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OPERATIONAL USE OF REAL-TIME FOUR-DIMENSIONAL DATA ASSIMILATION AT DUGWAY PROVING GROUND

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1. Introduction

Dugway Proving Ground (DPG) is a major U.S. Army test range where mission includes field tests of chemical and biological defense systems, military smoke and obscurants, artillery, and various other Department of Defense (DoD) materials. Many of these tests require DPG meteorologists to provide accurate forecasts of winds, precipitation, lightning, and other hazardous weather with a lead-time of 1-12 hours. The accuracy of these forecasts can have huge impact on test costs, schedules, logistics, and safety.

DPG is located at the southeast corner of the Great Salt Lake Desert at a base elevation of 1310 m. The majority of DPG tests occur on a grid that is bounded by a 2135 m peak to the west, salt flats to the north, a mountain range with elevations between 1675 and 2135 m. to the northeast and east, a small isolated peak to the east at 1675 m, and a gradual upslope to south. The main testing area is relatively flat, except for slight inclines on the east and west side. The desert climate provides a vegetative cover ranging from short grass to scrub brush as high as one meter. This type of orography makes it difficult for synoptic scale forecast models (e.g. Eta and Aviation), to predict mesoscale wind circulations and precipitation. The two most common types of mesoscale circulation at DPG are the salt breeze and mountain valley circulation. The salt breeze is caused by a thermal gradient between the salt flats (also know as the playa), and the surrounding desert region. The playa is a white salty crust about 5 mm, which reflects more incoming solar radiation than the dark basalt found in the surrounding higher terrain. Therefore, daytime temperatures over the playa are cooler than surrounding surfaces, while nighttime temperatures are warmer. The physics here act analogous to a lake breeze circulation. The location of the salt flats relative to DPG test grids creates northwesterly winds over the grids during the day. At night, when the playa is warmer than surrounding surfaces, southeasterly winds analogous to land breeze are predominant. The salt breeze circulation is most reliable during the summer and early autumn, and dispersion test planning often relies on this type of wind flow, Davis et al (1999).

Mesoscale models are the only types of models currently available to DPG meteorologists that are able to forecast these types of circulation, because they can resolve mesoscale variation in local terrain, land surface characteristics, and incorporate DPG meteorological data. DPG's Four-Dimensional Weather (4DWX) System was

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developed by NCAR/RAP to address these problems (Shantz, 1996). The 4DWX system executes the Penn State/NCAR MM5 model (Grell et al., 1995) twice daily with three or four nested computational domains (Shantz, 1996). The two inner domains (Domain 3 and 4, with grid spacing of 3.3 and 1.1 km respectively) are centered over DPG and resolve the local topography and land surface characteristics. These operational forecasts, which until recently have been the primary source of four-dimensional mesoscale data, have proven to be superior to the synoptic-scale National Centers for Environmental Prediction (NCEP) models for predicting DPG boundary layer winds. However, each MM5 forecast begins with a cold start from an objective analysis of all available observations onto the NCEP Eta model forecast, which create spin up problems early in the forecast. One solution would be to nudge the model towards observations for a period of several hours before the beginning of the forecast to avoid a cold start. The recent development of the 4DWX Real Time Four-Dimensional Data Assimilation (RT-FDDA) capability combines this benefit with much more frequent updates of short-term forecasts.

2. RT-FDDA Overview

RT-FDDA is an assimilation/forecast system developed for DPG by NCAR/RAP and described more thoroughly in Cram et al. (2001). The assimilation system is based on Newtonian relaxation of observational data into the MM5 model (Stauffer and Seaman, 1994; Grell et al., 1995). The mesoscale model is nudged continuously in order to obtain the best analysis of the current state of the atmosphere, (Nelson and Seaman, 1994). Model forecasts, which use RT-FDDA for initialization, have been shown to score better than non-RT-FDDA forecasts, given identical model physics and spatial resolution (Cram et al., 2001).

The 4DWX RT-FDDA system uses the MM5, and consists of three nested computational domains as shown in Figure 1. The largest domain has 30-km grid spacing and covers the western US. The middle domain has 10-km grid spacing and covers Utah and eastern Nevada. The smallest domain has 3.3-km grid spacing and is centered over DPG. There is two-way interaction between the inner and outer domains. The vertical resolution has 31 sigma levels between the ground and approximately 50 hPa. The model resolution and physics capture both the synoptic features, (e.g. cyclones, fronts, etc.), and mesoscale features, (e.g. salt/lake breezes, mountain valley circulations, etc.).

The RT-FDDA system uses traditional observations (e.g. metars, ship/buoy reports, rawinsonde), and also uses non-traditional observations e.g. local and regional mesonet, profilers, and satellite winds. The continuous aspect of the RT-FDDA system allows for the incorporation and usage of asynoptic observations such as specials and high frequency mesonet and profiler observations. Local mesonet observations for the Intermountain Region are provided courtesy of the Meteorology Department at the University of Utah, which compiles and disseminates observations from remote automated surface weather stations from a consortium of contributing agencies (e.g., DPG, University of Utah, National Weather Service, Bureau of Land Management, Department of Transportation, etc), and the private sector, (Horel et al., 2000). Profiler data used by the DPG RT-FDDA system include data from two DPG profilers. National Environmental Satellite, Data, and Information Service (NESDIS) satellite wind data are only available at 3 hourly intervals, with random locations and levels.

The DPG RT-FDDA system operates with a 3-hour cycling method. Every three hours in real time, three hours of final analysis, 3 hours of preliminary analysis and a new 12-hour forecast are produced. The MM5 model in each new cycle is restarted from the previous cycle's final analyses, thus avoiding spin-up problems. Again, the system is described more thoroughly in Cram et al., (2001).

3. Usage by the Operational Forecaster

How does the operational forecaster make use of RT-FDDA in preparing forecasts? The quantitative RT-FDDA forecast products are similar in many ways to typical mesoscale model forecast products. However, RT-FDDA is continuously generating new 12-hour forecasts eight times a day, in contrast to most operational mesoscale models that currently run twice a day for a 24-48 hour forecast. RT-FDDA data need to be available to some forecasters receiving data on low bandwidth network, (e.g. a modem). Because transporting even a small gridded data set is impractical, a web page was developed to organize and display this suite of static images on the Internet. The images load quasi-instantly over an Ethernet, but still load within a few seconds using a modem connection. The web page is setup to display a matrix of images statically, animatedly, or juxtaposed. The choices of products are defined in a row of pull down menus. These pull down menus control the run cycle, domain, time, fields, variables, animation, etc. For more information, visit the following URL; http://www.4dwx.org/model/fddad22.html

DPG meteorologists are responsible for forecasting plume concentrations and movement prior to and during dissemination tests. While crude estimates of plume movement can be made using RT-FDDA suite of images, plume concentration and dosages are nearly impossible for a human to forecast. Therefore, DPG meteorologists use the Second Order Integrated Puff (SCIPUFF) Gaussian dispersion model (DTRA, 1999) to analyze and forecast the plume movement and concentration. The SCIPUFF model uses RT-FDDA data as it's 4-dimensional meteorological input, and then computes the gaseous/aerosol spatial resolution of the plume and plume movement. The advantage of using RT-FDDA for SCIPUFF input is providing the test director a more accurate visual tool of the plume. Frequent RT-FDDA runs may adjust the previous forecast runs, and therefore allows the test director the opportunity to move their samplers to a more advantageous location.

One of the RT-FDDA products is the Multiscale Environmental Dispersion Over Complex Terrain (MEDOC), which is a four-dimensional data set for input into SCIPUFF. A web page was developed to retrieve the latest RT-FDDA forecast along with the current final and historical final runs on the Internet. The data can be retrieved for a 1-hour period or a block of multiple 1-hour periods. The block sizes are approximately 5 MB per 1-hour period. Therefore a 5-hour period is 25 MB.

4. Test Example

Active testing has allowed DPG meteorologists to use RT-FDDA to assist in providing improved test forecast support. It also allowed them to compare it with observations and other forecast models. At any time of the year, two different forcing mechanisms can impact the local wind circulation over DPG: synoptic and mesoscale. During weak synoptic forcing, durnal circulations are dominant. Strong synoptic forcing, e.g. pre-frontal and post-frontal winds, can override the local diurnal circulation. However synoptic forcing can reinforce the diurnal circulation creating higher wind maxima. For example, synoptic pre-frontal south winds will help to enhance the nocturnal southeasterly flow. Mesoscale forcing, e.g. cloud-cover, precipitation, and convection can also impact the local diurnal circulation.

A dissemination trial occurred during the early morning hours of 16 April 2001. The synoptic environment can be characterized by a high-pressure system centered over northern Utah with a high amplitude ridge in the upper levels. Skies were generally clear, except for some passing high thin cirrus overhead and north. Soundings during the early morning period suggested a PBL depth of approximately 90-m. Figure 2 shows the actual wind-field centered over the testing area for 0900 UTC. A southeasterly wind flow can be seen over the test grid between Granite Peak to the west and the Cedar Mountains to the northeast and east.

A 6-8 hour plume forecast two hours prior to the start of the dissemination was provided to the test director to facilitate the final go/no go decision. Both the 1200 UTC 15 April 2001 standard MM5 model run (traditional initialization) and the 0300 UTC 16 April 2001 RT-FDDA run were used in forecasting the plume's spatial resolution and movement. Two-hours of the SCIPUFF-modeled dissemination using the 1200 UTC MM5 model run output can be seen in Figure 3. After two hours, at 0900 UTC, the plume can be seen moving from east to west. Therefore, the samplers would not have detected the highest concentration of simulant. The two-hour SCIPUFF model run using 0300 UTC RT-FDDA run output is shown in Figure 4. The 0900 UTC plume can be seen moving north and northwest, and therefore the samplers would have detected the highest concentration of simulant. The onsite DPG meteorologist suggested to the test director that the environmental conditions were favorable, based on the RT-FDDA model and considerable experience of forecasting at DPG. The test director then made a go decision for a dissemination trial.

A post-test follow-up with the test director indicated sampler readings were found to the northwest to north of the dissemination point. This closely matched the 0300 UTC RT-FDDA forecast run and was verified by Figure 2. If the standard-initialized MM5 model had been followed, the test director could have made a no go decision, which would have impacted test costs and schedules. The continuously updating RT-FDDA system and its forecasts produced more realistic wind fields resulting in a successful test night.

5. Summary

The short time the RT-FDDA has been operationally available to DPG meteorologists; the model has proven to be a powerful tool for short term forecasting. The RT-FDDA forecasts on the web page and MEDOC retrieval are quick and easy use. This has reduced time and increased forecast skill. One caveat is that RT-FDDA has only been available to DPG meteorologists since fall of 2000, and therefore, there are currently only a few statistics showing model performance. The summer monsoon season over DPG, during the mid to late summer months has yet to be tested and should prove to be an interesting challenge for this model.

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Stauffer, D.R. and N.L. Seaman, 1994: Multiscale Four-Dimensional Data Assimilation. J. Applied Meteor., **33**, 416-434.

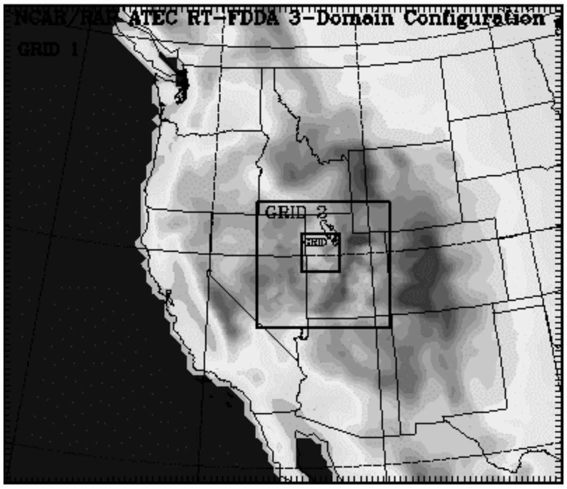

Figure 1. DPG RT-FDDA 3-domain configuration**.**

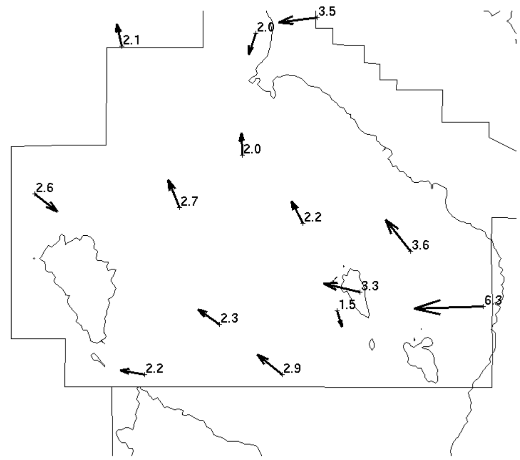

Figure 2. 10 m surface wind observations of wind vectors with wind speed (ms^{-1}) in the upper right corner from the DPG surface atmospheric measurement system (SAMS) at 0900 UTC on 16 April 2001**.**

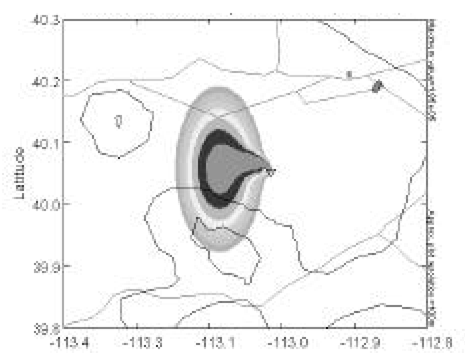

Figure 3. SCIPUFF model 2-hour dissemination using the once daily 1200 UTC 15 April 2001 MM5 forecast valid at 0900 UTC 16 April 2001. The plume originates at the triangle centered above, and dissemination started at 0700 UTC. The plume is contoured linearly between 10^{-12} to 10^{-7} kg m^{-3}.

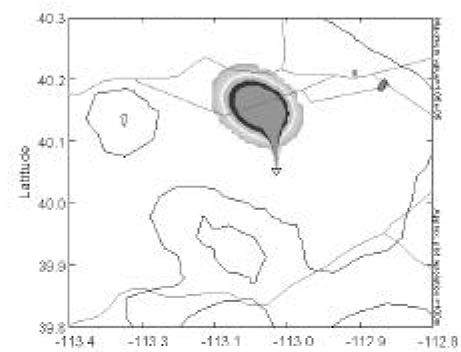

Figure 4. SCIPUFF model 2-hour dissemination using the 0600 UTC 16 April 2001 RT-FDDA forecast valid at 0900 UTC 16 April 2001. The plume originates at the triangle centered above, and dissemination started at 0700 UTC. The plume is contoured linearly between 10^{-12} to 10^{-7} kg m^{-3}.