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Meteorological Forecast Model Applications to Aerodynamic Decelerators

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The ability to deliver airdrop cargo loads precisely is vitally important to U.S. military operations. A critical factor affecting airdrop precision is the state of the atmosphere (winds and air density) through which the parachute descends. Instruments such as weather balloons and, more recently, "dropsondes" (parachute-borne devices that measure the winds near the cargo drops), provide detailed meteorological information for determining the required parachute release point. However, it might not be feasible to obtain atmospheric soundings using these instruments, either close enough to the intended target or during the time frame of the airdrop operations. In these cases, the use of a high-resolution meteorological computer model becomes extremely desirable. Such a model can predict the necessary atmospheric parameters at the location and time of interest. The evaluation of one such computer model in its application to airdrop operations is addressed. Model output is statistically evaluated against balloon and dropsonde soundings and also is incorporated into an airdrop simulator for comparison against actual parachute trajectories. Model comparisons against the in situ measurements showed very close correlation. Inputting the model predictions to the parachute simulator yielded less accurate, but still promising, results for the single case study that was available.

Introduction

THE current military methodology to determine a computed aerial release point (CARP) for an aerodynamic decelerator (parachute) incorporates winds measured by a radio wind sounding observation (RAOB) (a weather balloon) and assumes a constant parachute fall rate. Thus, the estimated displacement of a parachute by the wind in each discrete layer is just the west-to-east and north-to-south component wind speeds multiplied by the assumed dwell time in that layer. The individual layer displacements are summed to obtain the total estimated wind drift. The CARP then is found simply by offsetting a distance upwind that is equal to the total wind drift. For precision aerial delivery (PAD) operations to truly be precise (where the parachute impact would be as little as 50 ft from the intended target), this method of CARP determination can often be inadequate. Numerous decelerator aerodynamic factors, the initial velocity vector induced by the release aircraft, increasing atmospheric density as the parachute descends, and even vertical air currents, can all affect the impact point.

The New World Vistas (NWV) program is a basic research effort exploring methods to improve the airdrop delivery accuracy of supplies and equipment during military operations. In part, the NWV program involves the development of a CARP simulator called the Precision Airdrop Planning Software (PAPS) and a wind/atmospheric density predictor called the Wind-profile Precision Air Delivery System (WindPADS).[1] The PAPS is a laptop computer-based software system that calculates a CARP onboard the C-130 carrier aircraft while enroute to the drop zone (DZ). The PAPS requires the most accurate and up-to-date wind/density values possible along the parachute descent trajectory, to determine the CARP properly. The WindPADS (hosted on a separate laptop computer) addresses this need by receiving input from a meteorological forecast model called MM5 (Ref. 2). The MM5 is termed a mesoscale forecast model in that it predicts atmospheric phenomena as small as 1–12 miles across (depending on the actual grid spacing used), including such phenomena as the effect of terrain on the wind flow. It runs on an SGI workstation, making 24 hourly predictions of various meteorological parameters at points within a three-dimensional grid. The hourly three-dimensional grids are transferred to the WindPADS laptop computer (via a local area net) that is then taken onboard the carrier aircraft. Conceptually, the three-dimensional grids would subsequently be updated as new meteorological data become available. (The updates are actually adjustments to the three-dimensional grids that are accomplished via a sophisticated meteorological data assimilation routine, similar to that being incorporated by the major meteorological prediction models utilized by the National Weather Service.) These new data might include a RAOB or an observation from a similar, parachute-borne device called a "dropsonde."[3] Dropsonde and RAOB data would be transmitted by radio link to the WindPADS and automatically assimilated. The operator while en route to the initial DZ transfers the updated three-dimensional grid into the PAPS laptop computer, and a revised CARP prediction is generated. A preliminary test series of the NWV system was conducted at the U.S. Army Yuma Proving Ground (YPG), Arizona, during the summer of 2001.

The NWV program's method of meteorological data acquisition and application to PAD operations is but one approach. One possible limitation of the NWV method is that the MM5 currently used can only be run twice per day, due to model initialization, computer platform, and run-time constraints. This limitation means that the three-dimensional forecast grid that is input to the PAPS could be a 12-h forecast (or longer). In tactical battlefield situations, it is desirable to utilize a mesoscale model that could be run more often as data become available, subsequently inputting more up-to-date predictions (3–6-h forecast three-dimensional grids) to a CARP predictor such as PAPS.

This study employed a different mesoscale meteorological model called the battlescale forecast model (BFM)[4] during the NWV test series at YPG. The term battlescale refers to a square on the order of 120–300 miles on a side that would encompass a typical battlefield or PAD operations area. [The BFM is currently fielded in a battlefield intelligence system called the Integrated Meteorological System (IMETS), housed in a Humvee-mounted shelter, where an Air Force Staff Weather Officer uses it for general forecasting and decision guidance purposes.] The BFM is similar to the MM5 in many respects, in terms of the dimensions of its grid size and the types of meteorological parameters it predicts. However, unlike the MM5 and most other mesoscale forecast models, the BFM incorporates an implicit time-integration method that decreases its run time

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and platform requirements significantly (approximately 30 min for a complete 6-h forecast run, as opposed to several hours being needed for other mesoscale models), allowing it to run on either a desktop or laptop computer. An added advantage of the shorter run time is that new atmospheric sounding data can be readily incorporated for fresh model runs. This model has its roots in a model of the atmospheric boundary layer, and it is thought to be able to predict low-level winds very well. A potential drawback of the BFM is that it cannot incorporate some types of meteorological data, for example, satellite imagery, and it is not considered to be as sophisticated a model as the MM5 because of simplifying assumptions about the structure of the atmosphere. Consequently, one of the goals of this research was to determine whether the BFM's accuracy was adversely affected by these limitations.

Mesoscale forecast models have only become available for use in general public weather forecasting applications at major meteorological forecasting centers during the past several years. The employment of a mesoscale model in a tactical military setting (distant from major meteorological forecast centers) is somewhat in its infancy (at this point just the use of the BFM in the IMETS), due to computational, communications, and data acquisition constraints that are inherent on the battlefield. The development of the NWV WindPADS concept was a significant stride toward the use of a new kind of meteorological data (model predicted instead of RAOB measured) for a military airdrop operation. The use of the BFM during the NWV testing was another important step in the modeling development process, in which a mesoscale model was run in the field and its data applied in near-real time to a CARP simulation. (However, the BFM output was not formally utilized as a part of the NWV testing.) As computer processing speeds increase, more sophisticated models such as the MM5 may eventually be run on site in a similar fashion.

The study involved three general areas of research: 1) running the BFM for some earlier YPG airdrop test days and comparing the results to RAOB and dropsonde data, 2) applying the BFM output in a separate CARP simulator (i.e., not the NWV PAPS) that was developed in house by the YPG test community [a MATLAB®/Simulink-based model (MS-CARP)], and 3) participating in the summer, 2001 NWV flight demonstrations at YPG of a partially guided decelerator called the Affordable Guided Airdrop System (AGAS).[5] The AGAS onboard guidance system employs gas-powered pneumatic arms to steer the parachute autonomously toward a predetermined optimal descent trajectory. Although the AGAS possesses a steering capability, accurate meteorological data in the airdrop area are still critical for a correct reference descent trajectory to be established.

BFM

The BFM version used in this work is part of the Computer-Assisted Artillery Meteorology (CAAM-BFM) project.[6] The CAAM-BFM comprises three modules: preprocessing, the actual predictive model, and postprocessing. The preprocessing or initialization module consists of input file handling routines and a three-dimensional objective analysis (3DOBJ) routine that captures all recent local and large-scale meteorological data available at the forecast time and that produces the initial fields required to start the forecast module. BFM initialization data used for the NWV-PAD cases consisted of forecast fields from the Navy Operational Global Atmospheric Prediction System (NOGAPS) 1° latitude/longitude horizontal grids that are available at the standard meteorological pressure levels up to about 100,000 ft (10 mbars) (Ref. 7). (Such fields are required for any mesoscale model to help account for larger-scale atmospheric changes at the desired forecast hour.) Additional initialization data came from standard regional RAOBs launched twice each day at several locations across the southwestern United States. The last source of initialization data was a local RAOB launched near the target area 1.5–6 h before each airdrop. The BFM (as for any mesoscale model) is known to produce more accurate forecasts when initialized with a local RAOB. All initial data are interpolated to 55 flat levels by the 3DOBJ, and an analysis is performed to produce data at each horizontal grid point at each level. Finally, the flat levels are linearly interpolated in the vertical to the 32 terrain-following levels required by the forecast module. The interpolation to terrain-following levels requires a terrain database. In most cases, a worldwide military terrain database called the Digital Terrain Elevation Database is used by the BFM, as was the case for the YPG testing analyses.

The forecast module used as part of the BFM package is Yamada's higher-order turbulence model for atmospheric circulations (HOTMAC).[8] This module accepts the 3DOBJ output and conducts the actual predictive process. To produce the true 0-h wind fields in a dynamically adjusted fashion, a 3-h model spin-up integration is performed. During the spin-up, model surface temperatures can also be nudged to recorded surface observations from the surrounding area that are valid at the initial model time. HOTMAC also includes physical parameterizations for turbulent mixing, both long- and short-wave radiative transfer, the surface energy budget, and cloud and precipitation formation. During the HOTMAC run, forecast output is produced by solving the atmospheric predictive equations in a hydrostatic formulation along with nudging of the parameters toward the larger-scale NOGAPS solutions.

The third BFM module consists of postprocessing of HOTMAC output to produce forecasts of five standard variables: temperature, wind speed, wind direction, moisture, and height or pressure at each level output at a 3-mile horizontal grid resolution across approximately a 120×120 mile domain centered near the YPG Sidewinder target area (at approximately 32.9°N latitude, 114.4°W longitude).

A follow-on postprocessing routine was developed specifically for the NWV testing. This routine, called PARADROP, reformatted the three-dimensional BFM output grid appropriately for ingest into MS-CARP. PARADROP also interpolated the data from the three-dimensional grid points to a slant-path atmospheric sounding, such as is produced by a dropsonde (Fig. 1). The interpolation was a three-step process: 1) data (wind, temperature, and moisture) were interpolated (both horizontally and vertically) from the surrounding grid points to a vertical line directly above the target location, at 100-ft height increments from the surface up to 25,000 ft above ground level; 2) the wind direction and speed at each 100-ft increment in this vertical sounding were then used to estimate a slant-path parachute trajectory, assuming a 28-fps vertical descent rate (standard descent rate of the AGAS G-12 parachute used during the NWV testing at YPG); and 3) the data were interpolated from the surrounding grid points to the estimated slant-path descent trajectory.

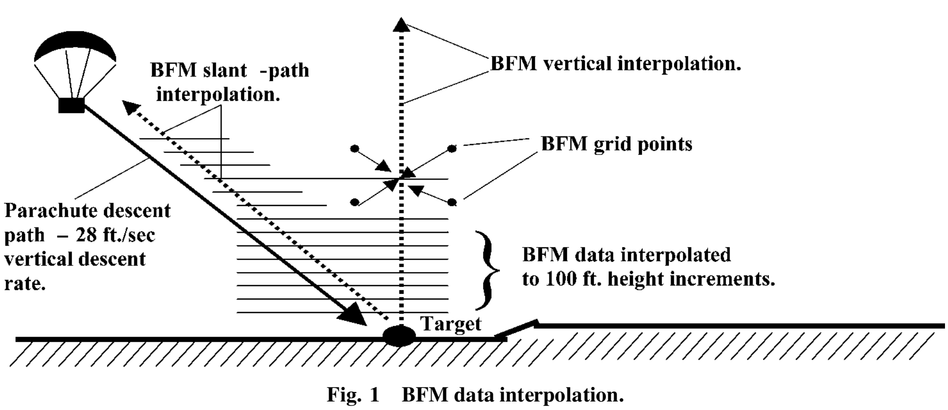

Fig. 1 BFM data interpolation.

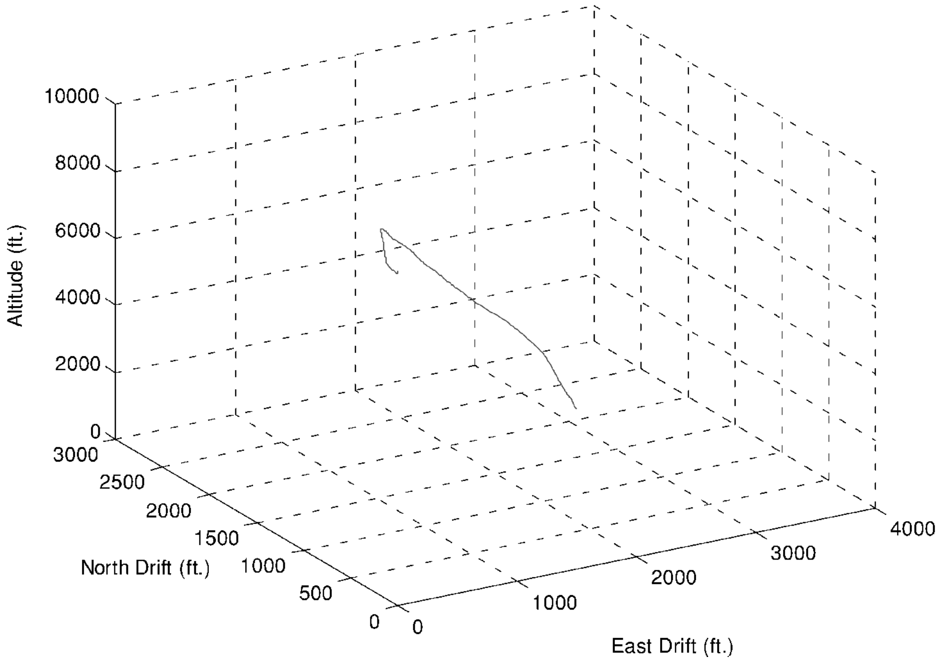

Fig. 2 MS-CARP three-dimensional output.

MS-CARP

The MS-CARP predictor incorporates the AGAS G-12 parachute's coefficient of drag, drop point altitude, and a meteorological file containing wind component speeds (feet per second) and atmospheric density values (slugs per cubic foot). It then solves the equations of motion to predict the parachute's descent trajectory (Fig. 2). The MS-CARP also provides a numerical output that indicates the distance the parachute drifted along the x and y axes (corresponding to the U or west–east and V or south–north wind components, respectively) during the simulation. The air density at the various levels during the descent determines the fall velocity and, hence, the time of flight through each layer, and was included in the meteorological input file. However, a minor glitch in MS-CARP prevented the use of the density data in the calculations. Atmospheric density was set at 0.0024 slugs/ft^3 resulting in a constant G-12 fall velocity of about 28 fps.

Direct Meteorological Data Comparisons

The first phase of the research involved direct comparisons of BFM data with RAOBs and dropsonde observations. Figures 3–6 are graphical examples of these comparisons for the U component of the wind (west–east being positive numbers), the V component of the wind (south–north being positive), temperature, and air density. (Note that the temperature was not a required parameter in these CARP calculations and was included here only to further illustrate the predictive capabilities of the BFM.) Heights are above mean sea level (MSL). The symbol B-1000 is the BFM forecast, valid at 1000 local L YPG time (mountain standard time). R-1000 and R-0500 are the RAOBs taken at 1000L and 0500L, respectively. D-1000 is the 1000L dropsonde observation. For the 23 January 2001 case, the BFM was initialized using the 0500L RAOB; consequently, the B-1000 line indicates the results of the 5-h forecast.

Starting with the U component (Fig. 3), the BFM plots at most of the levels below 11,000-ft MSL were closer to the R-1000 plot than the R-0500 plot. (Note that the U-component dropsonde winds have been omitted because they tended to overlay the other symbols closely and created excessive clutter on the plot.) This indicates that the model correctly predicted a change in the winds over the 5-h period.

The predictive skill of the BFM is more evident in the V-component graph (Fig. 4). Above 8000-ft MSL, the V component changed substantially between 0500L and 1000L (from in excess of

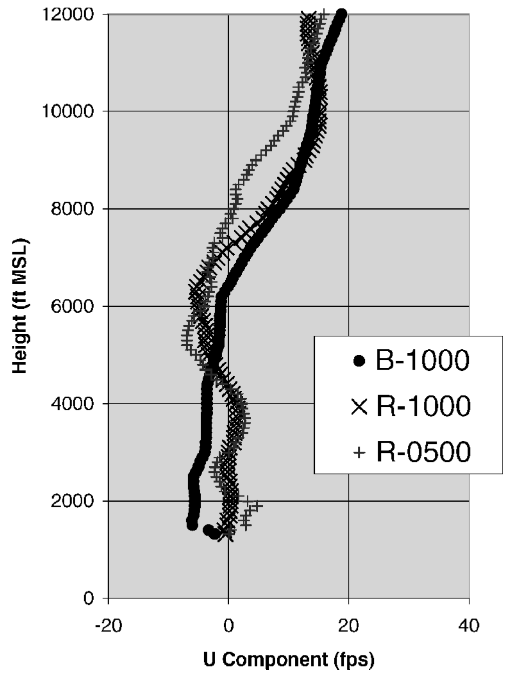

Fig. 3 U-component winds.

−30 fps to around −10 fps). The BFM correctly predicted this trend. The dropsonde trace shows considerably more fluctuation than either of the RAOBs or the BFM. This is because the dropsonde is essentially raw data measured at a frequency of 10 Hz, whereas the RAOB data are smoothed by the ground receiver station's software, and the BFM values are interpolated. Still, there appears to be reasonably good visual correlation between the V component of the model and the dropsonde. Statistical correlation data will be presented hereafter.

The temperature plot (Fig. 5) and the density plot (Fig. 6) do not include dropsonde values because the particular instrument used during the NWV test series does not measure temperature, pressure, or humidity (needed for density calculation). (Note that there are several commercial dropsonde systems available that do measure the meteorological parameters necessary to calculate air density.) The RAOB plots in Fig. 5 indicate that several degrees of

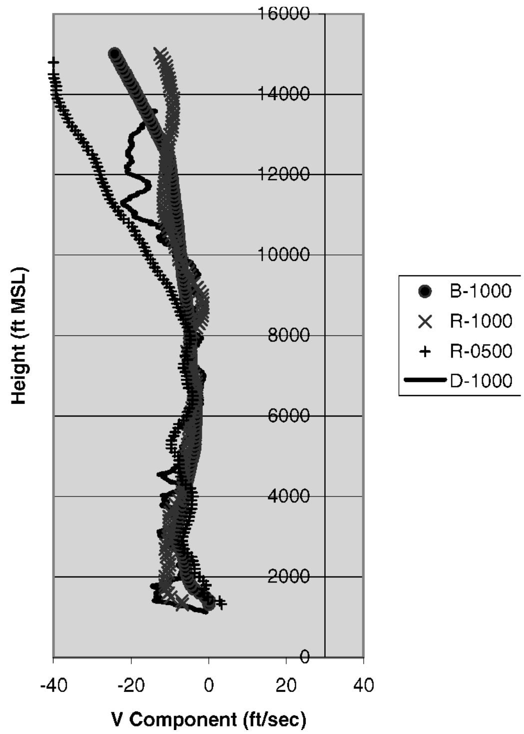

Fig. 4 V-component winds.

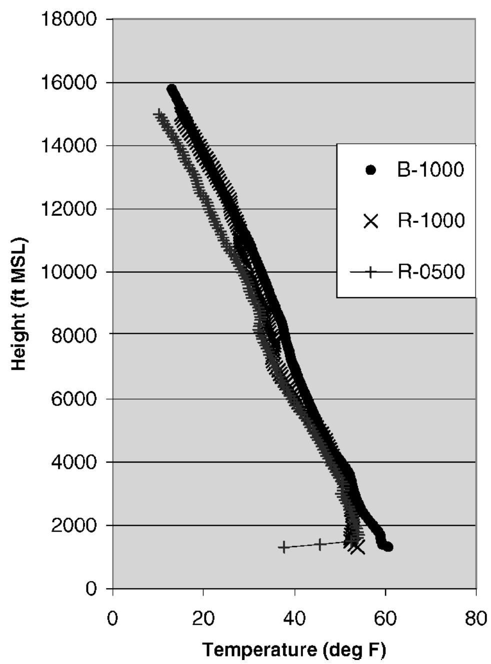

Fig. 5 Temperature.

warming occurred between 0500L and 1000L above 8000-ft MSL (which was probably due to the passage of an upper-atmosphere low-pressure trough). The BFM correctly forecast this tendency, especially above 11,000-ft MSL where its 5-h prediction plot for 1000L almost exactly overlays the corresponding RAOB taken at that time. Near the surface, the normal warming occurred during the morning hours. The BFM indicated this trend, although it was somewhat overpredicted.

The atmospheric density values depicted by the R-1000 line in Fig. 6 were almost exactly predicted by the BFM. However, there was essentially no density change at most of the levels from 0500L to 1000L in the RAOB values; hence, little model skill was required in this case to predict this parameter.

Table 1 MEAN and SD between BFM-predicted and RAOB-measured parameters

	Mean/SD		
Date	U component, fps	V component, fps	Density, slugs/ft^3
28 June 2001	+7.5/3.7	+4.4/4.6	$-1E-5/2E-5$
23 January 2001	+1.8/4.9	−0.2/4.3	$-1E-5/7E-6$
13 April 2000	−3.8/9.8	+0.3/7.3	$-3E-6/8E-6$
7 March 2000	−11.9/5.5	−8.8/10.4	$-2E-6/5E-6$

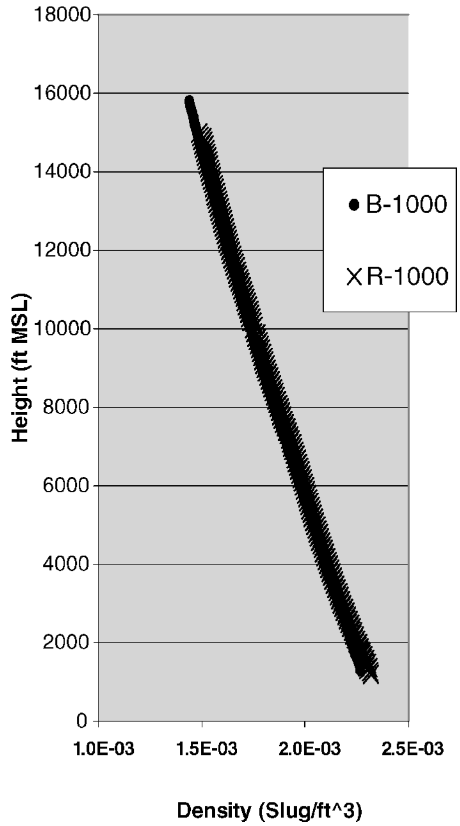

Fig. 6 Air density.

To quantify the direct comparisons between the BFM and the RAOBs, two statistical parameters were calculated, the mean difference and the standard deviation of the differences. The mean difference depicts forecast bias. It is the arithmetic average of the differences between BFM and RAOB at each 100-ft level, averaged over all of the levels from the surface upward to the decelerator drop altitude. The difference is the BFM value minus the RAOB value. For example, a positive mean difference indicates that, overall, the BFM values were greater than the RAOB values.

Table 1 shows the mean differences (mean) and the standard deviation of the differences (SD) for four case study days. The three parameters shown are the U (west–east, positive) and V (south–north, positive) wind components, and atmospheric density. For example, on 28 June 2001 the mean difference in the U component was +7.5 fps, meaning the BFM U component averaged 7.5 fps greater than that of the RAOB over all of the layers. As a point of reference, the wind speed accuracy of a RAOB instrument is usually given to be ±8.5 fps by manufacturers. Thus, the BFM predicted the wind speed components within the accuracy tolerance of the RAOB instrument for three of the four days. On 7 March 2000, the V-component prediction was just over the 8.5 fps threshold; however, the U component exceeded the threshold by 3.4 fps. Wind speed predictions such as these (which for the most part fall within the RAOB's accuracy tolerance) are consistent with those from a similar study of YPG winds during sense and destroy armor (SADARM) artillery firings.[9] These values could have been the result of rather constant differences from one level to the next, or from wide swings from positive to negative differences that just happened to average out to a relatively small number. The SD was also calculated to indicate which was the case.

The standard deviation of the U-component differences on 28 June 2001 was 3.7 fps. All of the SD values for the wind component differences were less than 10 fps, indicating that the differences remained fairly constant from level to level. Thus, although the BFM did not do a perfect job of predicting the wind components, it was for the most part well within the measurement accuracy of the RAOB, and its skill did not fluctuate significantly as a function of height. The mean and SD of the density differences were miniscule for all four days, indicating very close agreement between BFM and RAOB.

Comparison of Parachute Trajectories

Direct comparisons between the BFM and RAOB or dropsonde data are interesting, but of limited value in evaluating the model's ability to provide accurate data for CARP calculations. Consequently, a method was devised whereby CARP simulations (incorporating either BFM, RAOB, or dropsonde data) were compared against the actual parachute displacement (in the x and y axes) as measured by a YPG tracking radar. As explained in Ref. 3, YPG dropsondes are released simultaneously (or as close in time as possible) with the parachute loads, the intent being to sample almost the exact column of air that the main parachute will encounter. Thus, it was expected that the CARP simulations using dropsonde data would most closely correspond to the actual parachute tracks.

One case study, for 28 June 2001 at 1000L, has been fully analyzed at the time of this writing. (Unfortunately, complete data sets for most of the other case study days were not available, primarily because dropsonde data were not recorded.) Figure 7 shows the actual path over the ground that the AGAS traveled on that day, with north being the y axis and east being the x axis. The AGAS guidance system failed to operate during this airdrop and so this was a "ballistic" flight for which the parachute simply drifted with the wind, that is, there was no biasing of the ground track due to control system influence. The drop point was at the origin of the diagram at an altitude of 9300-ft MSL. Figure 7 shows that initially the parachute drifted toward the north-northeast, then almost directly northward. About midway through its descent the wind direction shifted, and the parachute drifted eastward. As the parachute neared the ground, another wind shift occurred, and the drift was back to the south. The landing point was 150 ft north and 1425 ft east of the DZ.

Figure 8 shows the result of the MS-CARP simulation for 28 June 2001 that incorporated the 1000L dropsonde wind file. The shape of the ground track in the simulation is quite similar to that of the AGAS path, although the impact point is about 850 ft farther to the north and east than the actual location. The differences between the two plots could be attributable to the dropsonde being released around 10 min before the AGAS load; thus, the winds could have changed somewhat in the interim. However, the very similar shapes of the two plots suggested a different explanation. Discussions with the

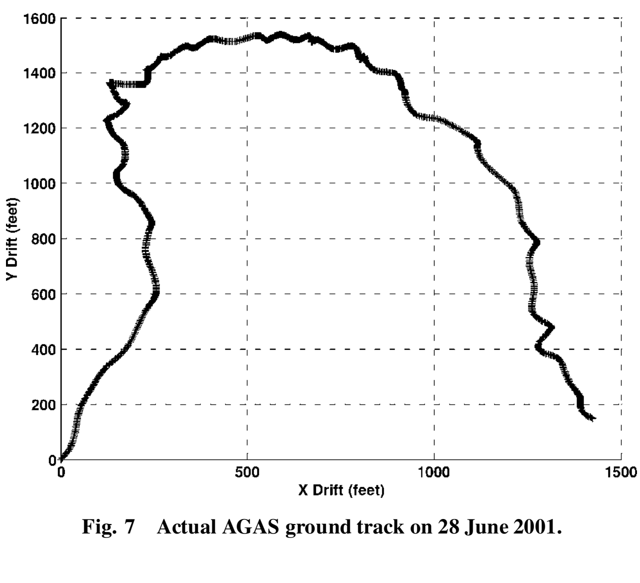

Fig. 7 Actual AGAS ground track on 28 June 2001.

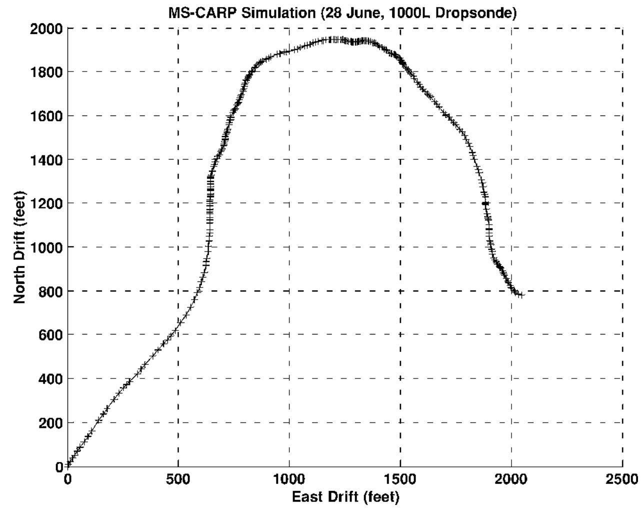

Fig. 8 MS-CARP simulated ground track using dropsonde winds.

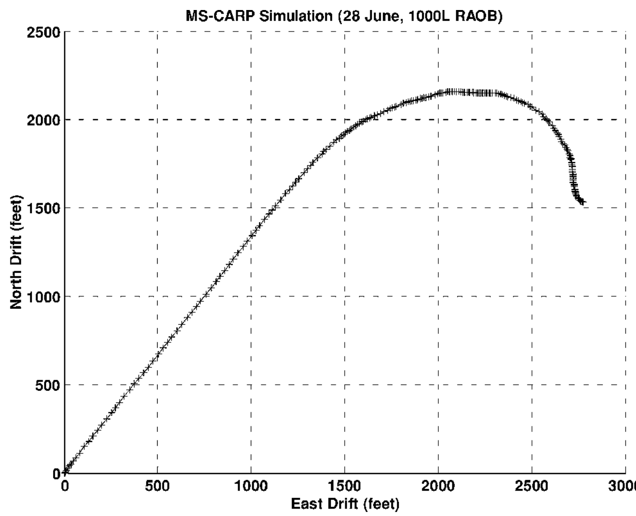

Fig. 9 MS-CARP simulated ground track using RAOB winds.

MS-CARP developer at YPG revealed that the version of the software being used in this study has a glitch in the manner in which air density is handled, that is, the actual air density from the RAOB at each 100-ft level was not incorporated into the calculations. As a workaround, a constant density value was temporarily hard coded into MS-CARP. The particular air density selected by the software developer is an annual average surface value for YPG (all seasons), which is greater than an appropriate number for the very warm conditions of late June, and, of course, does not represent the reduced densities at higher altitudes. As a result, the parachute in the simulation fell too slowly and, thus, drifted too far in each layer. Still, the MS-CARP simulations are useful for making relative displacement comparisons against the actual AGAS drift.

The MS-CARP simulation using a YPG RAOB that was released at 1000L near the target area is shown in Fig. 9. Note that the same general pattern (a drift to the northeast immediately after the drop, followed by a turn eastward, and concluding with a drift back to the south) occurred in this simulation. The pattern is smoothed in comparison to the actual ground track and the dropsonde-based CARP simulation, because RAOB winds are averaged and interpolated to layer values and, therefore, lack the fine resolution necessary to depict the corresponding fine-scale changes as seen in Figs. 7 and 8. However, some of the differences between Fig. 9 and Figs. 7 and 8 might also have occurred because the RAOB was drifting away from the DZ and, therefore, measured a low-level wind influenced by different terrain.

The simulation plot using a 5-h BFM wind forecast (initialized at 0500L, valid at 1000L) is displayed in Fig. 10. Although the same northeasterly drift that gradually turns to the east is evident, there

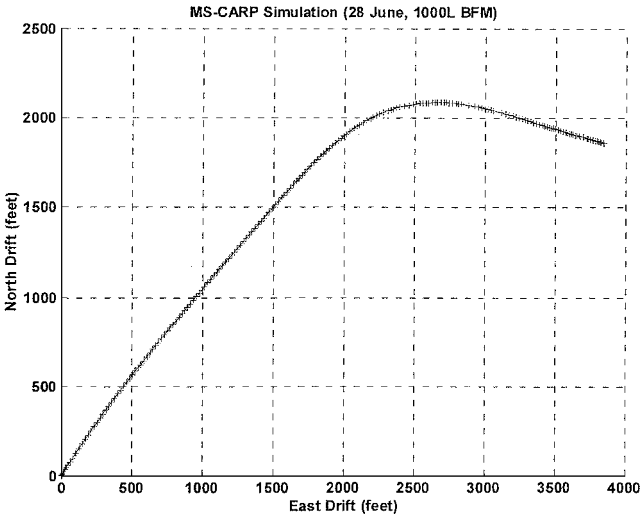

Fig. 10 MS-CARP simulated ground track using BFM forecast winds.

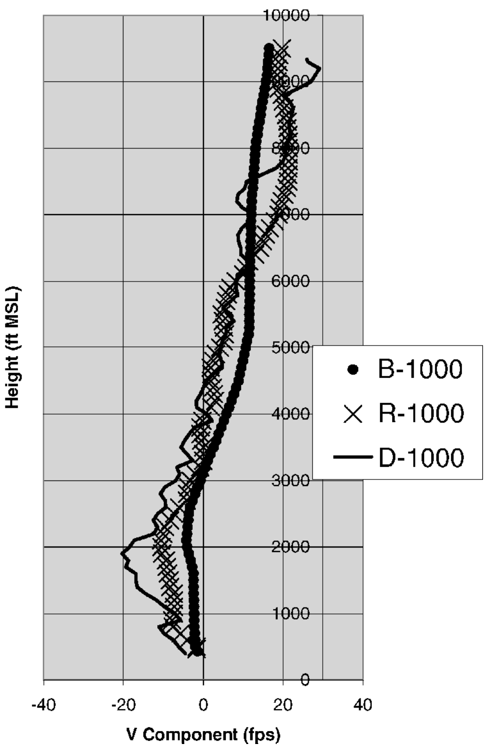

Fig. 11 *V*-component winds for 28 June 2001.

are a couple of notable differences as compared to the other three tracks. First, there is essentially no drift back down to the south as the simulation approaches the end of the descent. This means that the BFM did not predict a wind flowing from north to south in the layers near the surface. Figure 11 illustrates this point.

Note that from 4000-ft MSL downward to the surface, the dropsonde (D-1000) measured a negative V component (a north–south wind) that peaked at −20 fps at 2000 ft MSL. The RAOB (R-1000) measured a similar feature only to a lesser magnitude. As evident from the B-1000 plot, the BFM predicted only a slight negative V component near the surface that reversed sign at around 3000-ft MSL.

The second obvious difference between the BFM-based MS-CARP simulation and the Figs. 7–9, is the magnitude of the drift distances (particularly in the x direction, west to east). The eastward drift in the BFM-based simulation was 3800 ft, over twice that of the actual drift and in the other two simulations. This means that the BFM predicted winds that were too strong at many of the levels. Figure 12 shows the U-component winds from the BFM to

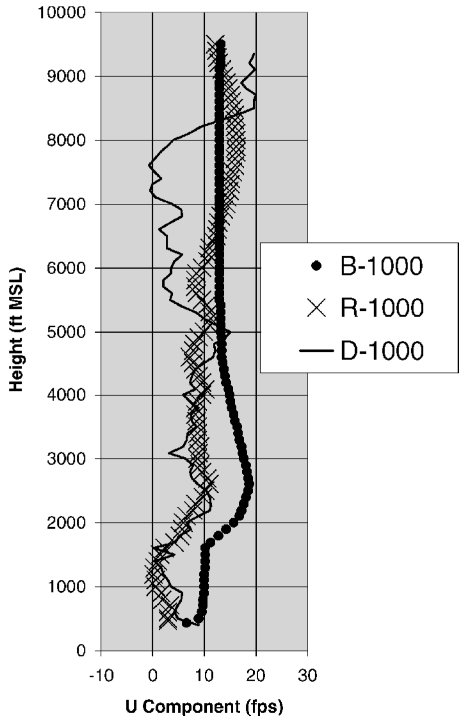

Fig. 12 *U*-component winds for 28 June 2001.

be stronger than either the dropsonde or RAOB at all levels (except a few above 8000-ft MSL).

BFM Case Study Performance

The BFM's wind component forecasts for the single case study described lacked the precision necessary to produce an accurate CARP simulation. An earlier U.S. Army Research Laboratory study that compared SADARM artillery trajectory simulations with live firings at YPG showed the opposite; overall, the simulations using BFM 5–6-h forecast input were about 20% more accurate than those that were RAOB based.[10] The SADARM weapon, which descends briefly on a parachute, is less susceptible to variations in the low-level target area winds than a decelerator system such as AGAS. The development of a north–south wind near the surface at 1000*L* on 28 June 2001 (not evident whatsoever at 0500*L*) made this case study particularly challenging for the BFM. However, one of the purposes of conducting this research was to identify areas where the model might need improvement, such as the more accurate prediction of winds near the surface. It is possible that a 3-h BFM forecast (initialized with the 0700*L* RAOB) would more accurately portray the northerly wind that was occurring at 1000*L* on 28 June 2001. The reanalysis of the 28 June 2001 case had not been accomplished at the time of this writing, but is a topic of future investigations.

Determining the CARP On-Site During Airdrop Operations

As mentioned earlier, the BFM-based CARP simulations were not a formal part of the NWV-PAD testing at YPG during the summer of 2001. The BFM and MS-CARP were run at YPG on a laptop computer for several days during the AGAS test series to determine the feasibility of utilizing a mesoscale model on-site during airdrop operations. Recall that the NWV WindPADS does not actually run the MM5 model but rather receives that model's output from an off-site workstation or mainframe computer and updates it as any new data (primarily a dropsonde) become available. One possible drawback is that the MM5 is only run twice each day, whereas the BFM can be rerun approximately once each hour if new local RAOB initialization data are obtained. One objective of this study was to establish a methodology by which the BFM could be initialized and run in a timely fashion, its output converted to the required MS-CARP format, and a revised CARP calculation made, entirely on a laptop computer.

Obtaining model initialization data is usually a significant consideration when attempting to run a mesoscale model in the field. Kirby et al.[11] describe the development of a Web site where the required data may be obtained. This Web site has links to universities and Department of Defense weather centers where the necessary data are assimilated or generated. The Website graphical user interface (GUI) allows file transfer protocols (FTP) to be easily invoked, with which the data are transferred to a centralized server for decoding and reformatting. The required files are then moved back to the onsite laptop computer via FTP, where they are input to the BFM. A single set of initialization data may be used for successive BFM runs (each time a new local RAOB becomes available). What once was a rather laborious and time-consuming process, requiring extensive user interaction and knowledge, has been made very straightforward and much quicker by the design of the GUI on this Web site. The airdrop testing at YPG was the first opportunity to utilize the new Web site in the field, and it proved quite successful. It is thought that at least some of the methods and concepts involved could be applicable in a tactical battlefield setting.

YPG RAOB data are not input to the national meteorological network and, thus, were not available via the Web site. However, YPG operates an intranet on which test data (including RAOBs) are posted. A MATLAB routine was developed that converted the YPG RAOB files into the proper BFM input format.

Additional MATLAB routines were prepared to convert the YPG RAOB and the dropsonde files into the MS-CARP format. Finally, a MATLAB program was written that scanned the radar track files for the point of the AGAS parachute deployment and plotted its x/y position relative to the ground.

Conclusions

The BFM, a mesoscale weather forecast model, was run for the YPG area to compare its forecasts directly with RAOB and dropsonde data that were obtained locally. Analyses of several case-study days indicated relatively good correlation between the forecasts and the measured data.

To more thoroughly evaluate the BFM's accuracy, its output was adapted for subsequent ingest into a CARP simulator. A full data set, including RAOB, dropsonde, BFM, and radar track data, was obtained for a single case study day. CARP simulations using these data were compared against the actual AGAS ground track. The CARP simulation using a 5-h BFM forecast bore some of the same characteristics as the simulations using measured data and the ground track of the parachute itself. However, the model predicted a U-component wind speed that was too strong at most levels, and failed to forecast a north–south wind component (negative V component) in the layer near the surface. Note that these results apply to just one case; thus, conclusions about BFM accuracy should not be made until many more case study results can be compiled.

A methodology was designed with which the BFM could be run on-site in near-real time during the NWV-PAD testing at YPG. The model was successfully initialized with data from a newly developed Web site and then run, and its output ingested into the MS-CARP. The initial CARP simulation was available in about 2 h. As additional YPG RAOB data became available, the BFM could be rerun and a new CARP produced in less than 1 h. This process demonstrated the feasibility of directly running and utilizing mesoscale forecast models in the field, for a U.S. Army application other than IMETS.

Although some improvements are needed in the model's accuracy, the use of the BFM output in CARP simulations at YPG was a significant step toward a full implementation of this promising technology in precision airdrop operations.

References

[1]Hattis, P. D., Fill, T. J., Rubenstein, D. S., Wright, R. P., Benney, R. J., and LeMoine, D., "Status of an Onboard Personal Computer-Based Airdrop Planner Demonstration," AIAA Paper 2001-2066, May 2001.

[2]Warner, T. T., Kuo, Y.-H., Doyle, J. D., Dudhia, J., Stauffer, D. R., and Seaman, N. L., "Nonhydrostatic, Mesobeta-Scale, Real-Data Simulations with the Penn State University/National Center for Atmospheric Research Mesoscale Model," *Meteorology and Atmospheric Physics*, Vol. 49, No. 1, 1992, pp. 209–227.

[3]Kelly, K., and Pena, B., "Wind Study and Global Positioning System Dropsonde Applicability to Airdrop Testing," AIAA Paper 2001-2022, May 2001.

[4]Henmi, T., and Dumais, R., "Description of the Battlescale Forecast Model," U.S. Army Research Lab., ARL TR 1032, White Sands Missile Range, NM, 1996.

[5]Dellicker, S., Kaminer, I., Howard, R., Benney, R., and Patel, S., "Performance, Control and Simulation of the Affordable Guided Airdrop System," AIAA Paper 2000-4309, Aug. 2000.

[6]Haines, P. A., Blanco, A. J., Luces, S. A., and Spaulding, J. B., "Meteorological Data Processing Methods in the Computer-Assisted Artillery Meteorology System (Battlescale Forecast Model)," U.S. Army Research Lab., ARL TR 559, White Sands Missile Range, NM, 1997.

[7]Bayler, G., and Lewit, H., "The Navy Operational Global and Regional Atmospheric Prediction System at the Fleet Numerical Oceanography Center," *Weather and Forecasting*, Vol. 7, No. 2, 1992.

[8]Yamada, T., and Bunker, S., "A Numerical Model Study of Nocturnal Drainage Flows with Strong Wind and Temperature Gradients," *Journal of Applied Meteorology*, Vol. 28, No. 7, 1989, pp. 545–554.

[9]Haines, P., Jameson, T., Luces, S., Knapp, D., Kirby, S., and Darcy, S., "Applications of the Battlescale Forecast Model Predictions to Sense and Destroy Armor," AIAA Paper 2001-2059, May 2001.

[10]Jameson, T., Luces, S., and Knapp, D., "Effects on SADARM Trajectory Simulations Using Meteorological Input from Local Balloons and the Battlescale Forecast Model for the 2000 RDAP and LUT Firings," U.S. Army Research Lab., ARL TR 2720, White Sands Missile Range, NM, 2002.

[11]Kirby, S., Yee, Y., Henmi, T., and Haines, P., "Web-Based Mesoscale Model Computing," *Proceedings of the International Conference on Internet Computing*, Vol. 2, CSREA Press, Las Vegas, NV, 2001, pp. 684–688.

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