Journal of Wind Engineering and Industrial Aerodynamics, 46 & 47 (1993) 229–237
Elsevier

Large eddy simulation of microburst winds flowing around a building

M. NICHOLLS
Research Associate, Department of Atmospheric Science, Colorado State University, Foothills Campus, Fort Collins, CO 80523, U.S.A.
R. PIELKE
Professor, Department of Atmospheric Science, Colorado State University, Foothills Campus, Fort Collins, CO 80523, U.S.A.
R. MERONEY
Professor, Civil Engineering, Colorado State University, Foothills Campus, Fort Collins, CO 80523, U.S.A.

Abstract

A large eddy simulation of a microburst producing thunderstorm is carried out . The thunderstorm is initiated when a thermal within a developing mixed layer reaches the lifting condensation level and strong latent heating occurs. A microburst is subsequently produced as condensate from the thunderstorm falls beneath the melting level. In this study, the viability of using two-way interactive multiple nested grids to investigate the interaction of the outflow from the microburst with a much smaller scale architectural structure is investigated. The relationship of the fluctuating winds around the building to the microburst structure is described.

1. INTRODUCTION

It has been estimated by Thom [1] that about one third of the extreme winds recorded in the U.S. are associated with thunderstorms. Outflows, which are often responsible for the extreme winds from thunderstorms, vary in scale. A small scale outflow which produces damaging winds near the surface has been termed a microburst by Fujita [2]. Larger scale outflows from thunderstorms can also cause damaging winds. For this preliminary study, an environment conducive to the formation of microbursts is considered. As discussed by Selvam [3], a downdraft wind profile is different from a developed boundary layer profile. Profiles in downdrafts often display a maximum close to the ground (~100 m) with lower velocities in the upper part of the outflowing layer of cold air. Moreover, downbursts are highly transient phenomena, and it is of some interest to determine the structure of the fluctuating winds associated with them and how this effects the wind loading on a building.

Numerical simulations of microbursts using an axi-symmetric model have been made by Proctor [4]. Downdrafts were initiated by specification of a distribution of precipitation at the top boundary of the model and allowing it to fall into the domain. In this present study, a microburst producing thunderstorm is initiated by a thermal within a

0167-6105/93/$06.00

developing mixed layer, in order to obtain a more realistic fluctuating wind than might be obtained from a more idealized initialization procedure.

It has been demonstrated by Murakami et al. [5] that a large eddy simulation model can successfully replicate many of the observed features of the flow around a building. Using a similar building model to Murakami et al., we investigate the wind flow around a building produced by a microburst. In order to simulate this phenomena which covers a wide range of scales, two-way interactive multiple nested grids are utilized. This enables the formation of the thunderstorm and microburst to be simulated on a coarse grid, after which, successively finer grids are used to "telescope down" to the small scale flow around a building.

2. MODEL

The model used in this study is the Colorado State University-Regional Atmospheric Modeling System (CSU-RAMS). The model contains a full set of nonhydrostatic compressible dynamic equations for water and ice-phase clouds and precipitation. The model has two-way interactive multiple nested grid capability [6], which makes it particularly suited to the simulation of phenomena which cover a wide range of scales. Acoustic terms are integrated with a small time step and low-frequency terms with a large time step. The equations are solved on a standard velocity staggered grid described by Tripoli and Cotton [7]. A first order eddy viscosity subgrid scale parameterization is used. The upper boundary is a rigid lid. A Rayleigh friction layer was incorporated at the upper-most levels to prevent reflection of gravity waves from the top of the domain. The surface parameterization of momentum fluxes is based on the Louis scheme [8]. The reader is referred to Nicholls et al. [9] for a description of the microphysical parameterizations used in the model and to Pielke et al. [10] for a general discussion of model applications.

For the building, the component of velocity normal to the surface is set to zero. At the corners of the building a vorticity constraint is used for the calculation of the advective terms. The profiles of the tangential velocity components were assumed to obey a power law expressed as $\overline{u} \; \alpha \; \sqrt{z}$, as in Murakami et al. [5].

3. EXPERIMENTAL DESIGN

For this preliminary experiment the domain is two dimensional. Five grids are used with grid increments of 202.5, 67.5, 22.5, 7.5 and 2.5 meters. Each grid has 90 horizontal grid points and 60 vertical grid points, except for the coarsest grid which has 70 vertical grid points. The Rayleigh friction layer is included at the uppermost 10 levels of the coarsest grid. The lateral boundaries are periodic. A schematic of the nested grids is shown in Fig. 1. Each successively finer grid is centered within the next coarsest grid. Each grid extends to the surface. The building is centered within the finest grid and has 20×20 grid points.

The sounding used in this experiment is shown in Fig. 2. It is based on the 2300 UTC 2 August 1985, Dallas–Ft. Worth, TX microburst sounding used by Proctor [4]. Small randomly distributed temperature perturbations ($\leq$ 0.2 k) are introduced at the lowest level above the surface to initiate thermals. In order to have some control over the position of the thunderstorm a slightly larger temperature perturbation of 0.4 K is introduced at a specified location.

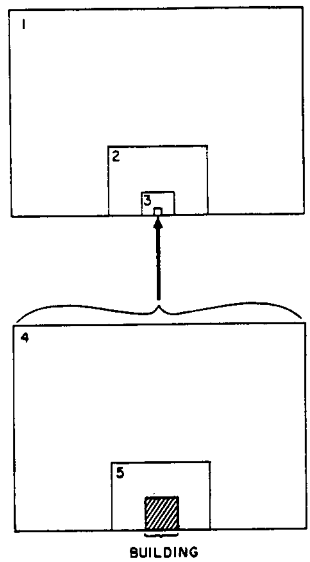

Figure 1: Schematic of nested grids.

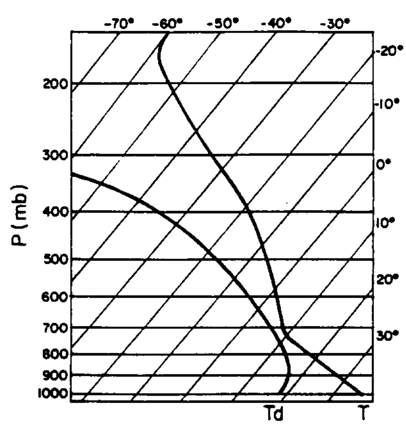

Figure 2: Sounding used to initialize model.

4. RESULTS

Figure 3a and b show the vertical velocity and total condensate, respectively, at t = 4800 s, for Grid 1. There is a deep convective cell and shallower thermals at low levels. The deep convective cell developed when one of the thermals in the mixed layer reached the lifted condensation level. During the next 600 s the downdraft within the lower region of the cloud develops into a downburst producing a strong outflow near the surface.

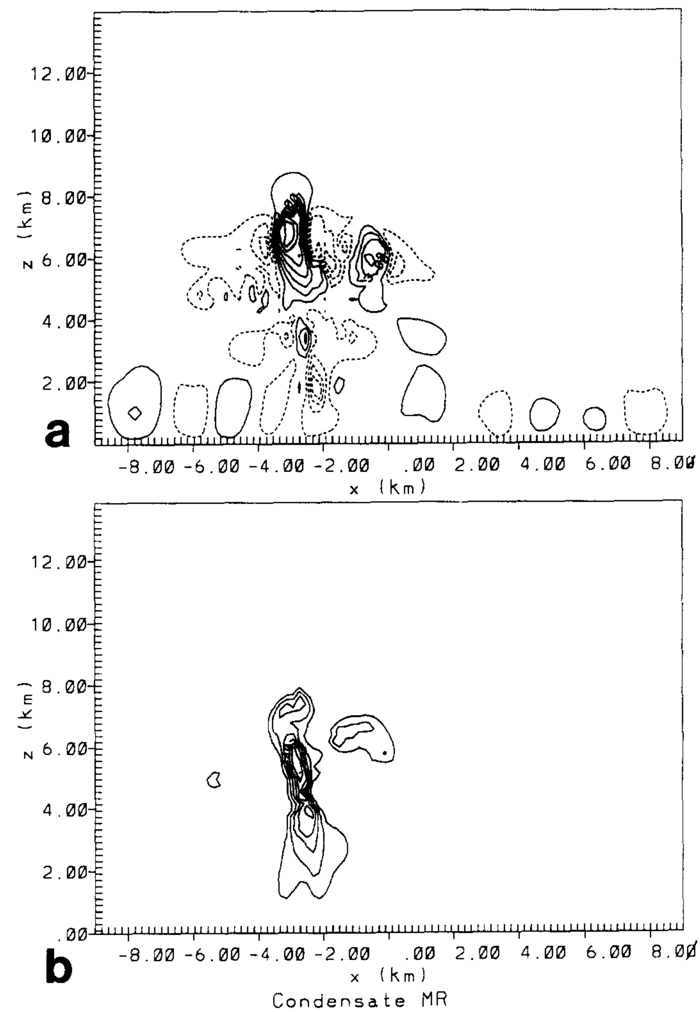

Figure 3: Fields at t = 4800 s, for Grid 1: (a) Vertical velocity. The contour interval is 2 m s^{-1}. Dashed isopleths indicate negative values in this and subsequent figures. (b) Total condensate. The contour interval is 1 g kg^{-1} and the label scale is 10.

Grids 2, 3, 4 and 5 were activated at t = 4500 s. Figure 4a, b and c shows the perturbation temperature, perturbation pressure and horizontal velocity, respectively, at t = 5400 s, for Grid 2 (perturbations are from the initial state). A cold outflow can be seen near the surface. An anti-clockwise rotating vortex occurs behind the leading edge of the outflow with a pressure minimum of -1.65 mb. The maximum horizontal wind velocities occur at ~100 m above the surface. The building is centered at x = 0.3 km and is evidenced by negative horizontal velocities which occur just behind it. The hemispheric region of warm air at x = 1.5 km, z = 3 km is a cumulus cloud which developed at the top of an upward moving thermal. Figure 5 shows the streamlines at t = 5400 s, for Grid 3. This shows the microburst vortex centered at a height of 0.8 km and a smaller clockwise rotating vortex which has been shed from the building. There are two finer grids which further "telescope down" in scale. Figure 6a and b show the streamlines and perturbation pressure, respectively, at t = 5400 s, for the finest grid. The streamlines show separation has occurred at the windward corner of the building. The clockwise rotating eddy which formed behind the building, seen in Grid 3, has already advected out of the fine grid. A smaller anticyclockwise rotating eddy has formed just behind the building. Smaller eddies occur above the roof and at the front of the building near the surface. A pressure minimum occurs at the windward corner. A low pressure occurs over most of the building which is mainly due to the pressure minima associated with the microburst vortex which is positioned above the building at this time.

For the simulated microburst there are actually two wind maxima which occur near the surface. The first strong wind gust is at the leading edge of the outflow. The second wind maxima is directly beneath the low pressure center aloft. This is consistent with the modeling study by Droegemeier and Wilhelmson [11].

5. CONCLUSIONS

In this study, it has been shown that two-way interactive multiple nested grids should prove a valuable tool for investigating the interaction of meteorological phenomena with architectural structures. It can be seen how the fluctuating winds around a building are related to the structure of the microburst. The fluctuating surface winds can depend on the type of thunderstorm outflow. For instance, if the outflow is cold and deep Kelvin Helmholtz instability is likely to occur. For a stably stratified lower atmosphere, gravity wavelike perturbations may coexist with the density current and eventually propagate ahead of it, as discussed by Fulton et al. [12]. Further investigation of downbursts interacting with buildings needs to be undertaken in a three-dimensional framework. The time scale for the development of a separation layer and eddies adjacent to the surface of the building is dependent on the surface friction parameterization. Further refinement of this parameterization and comparison with observations needs to be made. This type of analysis could also be extended to study the interaction of buildings with a simulated tornado (Pielke et al., [10]).

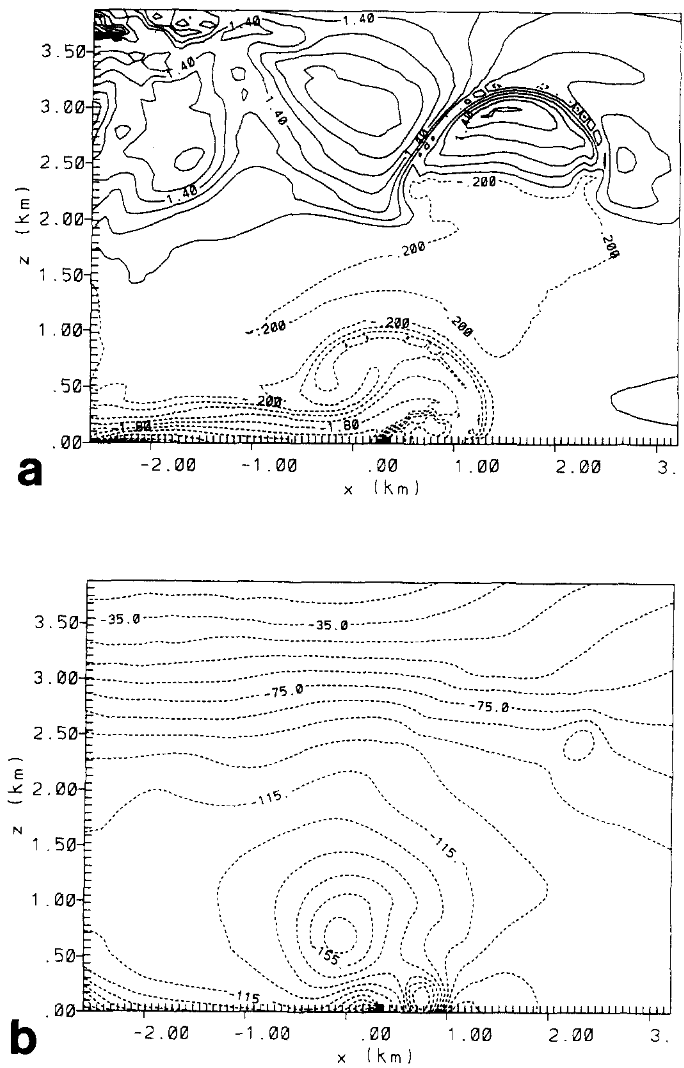

Figure 4: Fields at t = 5400 s, for Grid 2: (a) Perturbation temperature. The contour interval is 0.4 k. (b) Perturbation pressure. The contour interval is 10 Pascals. (c) Horizontal velocity. The contour interval is 1 m s^{-1}.

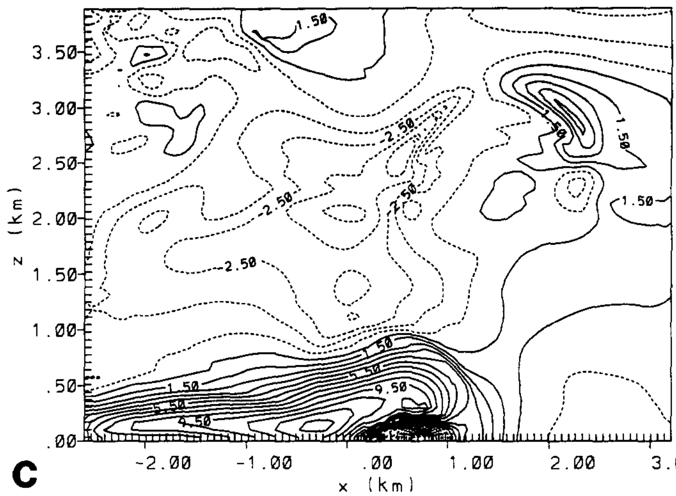

Figure 4: Continued

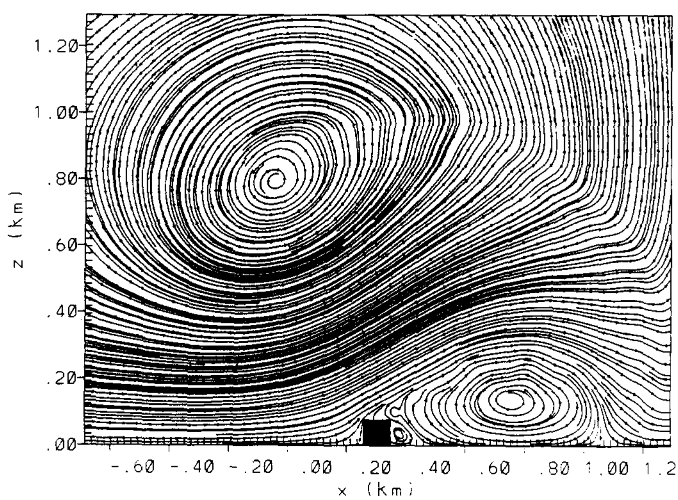

Figure 5: Streamlines for Grid 3, at t = 5400 s.

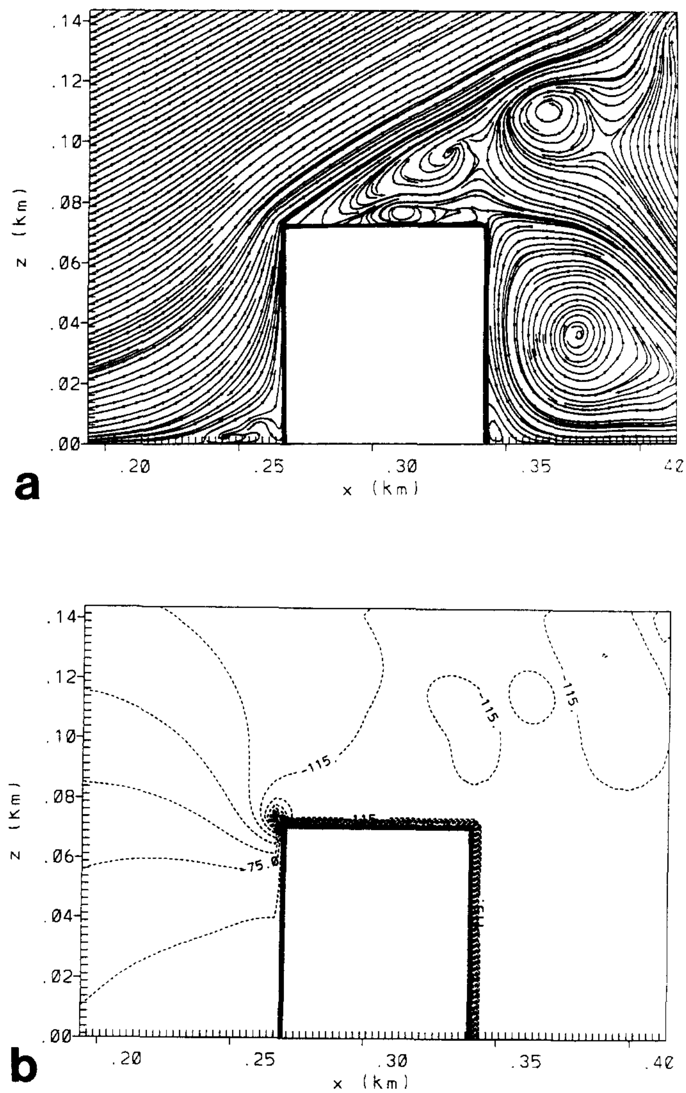

Figure 6: Fields at $t = 5400$ s, for Grid 5: (a) Streamlines. (b) Perturbation pressure The contour interval is 10 Pascals.

6. ACKNOWLEDGMENTS

We are grateful to Dr. Robert Walko for his assistance with the building model code. This research was supported by Grant #BCS-8821542 and #ATM-8915265.

7. REFERENCES

1. Thom, H.C.S., New Distributions of Extreme Wind Speeds in the United States, J. St. Division, ASCE, Vol. 94 (1969), pp. 1787-1801.
2. Fujita, T.T., Tornadoes and Downbursts in the Context of Generalized Planetary Scales, J. Atmos. Sci., Vol. 38 (1981), pp. 1511-1534.
3. Selvam, R.P., Numerical Simulation of Thunderstorm Downdrafts, 8th International Conference on Wind Engineering, London, Ontario, Canada, July 8-12, 1991.
4. Proctor, F.H., Numerical Simulations of an Isolated Microburst. Part II: Sensitivity Experiments, J. Atmos. Sci., Vol. 46 (1989), pp. 2143-2165.
5. Murakami, S., A. Mochida and K. Hibi, Three-Dimensional Numerical Simulation of Air Flow Around a Cubic Model by Means of Large Eddy Simulation, J. Wind Engineering and Industrial Aerodynamics, Vol. 25 (1987), pp. 291-305.
6. Clark, T.L. and R.D. Farley, Severe downslope windstorm calculations in two and three spatial dimensions using anelastic interactive grid nesting: A possible mechanism for gustiness. J. Atmos. Sci., Vol. 41 (1984), pp. 329-350.
7. Tripoli, G.J. and W.R. Cotton: The Colorado State University three-dimensional cloud/mesoscale model-1982. Part I: General theoretical framework and sensitivity experiments. J. Rech. Atmos., Vol. 16 (1982), pp. 185-220.
8. Louis, J.F., A parametric model of vertical eddy fluxes in the atmosphere. Bound.-Layer Meteor., 17, 187-202.
9. Nicholls, M.E., R.A. Pielke, and W.R. Cotton, 1991: A two-dimensional numerical investigation of the interaction between sea-breezes and deep convection over the Florida peninsula. Mon. Wea. Rev., Vol. 119, pp. 298-323.
10. Pielke, R.A., W.R. Cotton, R.L. Walko, C.J. Tremback, W.A. Lyons, L.D. Grasso, M.E. Nicholls, M.D. Moran, D.A. Wesley, T.J. Lee, and J.H. Copeland: A comprehensive meteorological modeling system-RAMS, (accepted to Meteorology and Atmospheric Physics).
11. Droegemeier, K.K., and R.B. Wilhelmson, Numerical Simulation of Thunderstorm Outflow Dynamics. Part I: Outflow Sensitivity Experiments and Turbulence Dynamics, J. Atmos. Sci., Vol. 44 (1987), pp. 1180-1210.
12. Fulton, R., D.S., Zrnić, and R.J. Doviak, Initiation of a solitary wave family in the demise of a nocturnal thunderstorm density current, J. Atmos. Sci., Vol. 47, 319-337.