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PROGNOSTIC ATMOSPHERIC AND DISPERSION MODELING IN THE VICINITY OF ROCKY FLATS PLANT

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DISCLAIMER

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SUMMARY

A multiscale four-dimensional data assimilation technique is incorporated into a mesoscale model and evaluated using meteorological and tracer data collected during the Atmospheric Studies in Complex Terrain (ASCOT) field experiment in the winter of 1991. The mesoscale model is used to predict the interaction of synoptically-driven flows and small-scale circulations influenced by terrain along the Front Range in Colorado in the vicinity of the Rocky Flats Plant for four nocturnal periods during the ASCOT field experiment. Data assimilation is used to create dynamically consistent analysis fields based on the mesoscale forecasts and the special asynoptic data taken during this experiment. The wind and turbulence quantities produced by the mesoscale model are then used to determine the dispersion of a tracer released from the Rocky Flats Plant for each evening. The mesoscale model is able to qualitatively predict the mesobeta-scale drainage flows from the Front Range into the South Platte River basin; however, the largest forecast errors occurred in a region immediately adjacent to the foothills. As expected, the current data assimilation technique reduced the overall errors in the atmospheric and dispersion calculations while the model generated realistic small-scale circulations not resolved by the data. Still, the model did not capture the shallow surface drainage flows just east of the Rocky Flats Plant for two of the evenings during the field experiment.

I. INTRODUCTION

In an effort to better understand local circulations along Colorado's Front Range in the vicinity of the Rocky Flats Plant (RFP), a field experiment was conducted between Jan. 28 and Feb. 8, 1991 as part of the U. S. Department of Energy's 1991 Atmospheric Studies in Complex Terrain (ASCOT) program.[1] The field experiment focused on the nocturnal, locally generated slope and canyon flows along the Front Range and their effect on transport and diffusion. Intensive measurements were made by the ASCOT participants during eight nighttime periods, and tracer (SF_6) experiments were performed by RFP personnel as part of their 1991 Winter Validation Study (WVS) for four of those nights. The instrumentation platforms that were deployed in the area included meteorological towers, tethersondes, minisodars, a rawinsonde, an airsonde, and a Doppler lidar. Figures 1 and 2 depict the locations of the meteorological observations in the vicinity of Rocky Flats, including those from the 1991 Winter Icing and Storms Project (1991) and the NOAA/Forecast System Laboratory (FSL) mesonet.

Of particular interest to the ASCOT program are nocturnal drainage flows, generated near the surface by radiative cooling along sloped terrain. Pollutants released within drainage flows may remain highly concentrated since the atmospheric stability reduces the amount of dispersion. If hazardous materials are released from the RFP into nocturnal drainage flows, they may significantly impact the air quality in the South Platte River basin and the Denver-Boulder metropolitan area. Drainage flows exiting Coal Creek and Eldorado Canyons are suspected to influence the nighttime circulations in the vicinity of RFP. However, other observations indicate that the boundary layer around RFP is not only affected by the local terrain features, but also by larger-scale terrain and synoptic influences. These multiple-scale interactions can produce highly variable flow patterns, in space and in time, that complicate the prediction of atmospheric circulations and pollutant dispersion.

In this study, four-dimensional data assimilation (FDDA)[2] is incorporated into a mesoscale atmospheric model and the model is evaluated using meteorological and tracer data taken during the 1991 ASCOT field study. This is done to determine the ability of the model to predict small-scale circulations influenced by terrain, such as drainage flows, and assess the impact of continuous data assimilation on the atmospheric and dispersion calculations. The numerical simulations in this study focused on four evenings of the ASCOT field experiment, although only some of the results from the evening of Feb. 7 - 8 will be shown in this paper.

II. MODEL DESCRIPTION

A. Atmospheric Model

The Regional Atmospheric Modeling System (RAMS) developed at Colorado State University is a three-dimensional, primitive equation model that employs a terrain-following vertical coordinate system.[3] Version 2c of RAMS is used with a nested grid configuration; the outermost domain encompasses most

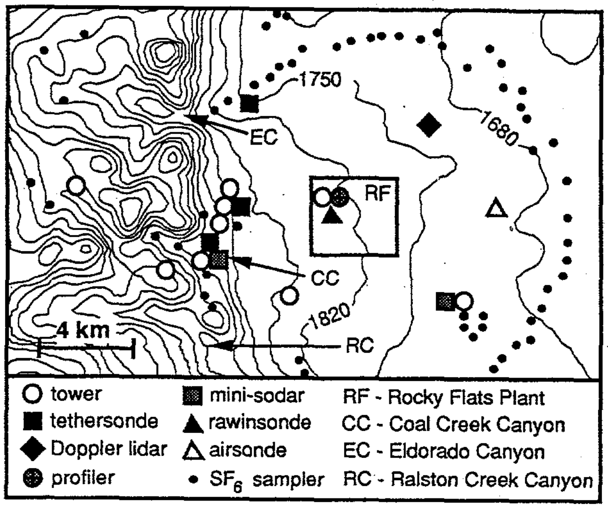

Fig. 1 Topography employed by RAMS on domain 4 and the locations of meteorological instrumentation and SF_6 samplers

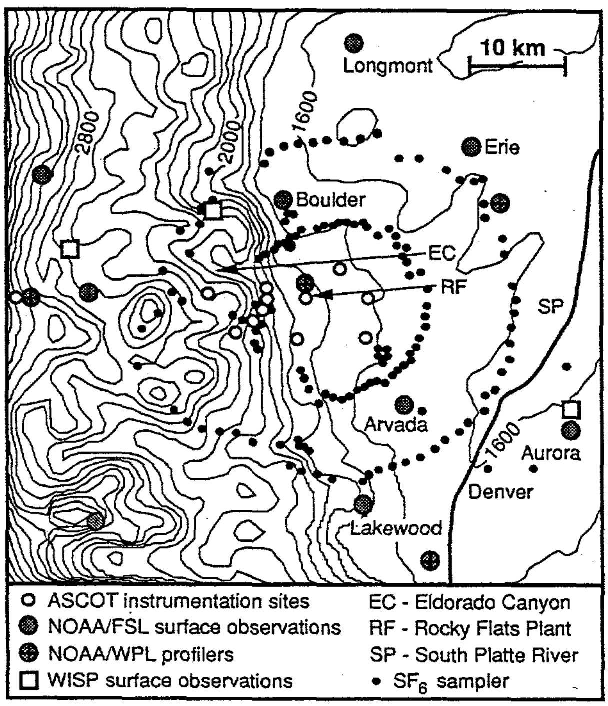

Fig. 2 Same as Fig. 1, except for domain 3

of Colorado and southern Wyoming and three nested grids are centered on the Rocky Flats Plant. The characteristics of the nested grids are described in Table 1. Each domain has a vertical grid spacing of 26 m at the surface that gradually increases to 1000 m near the model top about 16 km above ground level. The topography employed by the model for the two innermost nested grids (domains 3 and 4) are depicted in Figs. 1 and 2 along with some of the significant features in the area.

Grid Characteristics	Domain			
	1	2	3	4
# E/W nodes	27	38	50	78
# N/S nodes	27	42	42	50
# vertical nodes	32	32	32	32
Δx, Δy (km)	21.12	5.28	1.32	0.33
time step (s)	20.0	10.0	5.0	2.5

Table 1. Characteristics of the nested grids employed by RAMS

A second-order turbulence closure scheme[4] is incorporated into RAMS for the simulations in this study. Heterogeneous vegetation characteristics are employed in the model to more accurately represent the fluxes of heat and momentum at the surface.

The FDDA method incorporated in RAMS is based on Newtonian relaxation.[2] In this method, a tendency term is added to the governing equations of the form:

$$-G\, W(x,y,z)\, W(t)\, (V_o - V_m) \quad (1)$$

where G is the relaxation coefficient, W(x,y,z) the spatial weighting function, W(t) the temporal weighting function, V_o the observed variable analyzed at a given grid point, and V_m the model variable at a given grid point. Eq. (1) brings the prognostic variables into closer agreement with the high-resolution data taken during the ASCOT experiment. Any observed quantity that is also a prognostic variable can be employed in Eq. (1); however, V is either u or v for the simulations in this study.

Data are interpolated to the model grid at each observation time by a optimal interpolation method to obtain V_o. The spatial weighting function, W(x,y,z), is based on the estimation variance of the interpolated data obtained from this method. If an observation is located precisely at a model grid point, W(x,y,z) = 1, and if a model point is sufficiently distant from the observation location, W(x,y,z) = 0; otherwise, the weight varies between 0 and 1 depending upon the spatial distribution and number of observations. The temporal weight varies linearly in time between 0 and 1 and the value of G in this study is 0.005.

Newtonian relaxation is a practical FDDA method for complex terrain applications since it is conceptually simple and computationally inexpensive. Another advantage is that continuous FDDA produces a flow field that is a combination of the predicted and observed variables when and where the observations may occur. In data sparse regions, only the model governing equations are used to predict the three-dimensional flow field. Theoretically, continuous FDDA should be superior to mass-consistent diagnostic models that simply interpolate the wind field in three dimensions into data sparse regions. Spatial and temporal interpolation techniques employed by these diagnostic models may result in significant wind speed and direction errors, especially in highly complex terrain. Data assimilation also allows a prognostic model to "spin-up" to accurate, complex circulations in a shorter period of time. Currently, prognostic mesoscale models often employ horizontally homogeneous initial conditions for simulations in complex terrain; realistic terrain-induced circulations are obtained only after prolonged "spin-up" periods. While horizontally homogeneous initial conditions maybe adequate in certain situations, three-dimensional, synoptic or mesoscale influences that normally exist are neglected.

The disadvantages of Newtonian relaxation are that the relaxation coefficient, G, is assigned arbitrarily and the assimilation of unrepresentative components can occur (i.e., microscale observations may be spread over a relatively large area). For instance, the influence of an observation at a valley floor location can be spread up the valley walls. In nocturnal periods, this may result in a winds not flowing directly down the slope of the valley walls. To reduce the impact of this problem, the spatial weighting function, W(x,y,z), in this study approaches zero 2 km from an observation location on the innermost nested grid.

B. Dispersion Model

A Lagrangian Particle Dispersion Model (LPDM) is used to simulate tracer transport in complex terrain around RFP. Atmospheric dispersion is simulated by tracking a large number of particle positions that are based on the mean velocities produced by RAMS and a sub-grid scale turbulent velocity component.[5] The sub-grid scale turbulent velocities are determined from a finite-difference analog to the Langevin stochastic differential equation and depend on the turbulent velocities at the previous time steps and a random component. The turbulent velocity statistics are consistent with the second-order closure in RAMS and the effect of inhomogeneity in the second-order moments (drift corrections) are included in all the random velocity components.

IV. NUMERICAL RESULTS

A. Experimental Design

Two types of simulations are performed for this study. A control simulation that employs static, inhomogeneous initial conditions from the large-scale NMC analysis at 05 MST are used to make a 27 hour forecast for each evening. The model is initialized 15 hours before the release of the tracer at 20 MST so that a realistic boundary layer will evolve during the daytime. The FDDA simulations are identical to the control simulations, except that continuous FDDA is employed on all the nested grids. These simulations are used to evaluate the impact of data assimilation on the model results and to produce high-resolution mesoscale analysis fields for the dispersion calculations.

B. Results from February 7 - 8, 1991

The high-resolution wind and turbulence fields from the FDDA simulation are used to determine tracer transport around Rocky Flats during this evening. The near-surface wind fields at 00 MST and 02 MST from the FDDA simulation are shown in Figs. 3a and 3b, respectively. The hourly-averaged surface concentration between 00 - 01 MST and 02 - 03 MST is also shown in these figures. Between 00 - 02 MST, a shift in wind direction from the southwest to northwest occurred at RFP with wind speeds increasing from 2 to 6 m s^{-1} (Fig. 4). While the control simulation qualitatively produces the observed wind direction shifts and the first peak in wind speed in the evening, calm winds are predicted at RFP after 01 MST (Fig 4). As expected, the wind field from the FDDA simulation is in better agreement with the observed data at the tower. A horizontal eddy is produced by the model northeast of RFP by 02 MST (Fig. 3b) that is due, in part, to the strong northwesterly flows merging with the southerly South Platte River basin drainage flow and the assimilated northeasterly winds at Boulder.

Between 00 - 01 MST, the plume has advected downwind beyond the 16-km sampler arc, following the terrain slope down towards the S. Platte River (Fig. 3a). The observed and simulated maximum concentrations are nearly at the same location on the inner sampler arc east of RFP. The simulated plume does not reach as far east as the observed maximum concentration location on the outer arc northeast of RFP, indicating that the drainage flows from the foothills may not be strong enough at this time. Between 02 - 03 MST, the model again places the maximum concentration at nearly the same location at the observed value on the inner sampler arc (Fig. 3b). The plume is also spread over a large area as indicated by both the observations at the outer sampler arc and the simulated concentration field. However, the concentrations along the outer arc are slightly lower than observed (not shown), suggesting that the drainage flows may have been stronger and the observed plume edge might be a little farther down the slope. The model results show that the horizontal eddy in Fig. 3b may be the mechanism that spreads the plume over a large area 16 km downwind of RFP. The hourly-averaged surface concentrations along the sampler arcs compare very well to the observed values during most of the evening (not shown).

Plume transport for this evening appears to be correlated to the wind changes at RFP as seen by comparing the location of the maximum concentration in Fig. 5 with the wind direction in Fig. 4. The plume centerline moves from the east to the southeast section on the inner sampler arc and from the northeast to the

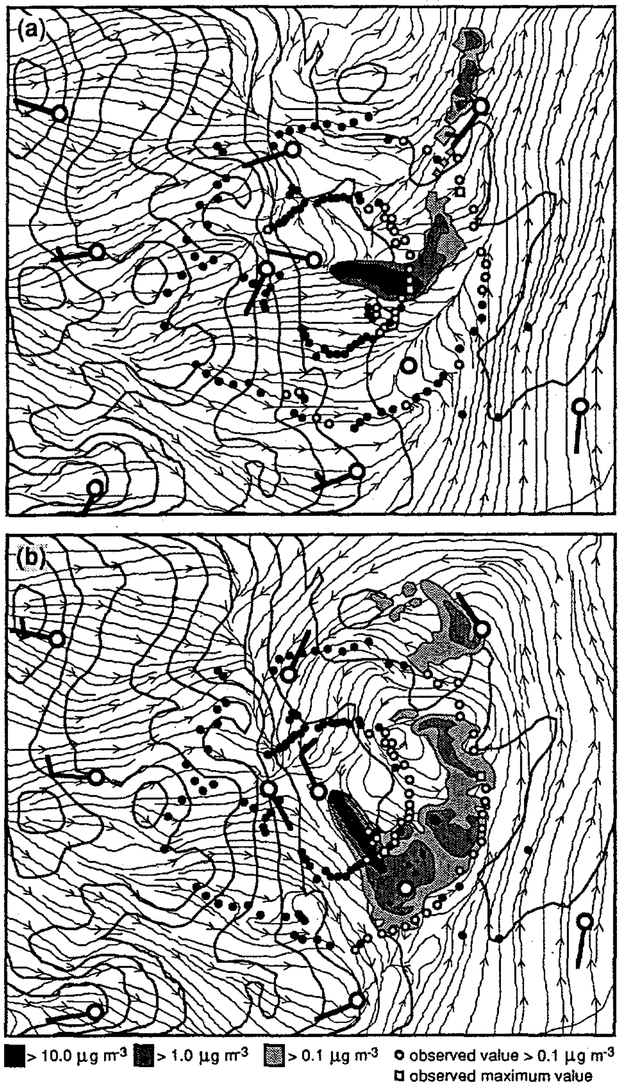

Fig. 3 Wind field (streamlines) 26 m AGL from grid 3 of FDDA simulation at (a) 00 MST, Feb. 8 with hourly-averaged surface concentration between 00 - 01 MST and (b) 02 MST, Feb. 8 with hourly-averaged surface concentration between 02 - 03 MST where wind barbs are observed data

southeast section on the outer sampler arc, reflecting the wind direction shift from southwest to northwest at RFP. This behavior was also observed for the evening of Feb. 3 - 4. The transport from the release location to the first sampler arc indicates that the plume did not necessarily follow the local terrain features and the local drainage flows originating along the Rocky Flats bench and its gullies were affected by other mechanisms. On the other hand, the observed maximum concentration location remained relatively constant for the evenings of Feb. 4 - 5 and 6 - 7, suggesting that the plume followed the local terrain slopes within a shallow drainage flow that was decoupled from flows above it.

Another way to evaluate the dispersion calculations is to examine the concentrations summed over the entire evening. This is useful for radiological releases in which a dose must to be computed or for chemical releases when long-term exposure is an issue. The observed and simulated summed concentrations are compared in Fig. 6 and the horizontal footprint of the plume is shown in Fig. 7. The model does quite well in determining the path of the plume, as well as reproducing multiple peak concentration values.

V. CONCLUSIONS

Continuous FDDA is a useful tool in producing high-resolution mesoscale analysis fields that can be

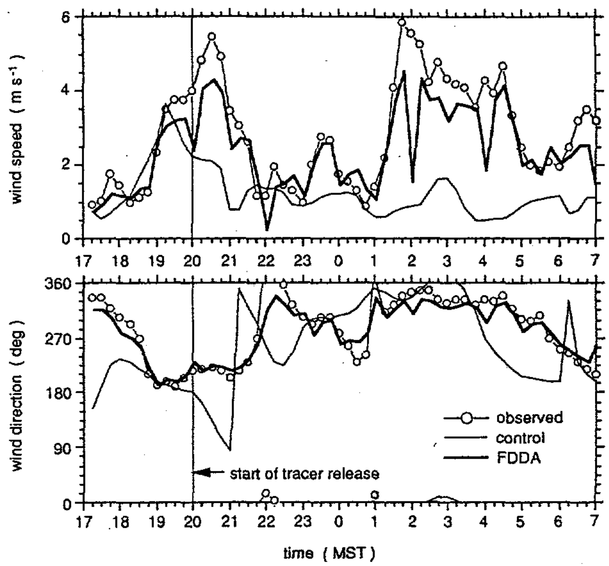

Fig. 4 Time series of wind direction and speed at the 25 m level of the RFP tower

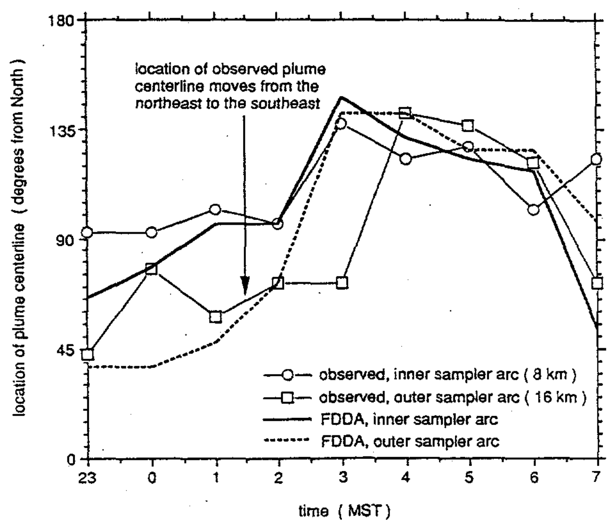

Fig. 5 Position of maximum plume concentration

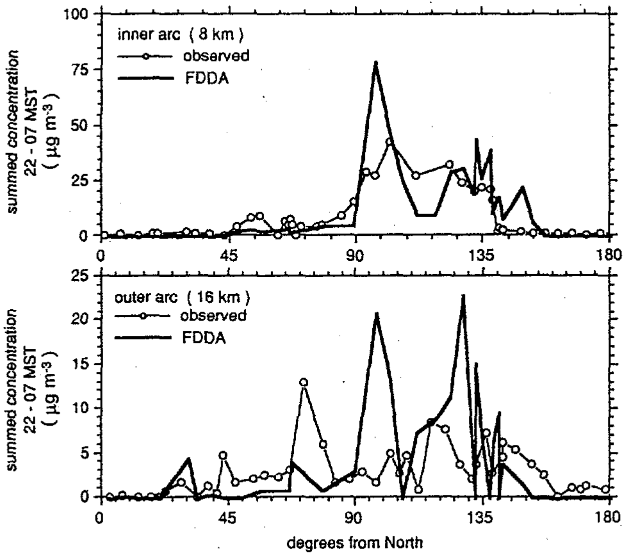

Fig. 6 Surface concentration summed over the entire evening at the sampler locations from the FDDA simulation

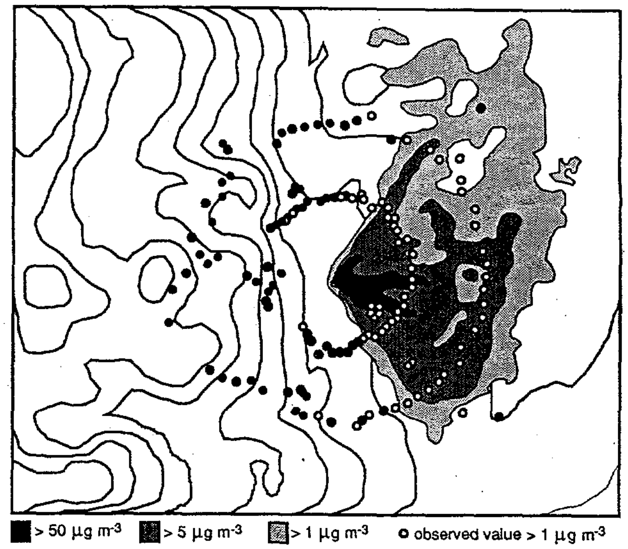

Fig. 7 Surface concentration summed over the entire evening on domain 3

used to create a better initial conditions for mesoscale atmospheric models and drive transport models for dispersion studies. While RAMS is capable of predicting the qualitative flow during the four evenings, additional experiments need to be performed to improve the prognostic forecasts made by RAMS and refine the FDDA procedure so that the overall errors are reduced even further.

Despite the fact that a great deal of computational time is necessary in executing RAMS and LPDM in the configuration employed in this study, recent advances in workstations are making applications such as this more practical. As the speed of these machines increases in the next few years, it will become feasible to employ prognostic, three-dimensional mesoscale/transport models to routinely predict atmospheric dispersion of pollutants, even in highly complex terrain. For example, the version of RAMS in this study could be run in a "nowcasting" mode that would continually assimilate local and regional observations as soon as they become available to produce wind fields similar to those in Fig. 3. The atmospheric physics in the model would be used to determine the wind field where no observations are available. The three-dimensional flow fields could be used as dynamic initial conditions for a model forecast. The output from this type of modeling system will have to be compared to existing diagnostic models to determine whether the wind and dispersion forecasts are significantly improved.

ACKNOWLEDGMENTS

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