FINAL REPORT

Subcontract 9XA3-6764H-1 CSU-LANL

**THE MODIFICATION AND APPLICATION
OF RAMS COMPUTER CODE**

Thomas B. McKee, Principal Investigator

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Department of Atmospheric Science
Colorado State University
Fort Collins, Colorado, 80523

Abstract

The Regional Atmospheric Modeling System (RAMS) has been utilized in its most updated form, version 3a, to simulate a case night from the Atmospheric Studies in COMplex Terrain (ASCOT) experimental program. ASCOT held a wintertime observational campaign during February, 1991 to observe the often strong drainage flows which form on the Great Plains and in the canyons embedded within the slope from the Continental Divide to the Great Plains. A high resolution (500 m grid spacing) simulation of the 4-5 Feb 1991 case night using the more advanced turbulence closure now available in RAMS 3a allowed greater analysis of the physical processes governing the drainage flows. It is found that shear interaction above and within the drainage flow are important, and are over-predicted with the new scheme at small grid spacing ($< \sim 1000$ m). The implication is that contaminants trapped in nighttime stable flows such as these, will be mixed too strongly in the vertical reducing predicted ground concentrations. The HYPACT code has been added to the capability at LANL, although due to the reduced scope of work, no simulations with HYPACT were performed.

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1. DESCRIPTION OF OBJECTIVES

In order to improve Los Alamos National Laboratory's atmospheric and dispersion modeling capability in complex terrain, two advanced models were to be implemented; 1) the Regional Atmospheric Modeling System (RAMS) version 3a, for atmospheric research, and 2) the HYbrid Particle and Concentration Transport (HYPACT) model, for pollutant studies. Three specific tasks were originally outlined, although a reduced scope of work was agreed upon for Task 1 per memorandum EES-5:94-529 when funding levels were reduced prematurely. The period of performance was 24 months beginning January 1, 1993 (therefore ending January 1, 1995). Two semi-annual reports were required as well as this final report.

1.1 Task 1

The first task stated was the following: The latest hybrid Lagrangian-Eulerian dispersion and concentration transport model (HYPACT) that uses RAMS output fields will be used to simulate the Rocky Flats tracer experiments in 1991. These simulated releases will be compared to EG&G concentration observations. It is expected that the introduction of HYPACT to LANL's existing dispersion capability will be a significant improvement. Results from HYPACT will also be compared to the existing Lagrangian Particle Dispersion Model.

As mentioned above, the scope of Task 1 was reduced in September, 1994, due to lowered funding levels. The reduced scope of work eliminates the primary goals of Task 1, the comparison of HYPACT output to the EG&G observations and to the Lagrangian Particle Dispersion Model. Accordingly, only the integration of HYPACT into LANL's existing capability was pursued.

1.2 Task 2

Task 2 was: The RAMS will be used to simulate the meteorological conditions during the ASCOT 1991 observations program. The simulations will be compared with observations and used to increase the understanding of the physical processes that control drainage flows.

1.3 Task 3

Task 3 was not research oriented, it read: A computer terminal (X-terminal) will be provided to connect to LANL's EES-5 Local Area Network (LAN), and all computing will be done on the EES-5 LAN. Travel expenses will be provided for two trips to ASCOT meetings, including the February, 1993 meeting in Salt Lake City.

2. RESULTS

The general task of improving LANL's modeling capability was met. That is, RAMS version 3a was implemented and run on the Laboratories' computers. Access is predominantly through IBM RISC/6000 Unix architectures but also available if the code is ported to Cray, Sun or Hewlett-Packard machines, among others. It is currently in full-scale use by various researchers in the Atmospheric Science Team of the Geoanalysis Group at LANL. Plume dispersion and transport modeling capability was also improved by the acquisition of HYPACT. Although not

specifically applied to the Rocky Flats ASCOT 1991 experiments due to the reduced scope of work, HYPACT has become operational on the Local Area Network. Specifically, HYPACT has been implemented using meteorological data from RAMS as input to produce dispersion and concentration estimates in the Los Alamos and Mexico City regions. The other general task of applying RAMS version 3a to an improved understanding of nocturnal drainage flows has also been accomplished. This is described more thoroughly in Section 2.2. All figures are located at the end of this report.

The first semi-annual progress report was submitted 7 July 1993. It indicated that neither RAMS version 3a, nor HYPACT was yet operational, although some preliminary analysis of capability had been completed. A computer terminal had been acquired at that time. The second semi-annual progress report was sent 28 January 1994, which indicated that RAMS 3a was operational and test runs were underway. As HYPACT had not yet been linked to RAMS output at that time, HYPACT was not yet implemented.

2.1 Task 1

Task 1, as originally stated prior to scope reduction, was not fully met. As suggested in the second semi-annual progress report, it was expected that meteorological modeling of the ASCOT 1991 experiment would have been underway after test runs of RAMS version 3a were complete, around April, 1994. Because the implementation and testing of RAMS 3a actually continued into the summer months of 1994, and the use of HYPACT depends on the output from RAMS, dispersion calculations could not be executed until Fall, 1994. However, in September, 1994, as previously stated, a reduction in scope of work was agreed upon which eliminated dispersion comparisons as part of Task 1. HYPACT was able to be tested and implemented at LANL, however, with output from version 3a, despite this reduction in scope. HYPACT has become operational at EES-5 using the advanced turbulence technology it has been formulated with. Realistic concentration, dosage and dispersion estimates have been calculated over very complex terrain in the region surrounding LANL where turbulent effects are expected to be significant. Additional work has been completed using HYPACT to analyze the severe pollution problems in Mexico City which are largely created by the mountainous terrain nearly encompassing the valley it is located in.

2.2 Task 2

Task 2 was accomplished by using RAMS version 3a to simulate the meteorological conditions during the overnight period of 4-5 February 1991 from the ASCOT observational program. In general, for larger grid spacing only, the model showed significant skill in reproducing the observed wind field for this night. Of particular significance to this night, and pollution problems on the Front Range in general, are drainage flows, otherwise known as katabatic winds. Such winds were observed to develop over large portions of the near Rocky Flats region, including complicated jet and shear structure in nearby Eldorado and Coal Creek Canyons. Figure 1 shows the study region for the ASCOT 1991 experiment, including observational sites, terrain contours and relevant topographic features (such as the canyons). It is evident in the figure that contaminants generated at Rocky Flats under stable westerly-component flow are likely to have an impact on populated areas, possibly the densely populated areas of Denver (off the southeast corner of

Figure 1) and Boulder.

Such westerly-component flows are expected and were observed during the drainage flow conditions existing on the case night, 4-5 February 1991. RAMS version 3a, simply initialized with a horizontally homogeneous condition from a sounding taken at Rocky Flats at 2000 LST of the case night, was able to predict these flows. The model configuration over the study area is depicted in Figure 2, which shows the three nested grids used as they focus on the ASCOT study area near Rocky Flats. Horizontal grid spacing was selected to be 6 km, 1.5 km and 500 m on the first, second and third grids, respectively, and vertical grid spacing was 20 m within 200 m of the surface above which the vertical grid spacing increased. Radiative and soil fluxes were included in the model formulation along with standard model features (see Pielke et al. 1992). The advanced turbulence formulation of Mellor and Yamada (1974) - the most significant improvement to the RAMS code - was also used in accordance with the goals of this subcontract. Related studies focusing on the same study area and case nights are Poulos and Bossert (1995) and Bossert and Poulos (1995). Both of these studies use an older version of RAMS which does not contain prognostic turbulent capability and therefore contain limited information on the role of turbulence in flows.

Figure 3 shows the 10 meter AGL wind vectors predicted for 0000 LST 5 Feb (midnight of the case night) on Grid 3 of the three nested grids used. The complex wind fields shown in the figure can be compared to observations which are shown on the same scale in dark lines. Some considerable discrepancies exist, and it is evident that the model has only grossly reproduced the major observed wind features in magnitude and direction. Similar figures in Poulos and Bossert (1995) are considerably more accurate in comparison to observations, indicating that the turbulent kinetic energy scheme in the newer version of RAMS, the only relevant change between the simulations in Poulos and Bossert (1995) and that depicted in Figure 3, degrades the results. Such degradation is likely to be caused by the utilization of the turbulence scheme outside the atmospheric realm it was developed for. The Mellor-Yamada level 2.5 turbulence closure was not developed for such small scale grid spacing applications so that some reduced ability is expected in these simulations on the smallest scales.

Figure 4 zooms out to a larger scale surrounding Coal Creek and Eldorado Canyons to the west of Rocky Flats with lower resolution. This figure was produced from model information based on 1500 m horizontal grid spacing, and shows wind vectors at 50 m AGL as in Figure 3 but on Grid 2, and for a later time 0400 LST 5 Feb. Compared to observations (shown in thick lines), again the model shows considerably more quantitative and qualitative skill than in Figure 3. Drainage flows, as were observed that night, flow persistently toward the east, mostly following the topographic features. As mentioned above the Mellor-Yamada scheme is better suited to larger scale grid spacing so that it is expected that the information on Grid 2 (which uses 3 times larger grid spacing) would be improved over the Grid 3 representation. In fact, the quality of the wind speed prediction for this figure is higher than that in Poulos and Bossert (1995), in contrast to the Grid 3 (Figure 3) comparison. This implies that the improved turbulent prediction in RAMS version 3a will only improve meteorological predictions over earlier versions of RAMS in simulations where grid spacing is sufficiently large. The threshold in this case appears to be near 1.5 km grid spacing, but a single comparison is inadequate for generalization.

The physical process producing katabatic flows is known to be radiative cooling, and subse-

quent thermal structure and the vertical wind structure can vary based on local conditions. Among the conditions that effect the vertical structure is turbulence. In this case, then, the use of the advanced turbulence module in RAMS 3a enables us to further elucidate the role of turbulence in drainage flows, one of the main ongoing physical properties of this flow. Cross sections of turbulent kinetic energy overlaid with streamlines are plotted in Figure 5 and Figure 6. The cross sections shown are for the crosssection indicated by the thick dashed line in Figure 3, and follow the terrain for ~700 m AGL approximately down the axis of Eldorado Canyon. It is clear that while turbulence is unimportant above the drainage flows ($> \sim 400$ m AGL) that within the katabatic flows turbulence is significant. Apparently shear flows generated between the katabatic wind and overlying ambient flow at about 50-300 m AGL mix momentum effectively preventing drainage winds from growing to observed speeds. The turbulent scheme overproduces turbulent mixing at small grid spacing. Turbulence also plays a role in defining the thermal structure of the atmosphere for these flows. By transporting heat as well as momentum, turbulence here acts to reduce the strength of the inversion in which the drainage jet normally resides, reducing stability. Normally, the stable condition of the inversion prevents the intrusion of air from aloft which might otherwise destroy the thermal structure necessary to maintain the drainage flow. Given the turbulent scheme's tendency toward excessive mixing, it is not surprising that katabatic flows on Grid 3 were not very accurate compared to observations.

2.3 Task 3

Task 3 was the least difficult to meet. The Sun Corporation computer terminal procured under this subcontract was sufficient and provided timely, frequent access to the EES-5 Local Area Network. As such, much of the success in Tasks 1 and 2 hinged on the successful acquisition of this machine. Two trips were made to ASCOT meetings, including the Salt Lake City meeting in February, 1993. These meetings discussed the meteorological conditions relevant to the case night investigated in this work as well as various models and modeling techniques in complex terrain.

3. SUMMARY AND CONCLUSIONS

Within the scope of the tasks, the 3 main goals of this project were met. A more advanced modeling capability has been transferred to Los Alamos National Laboratory and an example of model results using new technology was presented. The new turbulence scheme in RAMS version 3a appears to improve results for grid spacing of greater than 1 km. In that this is a single case study it is impossible to determine whether this result is applicable in all atmospheric conditions or is specific to katabatic flow simulations.

4. ACKNOWLEDGMENTS

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5. REFERENCES

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Front Range Instrument Locations

Figure 1. Topography and instrument locations for the ASCOT 1991 measurements program. Abbreviations are EC: Eldorado Canyon, MT: Mesa Trailhead, FV: Flatirons Vista, RF: Rocky Flats, RR: Rim Rock, FP: Filtration Plant, II: Route 128 and Indiana Street, JR: Jim's Ranch, PV: Plainview, OR: Lois' Ranch, CC: Coal Creek Canyon, PP: Paul's Peak, PF: Pat's Flat, BR: Bartlett's Ranch, TO: Tolland. This figure courtesy of Jerry Allwine, Pacific Northwest Laboratory

Figure 2. A depiction of the basic grid configuration used in the RAMS version 3a meteorological model simulations. The three grids focus on the ASCOT 1991 study region and Grids 1, 2 and 3 have grid spacings of 6 km, 1.5 km and 500 m, respectively. The topography is shown for Grid 1 only (the coarsest resolution) with 200 m contour intervals.

Rocky Flats 4-5 Feb 1991
RAMS3a Mellor-Yamada 2.5 Turbulence

Grid 3
700 UTC

From 100.0000 X (km)
to 3000.0000 Wind Vectors
by 100.0000

Z = 10.00 m

.481E+01
MAXIMUM VECTOR

Figure 3. Wind vectors at 10 m AGL (light arrows) at 0000 LST on Grid 3 for the 4-5 Feb 1991 ASCOT case night as predicted by RAMS, compared with observations (dark arrows). All vectors scaled to the longest arrow which represents 4.81 ms^{-1} and the underlying topography is contoured in 100 m intervals.

Rocky Flats 4-5 Feb 1991
RAMS3a Mellor-Yamada 2.5 Turbulence

Grid 2
1100 UTC

Figure 4. Wind vectors at 10 m AGL (light arrows) at 0400 LST on Grid 2 for 5 Feb 1991 as predicted by RAMS, compared with observations (dark arrows). All vectors scaled to the longest arrow which represents 8.24 m s^{-1} and the underlying topography is contoured in 100 m intervals.

Rocky Flats 4-5 Feb 1991
RAMS3a Mellor-Yamada 2.5 Turbulence

Grid 3
700 UTC

Figure 5. A TKE vertical cross section through Eldorado Canyon (along the dark, east-west line in Figure 4) at 0000 LST of the 4-5 Feb 1991 case night on Grid 3 overlain with streamlines. Note that turbulence is primarily confined to the lowest levels. Contours of energy are in $\text{m}^2 \text{s}^{-2}$ at 0.007 intervals.

Rocky Flats 4-5 Feb 1991
RAMS3a Mellor-Yamada 2.5 Turbulence

Grid 3
1100 UTC

Figure 6. A TKE vertical cross section through Eldorado Canyon (along the dark, east-west line in Figure 4) at 0400 LST of the 4-5 Feb 1991 case night on Grid 3 overlain with streamlines. Turbulence has become somewhat more developed than in Figure 5 representing the deeper shear condition of winds by this later time. Contours of energy are in $\text{m}^2 \text{s}^{-2}$ at 0.010 intervals.