IMPLEMENTATION OF OBSERVATION-NUDGING BASED FDDA INTO
WRF FOR SUPPORTING ATEC TEST OPERATIONS

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1. INTRODUCTION

In the last few years, NCAR and the Army Test and Evaluation Command (ATEC) have jointly developed a real-time rapid-cycling FDDA and forecast (RTFDDA) system. This MM5-based system has been deployed and is running operationally at five Army testing ranges. The ATEC RTFDDA data assimilation procedure was developed based on the observation-nudging scheme in the standard MM5 (Stauffer and Seaman 1994). It was imported into the WRF model as a part of the ATEC modeling transition from the MM5 to WRF framework. The basic code porting was completed in April 2005. Since then, the WRF-FDDA system has been tested with real-time cycling for the Dugway Provide Ground (DPG), in parallel with the MM5-based RTFDDA system running at the range. To achieve a fair comparison between the WRF- and MM5-based systems, the WRF model is configured to have the same domain configurations and similar physics to those of the operational MM5.

In this paper, we briefly describe the ATEC RTFDDA system, in particular, the enhancements to the observation-nudging scheme of the standard MM5. We introduce the technical design and implementation strategies of putting the ATEC FDDA scheme into WRF. Some preliminary results with case studies and verification statistics from the WRF-MM5 parallel runs are also presented.

2. THE ATEC RTFDDA SYSTEMS

Like many other weather-sensitive applications, the routine tests at the Army test ranges critically depend on accurate, high-resolution weather analyses and forecasts. However, analyzing and forecasting weather in these test regions are challenging because the test ranges are mostly located in regions of complex terrain where flows can be very complicated and they evolve very rapidly. Multi-scale flow-interaction and underlying dynamical and thermal forcing are driving forces for the local circulation formation. Unfortunately, neither local observations nor the coarse resolution model from national centers are able to resolve these factors in their data analyses and forecasts. The NCAR/ATEC RTFDDA system is specially designed to fill this gap. The RTFDDA system was originally built around MM5V3. By effectively incorporating detailed terrain, coastline masks, and land-use information, and using synoptic-scale model analyses from the NWS and real-time mesoscale observations, the RTFDDA system has proven capable of forecasting many realistic local circulations. Besides running operationally at five US Army Test ranges as of May 2005, the RTFDDA systems have also been implemented at 20+ other sites/regions globally, supporting various DoD missions and other applications.

Although the observation-nudging module available with the standard MM5 provides a basic mechanism for carrying out continuous FDDA, a few adjustments were put into the nudging module in order to adapt the system for real-time operation (Cram et al. 2001). Furthermore, in the last three years, many efforts have been taken to study and refine all aspects of the model system (Liu et al. 2002, 2004, 2005). A few bugs were also identified and fixed. The most significant improvements to the standard MM5 observation-nudging scheme can summarized as following:

(1) Added capability to incorporate all, conventional and non-conventional, synoptic and asymmetric data resources, including the twice daily radiosondes; hourly surface, ship and buoy observations, and special observations from GTS/WMO; NOAA/NESDIS satellite winds derived from cloud, water vapor and IR imageries; NOAA/FSL ACARS,

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AMDAR, TAMDAR and other aircraft reports; NOAA/FSL NPN (NOAA Profiler Network) and CAP (Corporate Agencies Profilers) profilers; the 3-hourly cloud-drifting winds and water-vapor-derived winds from NOAA/NESDIS; NASA Quikscat sea surface winds; and high-density, high-frequency observations from various mesonets of government agencies and private companies. In particular, special weights are assigned to the application-specific data, such as the SAMS network, special soundings and winder profilers located at and operated by the Army test ranges.

(2) Added capability to assimilate multi-level upper-air observations, such as radiosondes, wind profilers and radiometers, in a vertically coherent way, which is contrast to the algorithm for single point observations such as aircraft reports and satellite derived winds.

(3) Surface temperature (at 2 m AGL) and winds (at 10 m AGL) observations are first adjusted to the first model level according to the Similarity Theory that is built in the model surface-layer physics and the surface-layer stability state at the observation time. The adjusted temperature and wind innovations at the lowest model level are then used to correct the model through the mixing layer, with weights gradually reduced toward the PBL top.

(4) Steep mountains and valleys severely limit the horizontal correlation distances. For example, weather variables on the upwind slope are not correlated with those on the downwind slope. To take account this effect, a terrain-dependent nudging weight correction is designed to eliminate the influence of an observation to a model grid point if the two sites are physically separated by a mountain ridge or a deep valley. More details about the scheme and numerical test results can be found in Xu et al. 2002. Essentially, for a given observation and grid point, a terrain search is done along the line connecting the grid point and the observation site. If there is a terrain blockage or a valley (deeper than a given depth), the nudging weight for the observation at the given grid point is set to zero. Currently, this algorithm is applied for surface observations assimilation only.

(5) Unlike the hybrid-use analysis-nudging (for coarse grids) and observation-nudging (for fine grids) by Stauffer and Seaman (1994), only the observation-nudging is used in the ATEC modeling system and the scheme was adjusted to accomplish data assimilation on multi-scale domains in the RTFDDA system. Numerous fine-tunings were made into the horizontal weight functions to maximize the data impact on different scales and scale interaction. Two among the adjustments are noteworthy. The first is an addition of grid-size-dependent horizontal nudging weight for each domains and the correspondent inflation with heights. The second is adding the capability of “double-scans”, a two-step observation-nudging relaxation. The idea is similar to the successive corrections: the first scan, with large influence radii and smaller weights, allows observations to correct large scale fields, while the second scan, with smaller influence radii and large weights, permits the observation to better define the smaller-scale feature.

(6) An efficient data quality-control (QC) procedure was developed by using the fast-updated accurate 0 – 3 hour forecasts produced by rapid cycling of the RTFDDA model system (Liu et al. 2004). This new QC module is able to estimate the error of an observation, and assign a unique quality confidence level, scaled from 0 (worst) to 1 (best), for each observation. The data quality scale is then used in the data assimilation to weight the observations accordingly. It is demonstrated that the RTFDDA data assimilation and forecasts are improved when this algorithm is incorporated.

(7) Finally, observation-nudging allows the observation correction to be propagated into the model state in a given time influence window. One technical difficulty with this technique is that we do not have the model state at the observation time for computing the observation increment, or innovation, during the first half of the time window. In the Stauffer and Seaman’s scheme, at each time step within the time influence window, innovation is calculated (or approximated) by differencing the observation from the model state at the time step. This obviously leads to dragging the future forecasts toward previous (observation) states. To reduce this error, we keep the innovation calculation the same as before up to the observation time (this is OK since we are gradually tacking toward the observation state), but we keep and use the “true” innovation during the late half of the time influence window.

3. IMPLEMENTATING OBSERVATION-NUDGING IN WRF: STATUS AND PLANS

For the benefit of ATEC modeling and modelers who are familiar with the MM5 observation-nudging, it was designed so that the ATEC FDDA modules should be ported into WRF “as it is”, meaning to keep the same algorithms, logic and all nudging parameters as those in the MM5 counterpart. This design also permits convenient comparison between the WRF-FDDA with MM5-FDDA system and testing of the scheme during and after porting the codes. As shown in Fig.1, following the WRF coding convention and the
guideline for addition of a physics module, we interface the FDDBA module by adding a FDDBA driver into the WRF main time integration routine, “solve_em.F”. The FDDBA driver controls the sub-modules for observation data I/Os, innovation and nudging weight computation, and updates of the final analysis increments into the tendency equations. Arrays that hold the observation data and attributes, innovation, and analysis increments are defined in the WRF Registry, as is the namelist block that contains the nudging parameters to be given by users.

![Diagram](72x358 to 297x594)

**Fig. 1 Schematic of observational nudging in WRF**

Observation-nudging is quite a complicated process that interacts with many other model state variables. Differences in system architectures, model coordinate systems and forecasting variables make the porting work a tedious task. We started to port the code in July 2004, when the single-domain WRF 1.3 was available. Since then, many changes in WRF and a few major changes in the ATEC FDDBA model described in Section 2 have been introduced. By the time of writing, we have successfully updated the observation-nudging into the newest WRF public release, Version 2.0.3.1, released on Dec. 3, 2004. However, a few newly developed observation-nudging refinements have not been made into the WRF system. These new modifications include the item (5) - (7) described in Section 2. We are working on the “double-scans” (5) now and plan to work on (6) and (7) in the near future.

In spite of its conceptual simplicity, nudging-based FDDBA technology stands on the same foundation as all other data assimilations: the Kalman Filter theory. Essentially, the differences between the prevailing optimal schemes, such as statistical interpolation, 3DAVR, 4DVAR and EnKF, and the simple observation-nudging, are at the estimations of the Kalman Gain, which is dependent on estimation of background error and observation error. Although the experienced-based observation-nudging weighting function (the Kalman Gain in observation-nudging) appears ad-hoc, theoretically, there is no reason that we can not implement an optimized Kalman Gain into the nudging weighting scheme. As a matter of fact, the temporal relaxation in the observation-nudging gives the extra benefit that the model state can be tracked along the true states through continuous synchronization of observed and model states at each time step. It is our plan to further research in this area and provide incremental enhancements to the WRF observation-nudging model in the next few years. These enhancements will include developing capabilities for incorporation of statistical background error covariance based on local-scale flow climatologies and ensemble-based real-situ background error covariance. Due to the challenges of mesoscale ensemble forecasting, we believe some ad-hoc modifications to the Kalman Gain will continue to benefit meso- and small-scale data assimilation in the near future.

4. **PRELIMINARY TEST RESULTS**

For testing the WRF observation-nudging, the WRF model was set to run with the same model configuration that is used in the MM5-based RTFDDBA system operated at DPG and has been running semi-operationally since mid April, 2005. The models have three nested grids with grid sizes of 30, 10 and 3.333 km respectively. Fig. 2 shows the domain coverage. The model physics schemes, listed in Table 1, were chosen to be close to each other for WRF and MM5. Both models run with 36 vertical levels and assimilate the same observations. The NAM AWIP 212 forecasts are used to provide initial conditions at cold-starts and boundary conditions during continuous data assimilation and forecasts for both models. The systems are cycled a time interval of 3 hour and forecasts were started at 0, 3, 6 … 21Z each day, from the FDDBA analyses in the cycles. Again, it is noted that the nudging scheme in MM5 is up-to-date, while some new updates were not included in the WRF model.

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<th>Table 1: Comparison of basic model settings</th>
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<td><strong>Settings</strong></td>
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Fig. 2. DPG RTFDDA Domain configuration.

Fig. 3 compares the average RMS errors of upper-air temperature and humidity of MM5- and WRF-RTFDDA outputs from 1 to 16 May 2005. The statistics were computed by interpolating the model analyses and forecasts to all sounding locations at 00Z and 12Z in the Domain 1. The result shows that the WRF observation-nudging performs very similar to the MM5 counterpart. The nudging-processes are able to track the model states toward the observed states and the correction amount in the WRF are close to those in the MM5. The upper-air wind errors of the WRF model runs are significant larger than those in MM5 (not shown). We are currently looking into this problem. The small but obvious larger RMS errors in temperature and humidity of WRF than MM5 in Fig. 3 are partly due to the missing of new refinements of the nudging scheme in the MM5 and partly due to the problem of wind nudging. Notice also that there are differences in the other part of the two model systems.

On 3 June 2005, a rainband was moving through Utah. Verification using the NCEP surface precipitation analyses indicated that both WRF- and MM5-based RTFDDA systems captured this rainband reasonably well. Fig. 4 shows the snapshots of 1-hr accumulation precipitation of the 7-hr forecasts of the two models. Obviously, both models accurately forecasted the location, orientation and intensity of the rainband. WRF model, in this case, appears to better simulated the three rain cores within the band.

Fig. 4. 1-hr accumulated rain from 08 to 09Z, 3 June 2005 of WRF-RTFDDA (up left) and MM5 RTFDDA (up right) 7-h forecasts. The NCEP Stage IV precipitation analysis for the same period is shown on the left.

5. REFERENCES


