclusion of additional data sources in the real-time data-feed will permit the AOAWS system to make fuller use of 3DVAR's current capabilities.



Figure 1: Verification against radiosondes of the u-component of wind for MM5 forecasts as a function of forecast range. Scores for AOAWS domains 2 (above) and 3 (below) are

shown. Results are for one week - 00 UTC 2 to 00UTC 9 September 2002.

3. 3DVAR Typhoon Bogussing Scheme

A simple experiment has been performed to assess the use of a single pressure observation in 3DVAR as a typhoon bogussing scheme. The typhoon chosen for this case study is Sinlaku, which made landfall in southeast China in early September 2002. The AOAWS 3DVAR/MM5 implementation is used.

A vertical cross-section (E-W) of 3DVAR's temperature/pressure analysis increment response to a single bogus surface pressure observation of 955mb at location (25.6N, 132.0E) is shown in Figure 2.



Figure 2: Pressure (red, peaking at surface) and temperature (blue, with maxima in lower/mid-troposphere) analysis increments due to a single "bogus" surface pressure observation with O-B=-36mb. Valid at 00 UTC 3 September 2002.

The O-B value of -36mb represents the difference in Typhoon Sinlaku central pressure/location estimated by CWB typhoon reports (based on human interpretation of satellite imagery) and the CWB global analysis. Figure 2 indicates pressure and temperature increments extending into the upper-troposphere and maximum а temperature (warming) the midin troposphere. wind A related cvclonic circulation exists (not shown) in the lower /mid-troposphere that reverses in stratosphere.

The impact of the assimilated bogus observation on the subsequent forecast of the typhoon is now studied. Forecasts are integrated for 48 hours from analyses valid at 00 UTC 4 September 2002 following two initial spin-up cycles (18-21UTC, 21-00UTC). Three experiments are performed: a) NoBogus (assimilates standard observations, b) PBogus1 (NoBogus + 955mb bogus observation with observation error of 1mb), c) PBogus2 (as PBogus1 except observation error = 2mb).

Typhoon central pressure values through the forecast are presented in Figure 3. Without the bogus pressure observation, the "NoBogus" forecast gradually deepens through the period from an initial value of 991hPA to 980hPa at 00 UTC 6 September. The "PBogus1" and "PBogus2" curves indicate that the impact of the pressure observation is retained throughout the 48hr forecast in both bogus experiments resulting in 48hr forecast typhoon central pressures of 968/970hPa PBogus1/PBogus2 for experiments - respectively 23/21hPa lower than the "NoBogus" forecast.



Figure 3: Forecast typhoon Sinlaku central

pressure for the 3 experiments described in the text (0hr = 00 UTC 4 September 2002). "Report" is the (constant) typhoon warning value of 955mb.

In addition to the deepening of the typhoon, the 3DVAR assimilation of the surface bogus observation also modifies the track of the typhoon. The stronger pull to the bogus observation of "PBogus1" results in a typhoon position ~260km north of that of "NoBogus" (a positioning error of 130km to the north). The larger observation error applied in "PBogus2", results in a 48hr typhoon that is only ~50km from the true position (not shown). The conclusions drawn from this preliminary study are: a) The impact of 3DVAR assimilation of a bogus surface pressure observation does persist through the forecast. b) There is significant sensitivity of the typhoon forecast (particularly the track) to the way the bogus observation is assimilated in the 3DVAR initial conditions.

4. Faster 3DVAR Minimization and Outer Loop

The computation of the analysis state in variational data assimilation systems is achieved through the iterative minimization of a prescribed cost (or penalty) function. The present 3DVAR cost function minimization uses a modified version of the limited memory Ouasi-Newton Method (ONM). Recently, an alternative Conjugate Gradient Method (CGM) has been implemented. Unlike the QNM technique, the CGM method restricts 3DVAR's inner loop to be completely linear. This limitation is dealt with through the inclusion of an "outer loop" in 3DVAR, the purpose of which is update the nonlinear calculation of the innovation vectors (O-B) using the 3DVAR analysis from the previous iteration as new background. The outer loop may also be used as a form of variational quality control as

follows: observations are rejected if their O-B values are outside a prescribed range (typically several times the observation error standard deviation). This "errormax" test implicitly assumes the rejected large O-B values are due to a bad observation (O) rather than poor background (B). However, if it is the background B that is incorrect then the will reject the most useful system observations available to the assimilation system i.e. those in areas where the background forecast is poor. The outer loop alleviates this effect by allowing observations rejected in previous iterations to be accepted if their new O-B falls within the required range in subsequent outer loops. The assimilation of nearby observations in previous iterations essentially provides a "buddy check" to the observation in question.

The impact or effect of minimization technique is seen in Figure 4 for a standard case with three outer loops. It can be seen that the CGM method results in significantly faster convergence than the previously used QNM algorithm (104 compared to 166 iterations). For this test, the convergence criterion is made particularly stringent to ensure both methods converge to the same final J, as expected. The combination of few iterations, and the fact that each CGM iteration is itself faster (and uses less memory) results in a ~40-50% CPU reduction for 3DVAR. The impact of the repeated errormax O-B check is seen in the jumps of cost function value at the start of each outer loop – the inclusion of additional observation previously rejected as bad increases the total observational part of the cost function.

5. Summary and conclusions

After four years of development, a 3DVAR capability for MM5 was officially released to the general research community in early June 2003. On June 9 2003, over 50 participants attended the first 3DVAR tutorial

at NCAR. The 3DVAR system was implemented operationally with MM5 in 2002 in both the Taiwan CAA's AOAWS and also in 45km theaters of the US Air Force Weather Agency (AFWA - see Wegiel, this volume). The system also runs with MM5 in semioperational, full-cycling mode in the 10/30km resolution domains of the Korean Meteorological Administration (Xiao, this volume). The use of the 3DVAR system to initialize forecasts of the Weather Research and Forecasting (WRF) model continues to be developed. Further discussion of this topic is reserved for the WRF workshop.



Figure 4: Cost function J minimization for a standard 3DVAR case using QNM and CGM methods, and with 3 "outer loop" iterations.

6. References

Barker, D. M., W. Huang, Y.-R. Guo, and A. Bourgeois, 2003a: A Three-Dimensional Variational (3DVAR) Data Assimilation System For Use With MM5. *NCAR Tech Note*, NCAR/TN-453+STR, 68 pp. [Available from UCAR Communications, P.O. Box 3000, Boulder, CO, 80307.]

Barker, D. M., W. Huang, Y.-R. Guo, and Q. N. Xiao, 2003b: A Three-Dimensional (3DVAR) Data Assimilation System For Use With MM5: Implementation and Initial Results. *Mon. Wea. Rev.*, Submitted.