DEVELOPMENT AND EVALUATION OF A REAL-TIME FDDA AND FORECAST SYSTEM FOR THE YEAR-2002 SLC OLYMPICS

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1. INTRODUCTION

As part of the Homeland Security effort for the Year-2002 SLC Winter Olympics, NCAR/RAP, in collaboration with DTRA and US Army Dugway Proving Ground, developed and operated a real-time Four-Dimensional Data Assimilation (RTFDDA) and forecast system. The objective is to produce real-time four-dimensional, dynamically consistent, multiscale analyses with all available observations, and at the same time, the rapidly updating 0 - 15 hour forecasts, by using the multi-grid MM5. The analyses and the short-term forecasts on the fine grids are used to drive dispersion models in routine tests and/or real-time disaster/damage assessment and reduction support when leaking of hazardous materials or bio- and/or chemistry attacks by terrorists occur. It is suggested that a high-resolution full-physics mesoscale model (MM5) employing continuous four-dimensional assimilation of sysnoptic and asynoptic observational data produces high-quality local-scale meteorological analyses and short-term forecasts not available from numerical guidance produced by National centers such as NCEP.

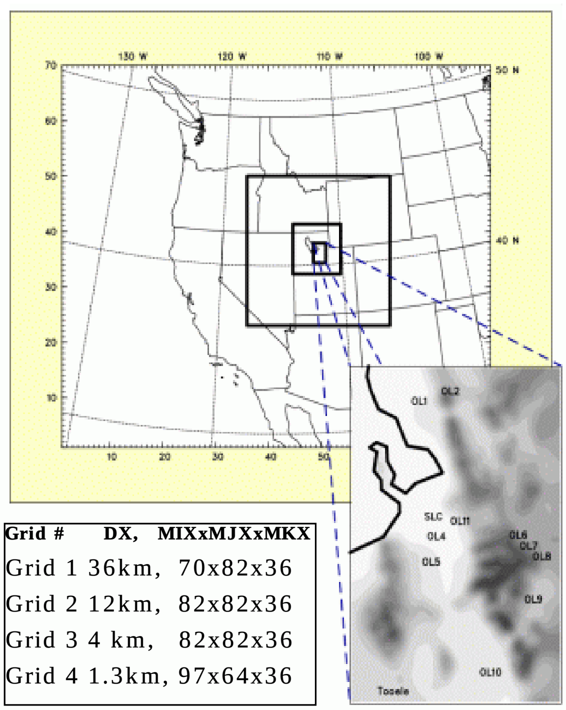
The system was developed and ran successfully throughout the Olympic period between Feb. 6 and Mar. 16, 2002. A significant amount of research and software engineering is required to develop and operate such a system. We will highlight some notable scientific and engineering aspects of the system. Verification statistics will be presented to evaluate the system performance. Limitation of the system and some on-going work to enhance the system for many other potential applications in future will be discussed.

2. SYSTEM DESIGN

2.1 Scientific Aspects

The RTFDDA system was built upon the PSU/NCAR MM5 version 3. The data assimilation technology is essentially based on the continuous Newtonian nudging method initially developed by Stauffer and Seaman (1994). Some modifications and adjustments were made by NCAR/RAP RTFDDA group in past 2 years (Cram et al., 2001 and Liu et al. 2002). In brief, the "observation nudging" was employed to assimilate all observations collected in real-time. Proper space and time weights are allowed to strengthen and spread the observation information from the observation time and location. To deal with multiscale interactions and balance the data cutoff and real-time requirements, the system was designed with four nested grids and ran in a three-hourly cycling mode. Figure 1 shows the domain configuration. The finest mesh (D4), with grid spacings of 1.33 km, covers all the Olympic venues and neighboring regions.

In each three-hour cycling window, were generated 1). three-hour final analyses (between t-4 and t-1), restarted from last cycle, 2). two to three hour preliminary (or partial data) analyses (between t-1 and running time), and 3). 15 hour forecasts. The cycling allows continuous updates and improvements of the model analyses and forecasts, for any target period, from longer forecasts to shorter ones, to partial analysis and at last, to a final analysis, as the time approaches it. The 0 - 24 hour ETA forecasts from 00Z and 12Z runs were used to



Grid #	DX,	MIXxMJXxMKX
Grid 1	36km,	70x82x36
Grid 2	12km,	82x82x36
Grid 3	4 km,	82x82x36
Grid 4	1.3km,	97x64x36

Fig.1 The domain configuration of the Year-2002 SLC Olympic RTFDDA and forecast system. The Olympic venues are labeled..

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provide the boundary conditions of the system. Furthermore, to cope with the SST and SNOWCOVER changes, the cycling was reset once every week.

In order to leave enough room for the RTFDDA cycling, the simple but reasonable model physics schemes were used: MRF PBL, Grell CUP, Dudhia radiation, simple ice microphysics and 5-layer soil scheme. The model has 36 sigma levels, with 12 levels in the lowest 1-km AGL. Since the full-physics model (MM5) was used in both analyses and forecasts, the analyses closely satisfy the control equations of the model and thus mitigates effectively the "spin-up" processes. Cloud and precipitation analyses are also generated.

The data sources assimilated in the system include the conventional twice-daily radiosondes; hourly surface, ship and buoy observations, and special observations from GTS/WMO; the 3-hourly cloud-drift winds and water-vapor-derived winds from NOAA/NESDIS; the high-frequency observations from SAMS network and two wind profilers of the US Army Dugway Proving Ground; and finally and importantly, the high-density and high-frequency observations from a large number of public and private agencies/companies over the west states from the Mesowest of the University of Utah (Horel et al., 2002). In addition, about 30 special surface stations were installed at the Olympic venues and villiges, which provide a good coverage in the local area. A snap-shot of the surface observations in the domain 4 is shown in Fig.2.

2.2 Engineering Developments

The real-time operation of the RT-FDDA system requires much software engineering initiative to ensure the reliability and good performances. Friendly user interfaces are needed for users to use the product and report problems conveniently. The major engineering accomplishments on the project are summarized as followings:

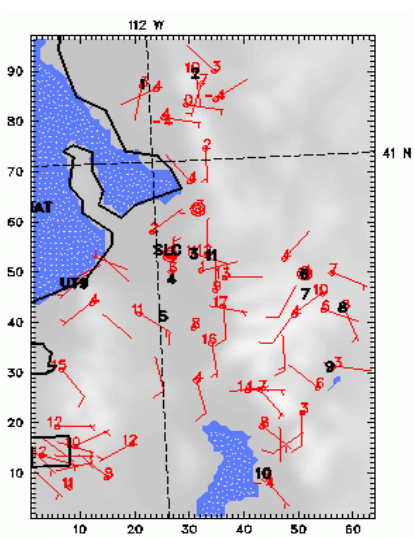

Fig.2 Distribution of the surface observations on the Domain 4, at 13Z, Feb. 23, 2002. (Wind barbs and temperature are labelled.. The stations are located at the end of the wind feathers. The ten Oplympic venues are labelled by heavy solid numbers.

1). Enhanced data quality control (QC): Observation quality control is one of the critical components for any data assimilation/analysis system, especially for the SLC RTFDDA system with very diverse data sources. The data quality control in RTFDDA was built on the existing “little_r” QC module. The accurate 1 - 3 hour RTFDDA cycling forecasts were interpolated to every 25 hPa and used as the first guess fields for the “litte_r” to conduct consistency, error-max and buddy checks. Besides numerious modifications on the little_r on specific observations, one of the large revision is to enhance the “little_r” to examine the observations which are not located on or close to the pressure levels of the first guess fields. Previously, these data are not QC-ed or ignored. This change allows all data to be examinated, at least, by the error-max. It is very valuable to the single-point upper-air observations such as ACARS and satellite wind observatons, and the high vertical resolution observations of wind profilers, RASS and others as well.

2). Redundant Model Application Clusters(MAC): Since the SLC RTFDDA was considerred mission-critical application, the system reliability and product availabilty should be addressed. Two 32-node duel-PIII-cpu with Myrinet interprocess links were used to run RTFDDA systems with the same configuration in parallel. One system was set at NCAR, Boulder, Colorado and the other was at the Dugway Proving Ground, Utah. The two systems ingested the same data, but from different channels, with a little bit different timing. Both systems ran indepenently, whereas, their products were coordinated to present the best model data. Thus, the user could always access “good” model data as long as the two systems are not down at same time.

3). Web-based Graphic User Interface (GUI): The rapidly cycling RTFDDA system generates enormous data and products during the operation. It produces a total of 144 hour analyses and forecasts from 8 cycles in a single day. About 250 pages of plots were generated for the model output at each stage at each hour. To permit the users to easily browse the products of their interest, an advanced web application was built. On the web page are also real-time model verification statistics, controls for uploading the real-time model data in appropiate formats to drive dispersion models, and a complete suite of the system status reports.

4). System monitoring: closely monitoring the data feed/usage and evaluating the scientific performance of the system during operation are necessary. In addition, because of the "restart-featured" continuous model runs from one cycle to the next, it is necessary to maintain the system running continuously. A 7/24 on-call support was provided.

5). Networking for data transfer and archiving.

3. PERFORMANCE AND VERIFICATION

The RTFDDA system successfully operated during the Olympics period. Its products were available at more than 99.5 % time, higher than all other models used in the Olympic weather prediction and surport. In general, the real-time verification statistics, the daily usage and evaluation of the model by weather experts and frequent subjective comparison of model cloud/precipitation with radar and satellite observations indicate a reasonable performance of the system. The RTFDDA was able to depict many details of the local circulations and precipitaion distributions, as forced by local thermal contrasts and/or topographic affects of synoptic weather systems.

After completing the real-time operation, verification statistics against twice-daily rawinsonde observations and hourly surface observations were carried out and averaged for different periods. Given the large temporal and spatial variations of circulations in the local scale weather systems, the verification may not be viewed as an *absolute* measure of the system performance. Nevertheless, these statistcs still provide valuable guides in evaluating the relative performances of the system.

Fig. 3 shows the diurnal evolution of the mean absolute errors of surface variables from the RTFDDA analyses and forecasts. The analyses appear to fit the observations generally well. On average, the MAE of the surface temperature analyses is about 1.5 C and the vector difference of the surface winds is about 2.75 m/s. The model error increases with the forecast length, which re-enforces the advantage of the mitigated "spin-up" forecasts from the system and the benefit of the continuous updating of shorter forecasts for a specific time through the system cycling. Comparing the errors of forecasts of different lengths, it is seen that the errors accumulate quicker during first several hours of the forecast than the long forecasts. The MAEs of surface temperature, specific humidity and wind vector differences of the 4 - 6 hour forecasts increase by 0.5 C, 0.3 g/kg and 0.3 m/s respectively, from those of the analyses, while the error differences between the 4 - 6 hour and 10 - 12 hour forecasts are much smaller (Fig.3). Among the many factors responsible for the large error increase during first few hours is the sparse upper-air observations (mostly the twice-daily conventional upper-air rawindsondes) which may not closely represent the synoptic environments of the local circulations.

After looking at the overall performance of the system, it is of interest to examine more detail of the verification. Fig.4 depicts the hourly error evolution of surface tempera-

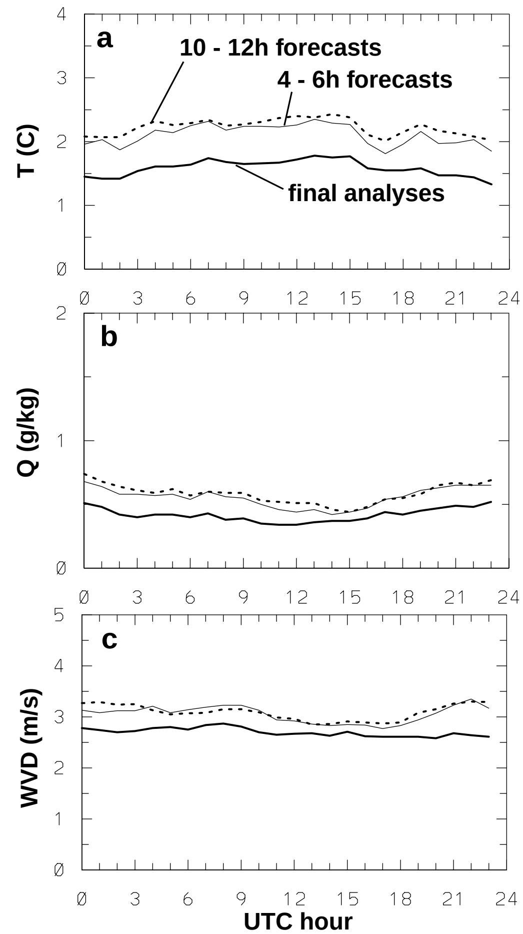

Fig.3 Diurnal changes of the mean absolute errors(MAE) of the rtfdda analysis (heavy solid), 4 - 6 hour forecasts (thin) and 10 - 12 hour forecasts (dashed) of the surface temperature (a), specific humidity (b) and wind vector differences (c) on the Domain 4, averaged during the Olympic period (Feb. 6 to Mar. 16, 2002).

ture analyses, and surface wind analyses and 4 - 6 hour forecasts over the Feb. 6 - Mar. 16, 2002 period. Obviously, the errors occillated with time in several modes: diurnal changes, 3 day occillations and 6 - 7 day occillations. The diurnal error changes are evidently related the diurnal changes of PBL regimes due to the surface heat forcing, while the 3 day and 6 -7 day changes may be related to the periods of synoptic scale waves. The phases of the wind error evolution are consistent with the thermal errors. Another notable feature in Fig. 4 is those of short-period (1 to several hours) but large error peaks, where the temperature MAE excesses 3 C and wind error > 3 m/s. Some of these peaks are associated with the weekly "cold-start" of the system (e.g. Day 10 and Day 17), and the others may be related to some specific weather processes. We are in the process of analyzing these features in more detail.

Finally, let us see how the analyses and forecasts of the fine-resolution RTFDDA system are comparable to those from other operational models. Analyses (0 h forecasts) and forecasts from RUC, ETA and AVN were verified gainst the observations on the RTFDDA Domain 4 and compared with the corresponding RTFDDA products. Fig. 5(a) shows the MAE of surface wind directions from the three-hourly RUC and RTFDDA analyses, averaged between Feb. 3 and Apr. 30, 2002. ETA and AVN analyses at 00Z and 12Z were also marked. The analyses from all models exhibits same trend of the diurnal changes, but the RTFDDA analysis are systematically about 15 degrees better than the RUC and 7 - 10 degrees better than ETA and AVN. The maximum correction of wind directions by the RTFDDA occurs at around 12Z. Starting from the better analyses, the RTFDDA forecasts are also superior to all other three models, as indicated by the comparison of the 6 h forecasts of all models (Fig.5(b)).

4. ON-GOING WORK AND FUTURE PLAN

Our major on-going work is summarized below:

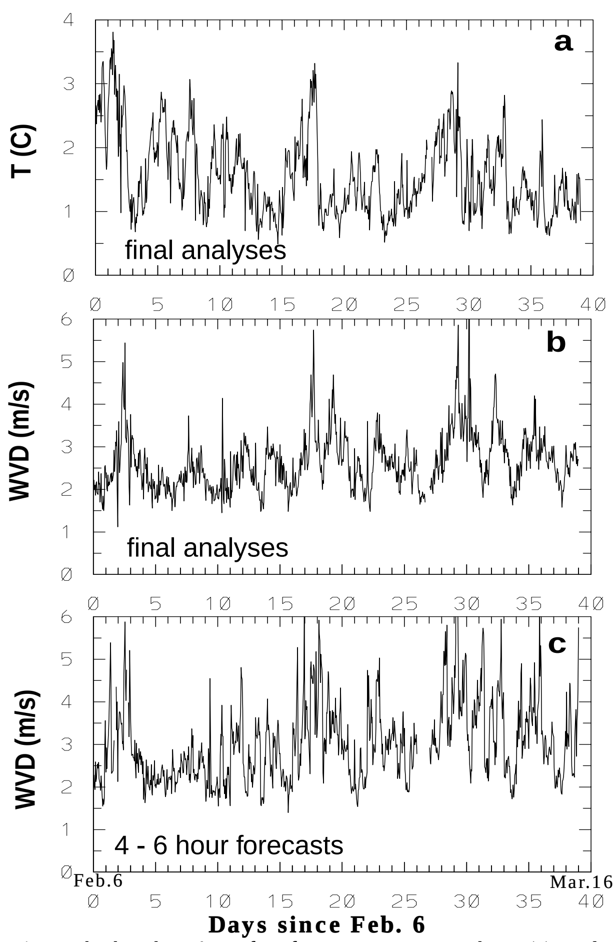

Fig.4 The hourly MAEs of surface temperature analyses (a), and and wind vector differences of the analyses (b) and the 4 - 6 hour forecast (c), calculated against surface observations on Domain 4 during the Olympic period.

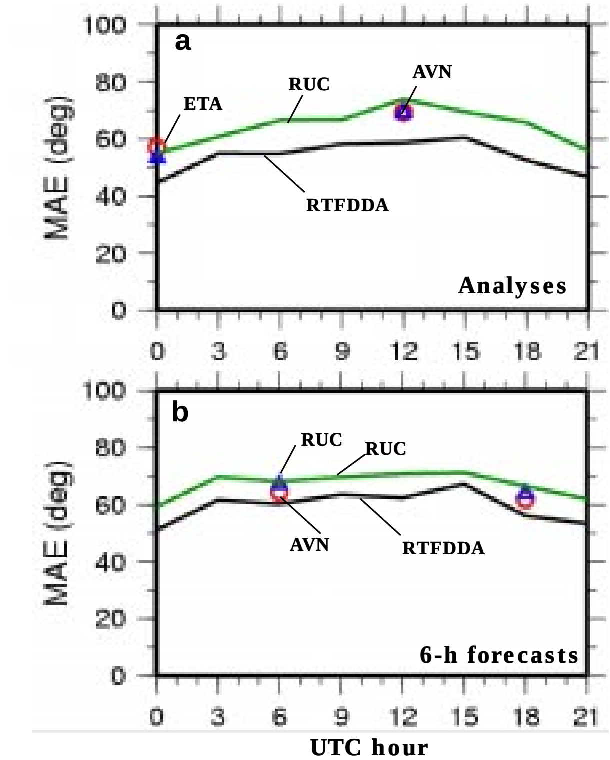

Fig.5 Comparison of wind direction errors of RTFDDA analyses and forecasts with those of RUC, ETA and AVN on the Domain 4, averaged during Feb 3 and April 30

1). incorporating more observations, especially the the upper-air data, such as data from ACARS, NOAA NPN-profilers and BLP-profilers, and NOAA quick-scan statellite winds.

2). optimizing the nudging-parameters (spatial and temporal weights, infuence radius and nudging coeffiecients) and incorporating terrain effects on the horizontal weight and observation errors.

3). combining with 3DVAR technology to improve the data assimilation mechanisms and incorporate non-conventional observations, including satellite brightness temperature, GPS precipitable water and Doppler radar volume-scans, and

4). carrying out more rigorious verification studies and adjusting model physics paramerizations.

REFERENCES

Cram, J.M., Y. Liu, S. Low-Nam, R-S. Sheu, L. Carson, C.A. Davis, T. Warner, J.F. Bowers, 2001: An operational mesoscale RT-FDDA analysis and forecasting system. *Preprints 18th WAF and 14th NWP Confs*., Ft. Lauderdale, AMS, Boston, MA.

Horel, J. and co-authors, 2002: Mesowest: cooperative mesonets in the wester United States, *Bull. Amer. Meteror. Soc*., **83**, P211-225.

Liu, Y. and co-authors, 2002: Performance and enhancements of the NCAR/ATEC Mesoscale FDDA and forecasting system. *Preprints 15th NWP Confs*., San Antonio, AMS, Boston, MA.

Stauffer, D.R., and N. L. Seaman, 1994: Multiscale four-dimensional data assimilation. *J. Appl. Meteor., 33, 416-434.*