4.3 STUDIES OF TRANSPORT AND DISPERSION IN COASTAL REGIONS

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1. INTRODUCTION

The Model Validation Program (MVP) was an atmospheric transport and dispersion field study, sponsored by the U.S. Air Force Space and Missile Systems Center, to improve forecasts of dispersion from rocket launch clouds (Kamada et al., 1997; Start and Kamada, 2001). Recently, the U.S. Defense Threat Reduction Agency (DTRA) sponsored a chem/bio threat mitigation study to simulate MVP data using the Weather Research and Forecast (WRF) model and the Hazard Prediction Advisory Capability/Second Order Closure Integrated Puff (HPAC/SCIPUFF) model. This paper highlights some results from these studies for improving transport and dispersion forecasts in coastal and littoral regions.

2. MVP FIELD EXPERIMENT

MVP was designed to provide a coastal dispersion data archive to evaluate the performance of atmospheric plume dispersion models. MVP also extends our knowledge of pollutant transport and turbulent diffusion in coastal areas, where most of the nation's population, business and commerce are located. 331 short puffs and 99 plumes of SF_6 tracer were released during four MVP field sessions over different seasons from 1995 to 1997. The first three sessions were at Cape Canaveral Air Station (CCAS), FL, the final session at Vandenberg AFB (VAFB), CA. Unlike most atmospheric dispersion studies, the MVP collected extensive meteorological and tracer concentration data, not just near the surface, but throughout the atmospheric boundary layer (ABL) and above to altitudes of 1200 m MSL.

MVP highlights include a unique, extensive series of tracer releases from a hovering blimp, and the first use of narrow-band infrared cameras to measure along and cross-wind dispersion for elevated, otherwise invisible, SF_6 puffs released above the mixed layer from 600 to 950 m MSL (Min et al., 2002). The 2-3 hour-long releases occurred typically twice a day, at ~20 kg/hr. Fast-response SF_6 analyzers mounted on mobile vans and aircraft were used to monitor both ground and elevated releases. Many plumes were sampled to distances of 10 to 25 km downwind. Rao (2003) discussed the methods and analysis of mobile-sampled surface concentration data, including computer programs used to derive time-averaged concentrations for comparison with model predictions.

MVP included mean and turbulent meteorological data from dozens of wind towers, NOAA aircraft, rawinsondes, surface flux stations, Doppler radar wind/ temperature profilers, Doppler SODAR, buoys and satellites. The MVP data span a uniquely wide range of plume release heights (h), up to 1.2 times the ABL depth (H), with downwind sampling at a variety of heights throughout the ABL, and a range of stabilities, including a few stable and intermittent turbulence cases. Figure 1, from Kamada et al. (2004), shows the scaled release height (h/H) versus atmospheric stability (H/L), where L is the Monin-Obuhkhov length. MVP remains a unique data set for evaluating transport and dispersion models for both surface and elevated chem/bio and other plume types within a coastal setting.

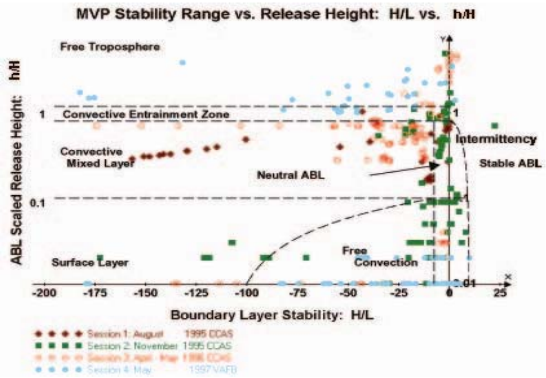

Fig. 1: Scaled release height versus stability for all MVP plume releases (Kamada et al., 2004).

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Among other significant results, Start et al. (2001) showed that tracer often passed easily through cloud convergence zones in the complex coastal region around Cape Canaveral. Source point winds often provided good vectors for maximum downwind concentrations. Data showed consistently wider plumes aloft than near the surface and multiple cross-wind concentration peaks often occurred, with or without intervening convergence zone encounters. Over-water subsidence rates of 0.1 to 0.5 m/s, were often observed, as tracer trajectories extended across warm land to cooler water surfaces.

3. WRF/HPAC SIMULATIONS OF MVP DATA

In MVP Test 209, 20.57 kg/hr of SF_6 was released on Nov. 6, 1995, 21:22 - 23:56 UTC, from CCAS Space Launch Complex-37 (SLC-37) at a height of 20 m MSL. This near-surface release became a reference case, as it provided a steady sea breeze, a continuous plume, and a full set of local/regional meteorological and dispersion data. Rao (2003) described the meteorological and tracer data for Test 209.

3.1 *WRF Meteorological Simulations*

WRF was run on a 570 km x 570 km horizontal grid with 35 vertical levels, starting at 27.6 m. The lateral boundaries were initialized and nudged every 3 hours by the North American Regional Re-analysis (NARR) 32 km archive of surface data, fluxes, and 3-D meteorological fields. WRF was initialized shortly after local sunrise to provide time to dampen gravity and acoustic waves generated by imbalances between NARR forcing and the model physics.

Streamlines overlying surface sensible heat flux, wind speed, and equivalent potential temperature (EPT) contours were plotted at various times and at three ABL levels: 28, 90, and 320 m. Results for 3 km and 2 km meshes are quite similar. They show a steady, northeasterly, post-frontal sea breeze, at 6 to 8 kts and 64 to 55 degrees, opposing the westerly zonal flow, consistent with *in situ* MVP data. During the plume release, the sea breeze front pushed inland from 20 km to 35 km west of the release location. At 22:00 UTC, the mid-ABL, 320 m plot in Fig. 2 shows, within its 275 x 170 km display, a local, warm tongue of EPT above the surface layer, with complex streamlines around an eastward Atlantic high. Figure 3, a “zoom” plot of the central 121 km x 74 km of the domain, depicts near-surface streamlines and isotach contours at 24:00 UTC, 2.75 hr after the release began. SLC-37 is near the eastern tip of the triangular CCAS area, outlined in orange and slightly below center in both plots.

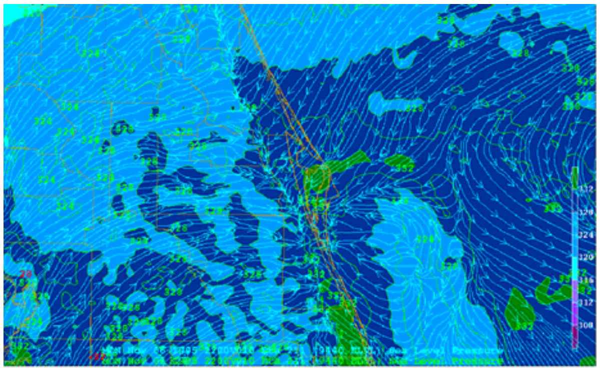

Fig. 2: WRF streamlines and equiv. pot. temp. contours, Nov. 6, 1995, 22:00 UTC. CCAS is in center, orange indicates coastline.

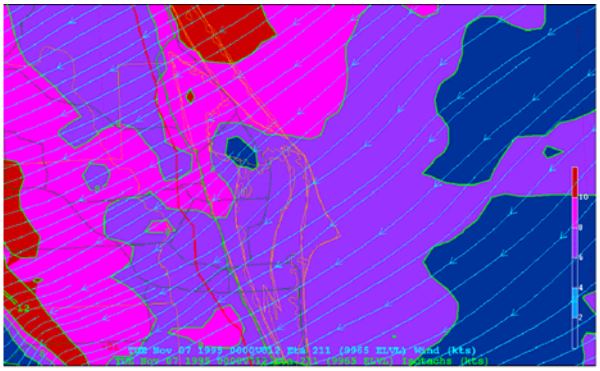

Fig. 3: WRF streamlines and isotach contours, Nov. 7, 1995, 00:00 UTC. Red area to the west indicates sea breeze front.

3.2 *HPAC Simulations of Plume Dispersion*

WRF’s netCDF (network Common Data Form) output covering 1200-2400 UTC, Nov. 6, 1995, was converted to MEDOC format (Sykes et al., 2006) for input to HPAC. The MEDOC conversion program outputs winds to a staggered 269 x 179 horizontal grid, and truncates the number of vertical levels in WRF to 20. HPAC used the WRF/MEDOC meteorological fields to simulate Test 209. Plume contours at 22:15, 23:15, and 24:00 UTC were plotted. The HPAC plume, using only rawinsonde profiles from a site to the south of the tracer release location, was somewhat north of the observed surface plume. In another HPAC run, interpolated data from meteorological towers 62, 803, and 1000, located directly downwind of the tracer release site were used, without “spinning-up” and re-running WRF, to improve the plume simulation results. For this case, Fig. 4 shows the predicted plume at 00:00 UTC, Nov. 7, 1995, with sampling tracks of vans 1, 3, and 6.

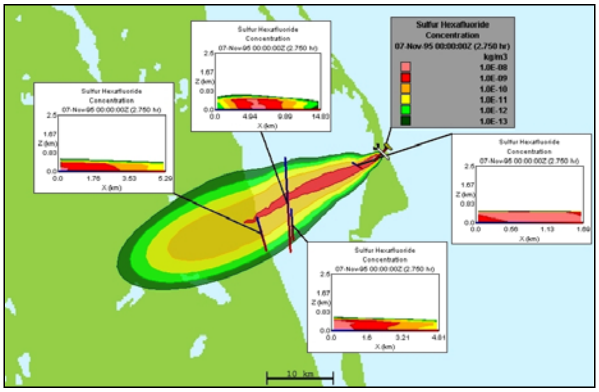

Fig. 4: Simulated HPAC plume released from SLC-37 in Test 209, Nov. 7, 1995, 00:00 UTC. Cross-plume sampling tracks of Vans 1, 3, and 6, and a virtual track near Van 3 are shown.

Figures 5 (a), (b) and (c) compare HPAC-predicted half-hour average, near-surface concentrations with the corresponding cross-plume data for vans 1, 3, and 6, respectively. HPAC under-predicted the near-source concentrations substantially, as shown in Fig. 5(a) (see discussion), while Fig. 5(c) shows that the under-prediction was more modest (~40%) further downwind. The prediction for van 3 in Fig. 5(b) was in between. The maximum concentration of 260 ppt observed by van 3 was predicted well (225 ppt) at the center of the HPAC plume.

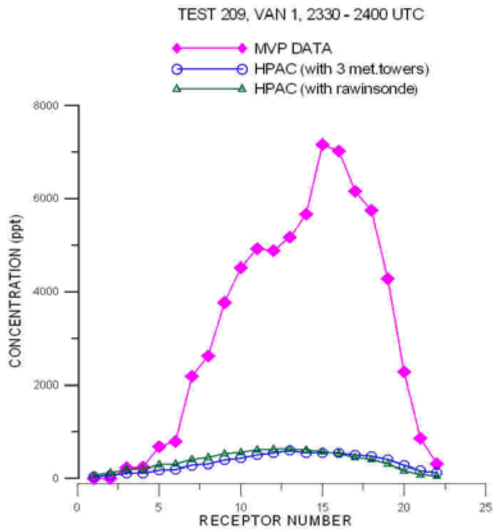

Fig. 5(a): Observed vs. predicted concentrations for Van 1.

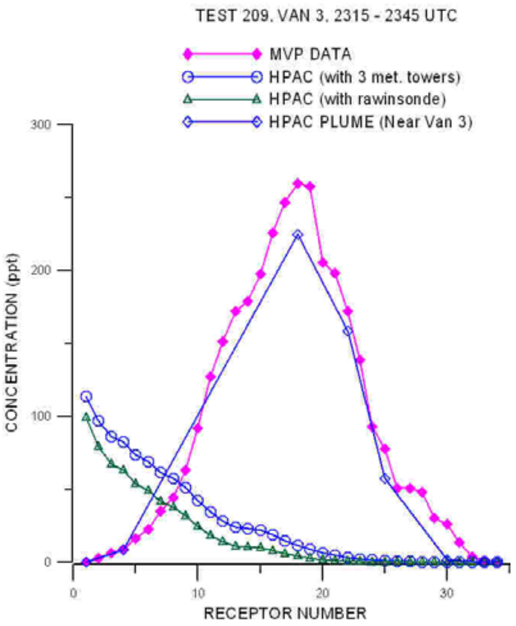

Fig. 5(b): Observed vs. predicted concentrations for Van 3.

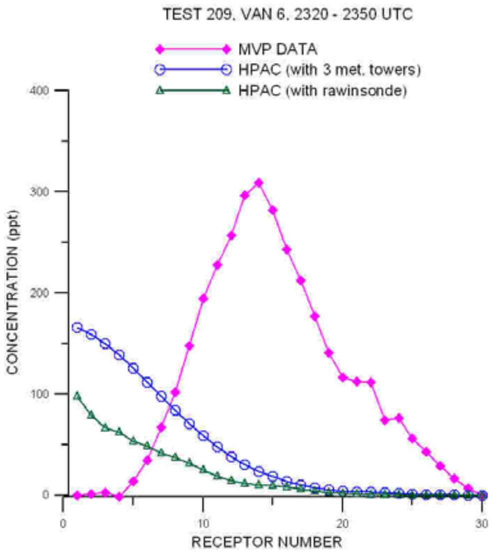

Fig. 5(c): Observed vs. predicted concentrations for Van 6.

4. DISCUSSION

WRF/HPAC model simulations of data from research-grade dispersion experiments such as MVP, as briefly described in this paper, can be used to evaluate the modeling systems, and to determine the types and density of local data and remote-sensing data that are necessary for improving wind flow and dispersion forecasts. One of the DTRA project’s goals is to assess the potential for refining source strength and location estimates via a collaborative process involving model simulations and local and remotely sensed data, ingested in real-time. Methods and codes for this purpose have been developed and seem promising but require further testing.

Meanwhile, the under-predicted near-source concentrations found for HPAC may be due to two factors: larger than realistic initial puff sizes and an unusually shallow surface layer. MVP IR video imagery and more test cases should be studied prior to forming conclusions. However, the overlying warm tongue depicted in Fig. 2 is consistent with the latter factor, which is also mentioned in the MVP field notes. This suggests that WRF's lower boundary height limit of about 28 m probably needs to be lowered, since models tend to over-predict near-surface diffusion rates over cool, shallow, surface layers, if the true vertical profile of near-surface turbulence is not sufficiently resolved. This study suggests that such missing details may be significant, even for seemingly simple sea breeze cases. Yet, the trial inclusion of local data shows that other important aspects of plume forecasting may be improved readily without re-structuring or even re-running WRF, if the local data are within the plume-impact area.

The above discussion also indicates that the MVP archive, though under-utilized so far, remains a prime data set for atmospheric studies, and is sufficiently robust for detailed model evaluations involving ABL plume releases, within as well as above the surface layer, particularly under convective conditions.

ACKNOWLEDGEMENTS

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