

FORECASTING SYSTEM

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1. INTRODUCTION

Many fields and applications need current and near-future local-scale weather information. The routine test of weapons, bio- and chemistry dispersion, airdrops, missile launches ... at US Army testing ranges is an example of such a need. To warrant a successful and safe test, weather analyses and forecasts at regions and times of interest are critical. Although each Army range has set up a network of surface observations, and special radiosondes and boundary wind profiler(s), the observations available are still too sparse to describe the complicated local circulations and thermodynamic structure, either to support accurate nowcasting and short-term (0 - 12h) weather prediction with the conventional data analysis and forecast methods. To address the problem, NCAR/RAP, in collaboration with the US Army ATEC (Army Test and Evaluation Command), has been developing a real-time four-dimensional data assimilation and forecast system (RTFDDA) since late 1999. The system incorporates various data sources to generate accurate multi-scale analyses, and in turn generates 0 - 12 (or longer) hour weather forecasts starting from the "spin-up-free" analyses.

A detailed description of an early version of the system can be found in Cram et al. (2001). Briefly, the PSU/NCAR MM5 Version 3 and the continuous Newtonian nudging method (Stauffer and Seaman, 1994) is employed. Each observation is ingested into the model at its observed time and location, with proper space and time weights. Several modifications have been put into the nudging scheme and model physics in the standard MM5. To deal with multi-scale interactions and balance the data cutoff and test needs, the system runs in three-hourly cycling mode on multi-level nested grids. In each cycling window, are generated 1). three-hour final analyses (between t-4 and t-1) continued from last cycle, 2). two to three hour preliminary (or partial data) analyses (between t-1 and running time), and 3). 12 - 36 hour forecast (dependent on computer speed). Preliminary qualitative and quantitative verification at DPG, Utah, over the 2000-

2001 winter period showed a reasonable good performance of the system.

In the past 1.5 years, several components of this system have been refined and upgraded. The system has been tested and ported to several other Army ranges. Parallel tests were conducted to evaluate gains of these new developments. In this report, we will briefly review the status and the real-time applications of the RT-FDDA system. Statistic verification results from the parallel tests will be discussed. The limitations of the current system are assessed and, finally, a development plan to further enhance the data assimilation capability is proposed.

2. OPERATIONAL APPLICATIONS

The first RT-FDDA system was built at the Dugway Proving Ground (DPG) in Utah in late 2000. The data sources in this initial system include conventional twice-daily radiosondes; hourly surface, ship and buoy observations, and special observations from GTS/WMO; the 3-hourly cloud-drifting winds and water-vapor-derived winds from NOAA/NESDIS; the high-frequency DPG local surface network (SAMS) and two wind profilers; and finally and importantly, the high-density and high-frequency observations from various public and private agencies/companies over the west states, from the Mesowest of the University of Utah. Since the summer of 2001, along with continuous enhancements and developments (see Section 4), the system was ported to four other Army testing ranges: the Yuma Proving Ground (YPG) in Arizona, the WhiteSand Missile Range (WSMR) in New Mexico, the Cold Region Test Center (CRTC) in Alaska and the Aberdeen Test Center (ATC) in Maryland (Fig.1). Although the MM5 basic framework supports an easy domain relocation globally, to best adapt the RTFDDA system to a new range requires specific adjustments according to the local topographic and underlying characteristics and climate weather environments. Local (range) observations are gathered, quality-controlled and ingested into the system. Closely monitoring the data feed and evaluating the scientific performance of the system during operation are necessary. Furthermore, because of the "restart-featured"

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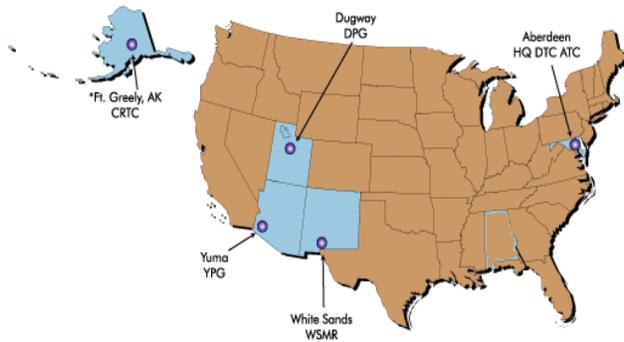


Fig.1 The US Army ranges where RTFDDA has been implemented

continuous model runs of model analysis and forecast from one cycle to the next, it is necessary to carefully maintain the system running continuously.

Table 1 depicts some basic features of the five RTFDDA systems currently running at the five Army ranges. The "start-up" operation dates are also denoted. Varying configurations are customized to each range. Since the grid points and time steps dominate the total cost, and thus the length of the forecasts, we started with similar physics settings that we think reasonable for all ranges, while the domains and nesting levels are configured to best satisfy the specific requirements of a range testing, given the capacity (CPU speed and number of nodes) of the model application clusters (MAC). For example, at YPG and WSMR, three model domains with a fine mesh grid spacing of 3.33-km are used. This configuration allows 36 - 42 hour forecasts in each three-hour cycle on a 16-node 900-Mhz dual-CPU PC cluster. On the other hand, four-domains with a large fine-mesh (at 1.11 km grid spacing) Domain 4 are running on a 32 nodes 850-Mhz dual-CPU PC cluster, which replaced, in May 2002, the 3-domain 12-hour forecasts, running on a 8 nodes 600-Mhz dual-CPU PC cluster.

Table 1: Model settings of NCAR/ATEC RTFDDA

Range name	numbers of Domain	vertical levels	physics schemes	data sources	start-up dates
DPG	4	36	MRF/PBL; Simple Ice micro-physics;	GTS/WMO; Mesowest; Satellite winds;	Oct. 10, 00
YPG	3	36	Grell CUP (for D1 and D2 only);	ACARS; NPN and BLP profilers;	Jul. 02, 01
WSMR	3	36	Dudhia radiation; OSU/LSM	range SAMS, Special soundings and wind profilers	Sep. 04, 01
CRTC	4	31			Feb. 15, 02
ATC	3	36			Jun. 01, 02

Verification statistics against twice-daily rawinsonde observations and hourly surface observations were car-

ried out in both real-time and historical modes and averaged for different periods. Analyzing and describing the details of the verification statistics for each range is beyond the scope of this paper. Briefly, both RT-FDDA analysis and short-term forecasts at all ranges appear to perform reasonably better than simpler/coarse-resolution analyses and the conventional cold-start model forecasts. The RTFDDA model describes many details of local circulations forced by local thermal contrasts and/or topographic influence of synoptic weather systems. With the incorporation of the real-time observations, RTFDDA analyses could properly correct the model error and meanwhile maintain the model balance. Since the nudging process can effectively eliminate the "spin-up" process, the accuracy of the model products degrade gradually with the increase of the forecast time. The final analysis possesses minimum errors. Qualitative comparison of the model cloud and precipitation with satellite images and NCEP "STAGE" surface precipitation analyses shows good cloud and precipitation distributions in the RTFDDA final analysis. Noting that at present no cloud/precipitation observation has been directly assimilated into the system, the good RTFDDA cloud/precipitation analysis indicates a proper interaction between the model dynamical and physical processes with the nudging of wind, temperature and humidity observations. In general, the RTFDDA systems have been running at the ranges robustly and effectively serve the test planning and real-time operations. The great value of the RTFDDA products has been recognized and highly appreciated by the range users.

3. RECENT DEVELOPMENTS AND IMPROVEMENTS

Data assimilation quality is mainly affected by three major factors: the model (background) accuracy, the quality and quantity of available observations, and the data assimilation scheme employed. In spite of some preliminary successes, there are many details to be tested and improved in each of the three areas of the high-resolution RT-FDDA system. Different settings of the model configuration and physics need to be tested. Nudging parameters (influence radii, spatial and time weights and nudging coefficients) should be adjusted through careful sensitivity tests. On the other hand, observations available for the assimilation on the cloud-scale high-resolution fine meshes are normally very sparse, and nudging-based data assimilation is limited to modern non-conventional measurements.

The NCAR/RAP RTFDDA group has been working on using non-traditional data. A series of parallel tests of

model configuration and physics, new data resources, and observation quality-control schemes have been carried out. In this section, we will concentrate on some results from a pair of a month-long parallel tests to evaluate a system modification. One of the important task is to adjust influence radii according to local terrain features and the model grid size. The impact with the new nudging scheme is discussed in another paper on this conference (Xu et al., in this volume - **4B.4**). In the next section, we will briefly introduce a new plan to combine the MM5 3DVAR technique with the current nudging scheme.

Figure 2 compares the surface verification of two parallel RTFDDA model runs at the DPG: the "new" RTFDDA and the "old" RTFDDA. The "old" stands for the RTFDDA systems initially developed for DPG (Cram et al. 2001). The "new" stands for the model runs with additions of new data sources (hourly observations from the NPN-profiler network and Boundary Layer Profiler networks and ACARS [United Airlines only] data from FSL/NOAA); a new strict and reliable Quality-Controlled (QC) scheme that makes use of the fast-updated accurate 1 - 3 hour forecast of the system to remove suspected/unrepresentative observations; and the land-surface physics upgraded to the OSU Land-Surface Model (LSM)

from the previous simple "force-restore" slab-soil model. The two parallel systems ran for one month from Feb. 22 to March 23. Figure 2 presents the Mean Absolute Errors (MAE) of temperature, specific humidity, wind speeds and directions, computed based on all samples in the domain 1 during the one-month test period for each UTC hour. Four curves are shown in each panel with final analysis (solid) and the 10 - 12 hours forecast (the longest forecast from each 3-hour cycle, dashed) from both "old" (gray) and "new" (black) RTFDDA. The impact of the "new" development is very impressive. On average, the "new" RTFDDA was able to improve the analyses and the 0 - 12 hour forecasts by 0.3 C for surface temperature, 0.15 g/kg for the mixing ratio of humidity, and 0.25 m/s for the surface winds. Although there are some diurnal variations, the "new" scheme consistently improve the surface meteorological variables. The maximum reduction of the temperature error occurs around early morning, while the surface wind speeds in the afternoon. The result from the fine mesh shows similar properties.

The "new" RTFDDA also improves the upper-air analysis and forecasts. Figure 3 compares the vertical profiles of the Root-Square-Mean-Error (RMSE) of temperature, specific humidity and wind speed of the

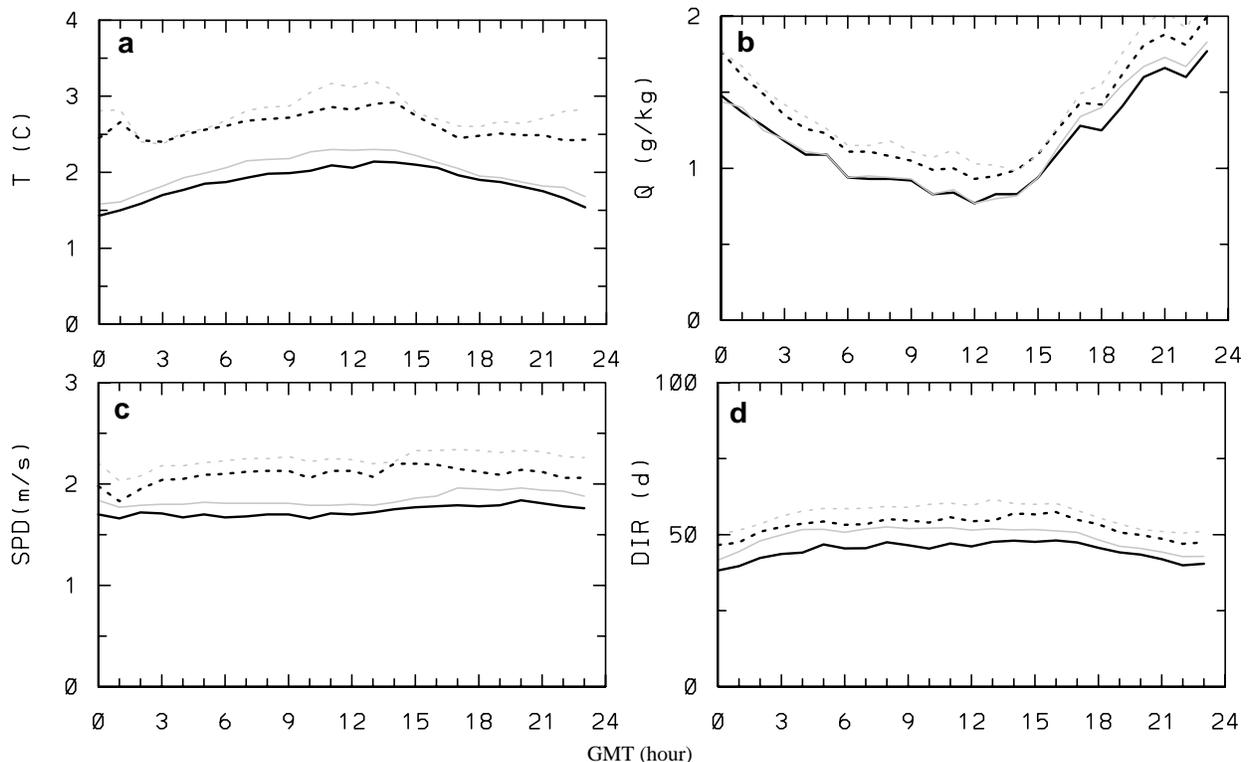


Fig.2 Comparison of the MAE of surface temperature (a), specific humidity (b), wind speed (c) and wind direction on Domain 1, averaged at each UTC hour for all cycles between Feb. 22 and March 22, 2002, of the "new" (black) and "old" (gray) RT-FDDA runs. The solid and dashed curves denote the final analyses and 10-12 hour forecasts respectively.

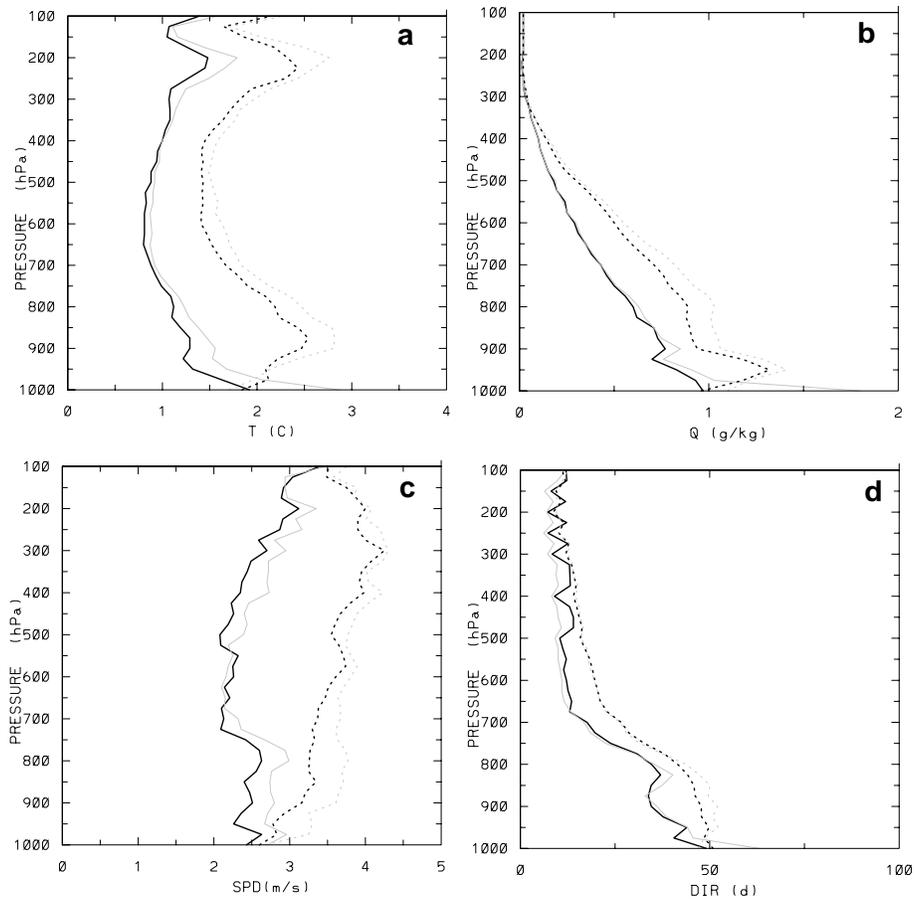


Fig.3 Same as Fig.2, but for the upper-air RMSE calculated at every 25 hPa.

final analysis on the Domain1 from the "new" RTFDDA with those from the "old". The statistics are calculated based on verifications against the conventional rawinsonde observations at every 25 hPa at 00Z and 12Z. Obviously, similar to the surface verification results, the "new" RT-FDDA out-performs the "old" for all of variables at almost all layers in both analyses and forecasts. In particular, the "new" RTFDDA generates a maximum correction for temperature in the upper portion of the PBL and the lower tropopause. Large improvements of humidity and winds can be seen in the lower troposphere.

By reviewing the differences between the "new" and the "old" RT-FDDA systems, one may easily understand why the "new" RTFDDA produces the better result. The addition of the NPN and BLP profilers and ACARS measurements provide much more upper-air information than the twice-daily conventional soundings; the new QC scheme will ensure that only good observations enter into the system; and the OSU/LSM soil scheme represents more realistic soil/snow physics.

4. FUTURE PLAN

Nudging-based four-dimensional data assimilation is limited to assimilate the observations of the model predicted variables. Since such observations available currently are much insufficient, finding a way to incorporate non-conventional observations, such as satellite brightness temperature, GPS precipitable water and Doppler radar volume-scans, is necessary. Our plan is to make use of the MM5 3DVAR technology to enhance our nudging based FDDA system. The 3DVAR provides a mechanism for incorporating the non-conventional observations. As the cost to run 3DVAR analysis is trivial, a proper combination of 3DVAR will lead to a cheap and practical operational FDDA with more complete data sources.

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