J2.13 A MULTI-SCALE MESOSCALE ATMOSPHERIC MODEL FOR SIMULATION OF AIRFLOW AROUND BUILDINGS IN COMPLEX TERRAIN

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1. INTRODUCTION

Considerable interest exists in modeling airflows and transport/diffusion of airborne materials in urban environment. A mesoscale atmospheric model HOTMAC (Yamada and Bunker, 1988) was modified to simulate explicitly airflows around buildings in a fashion similar to a CFD (computational fluid dynamics) code. The modified model is tentatively called HOTCFD (Higher Order Turbulence Closure for Fluid Dynamics). The model physics, including second-moment turbulence-closure equations, are almost identical to its original code, HOTMAC.

Atmospheric pressure distributions are generated by the differences in air density in the vertical columns, and the hydrostatic equilibrium is a good approximation in the atmosphere. On the other hand, airflows around buildings are not in the hydrostatic equilibrium. Pressure variations are generated by changes in wind speeds, and the resulted pressure gradients subsequently affect wind distributions. We adopted HSMAC method (Hirt and Cook, 1972) for pressure computation because the method is simple yet efficient. The method is equivalent in solving a Poisson equation, which is commonly used in non-hydrostatic atmospheric models. We tested both the HSMAC method and solving a Poisson equation, and found that the HSMAC method produced the results that appear to be realistic.

2. SIMULATION RESULTS

HOTCFD was applied to simulate airflows around a building. A square-base building was placed along the axis in the east-west direction. The building base was 28 m x 28 m and the height was 40 m. The computational domain was 200 m x 200 m x 500 m (vertical). The horizontal grid spacing was 4 m and the vertical grid spacing was 2 m for the first 20 m above the ground and increased gradually to reach 43 m at the top of computational domain. A total of 51 x 51 x 31 grid points were used.

Simulations were conducted in two coordinate systems: The Cartesian coordinates commonly used in the CFD simulations and a terrain-following coordinates widely used in mesoscale atmospheric models.

Figure 1 shows the modeled horizontal wind distributions at 5 m above the ground. The divergence of winds is obvious upwind of the building and return flows are evident downwind of the building.

Figure 2 is the counterpart of Fig. 1, where the building was treated as a part of terrain and a terrain-following coordinate was used. Winds are at 5 m above the terrain, which means that winds at the building location are at 5 m above the roof.

We now consider terrain effects, where a cone shaped, small hill was placed in the computational domain. The elevation distribution was specified by a Gaussian function, where a peak height was 50 m and standard deviation was 25 m. Then, a short building (8 m high) was placed over a flat area downstream of the hill.

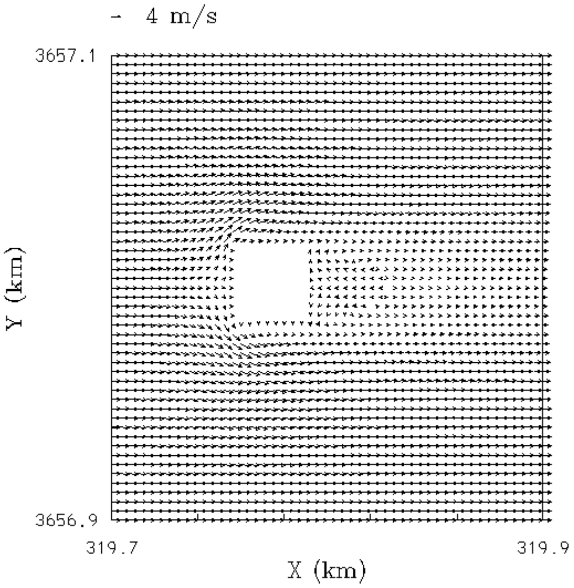

Fig 1: The modeled wind distributions at 5 m above the ground (The Cartesian coordinates)

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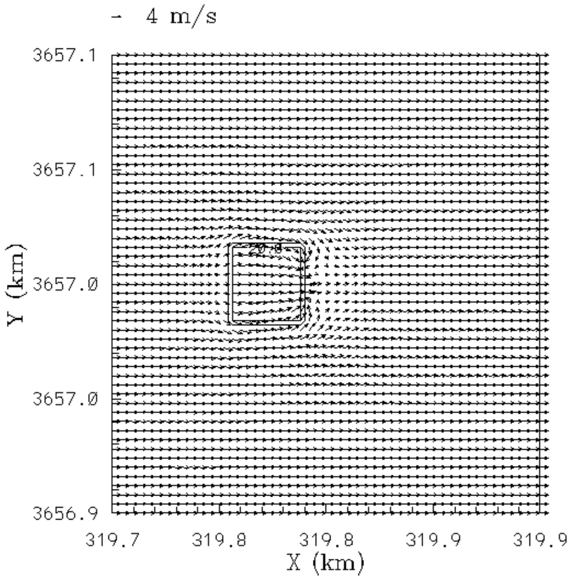

Fig 2: The modeled wind distribution at 5m above the ground (A terrain-following coordinates)

Figure 3 shows the modeled stream lines in the vertical section, where a wake is simulated downstream of the hill. A building was located slightly downstream of the wake region.

Figure 4 shows the counterpart of Fig. 3, where the building was treated as a part of terrain and a terrain-following coordinate was used for both the cone mountain and the building.

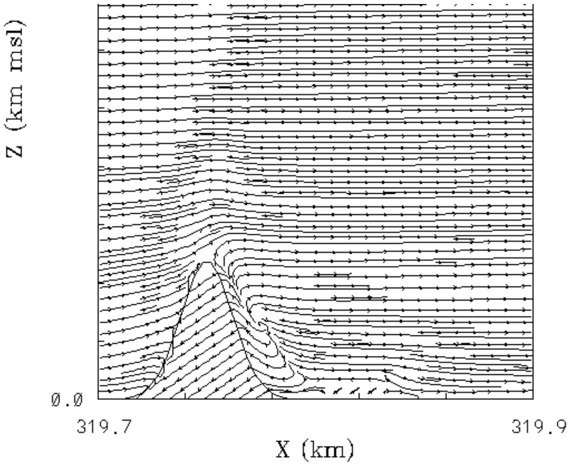

Fig 3: The modeled wind vectors in a vertical cross section. (The Cartesian coordinates)

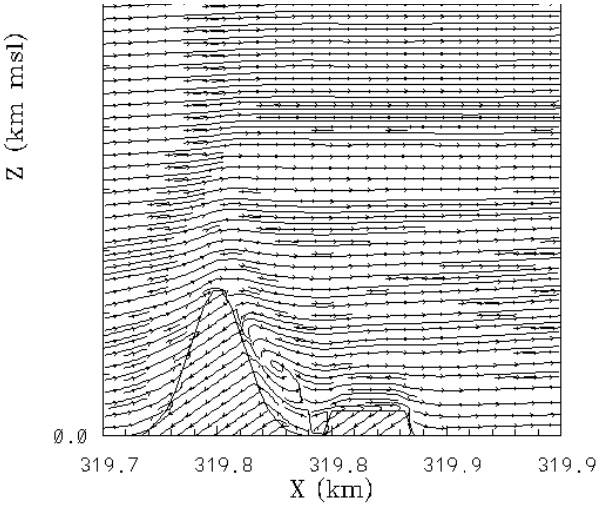

Fig 4: The modeled wind vectors in a vertical cross section. (A terrain-following coordinates)

3. SUMMARY

The modified mesoscale model HOTCFD successfully simulated wind and turbulence distributions behind obstacles, which showed many characteristics similar to those observed in wind tunnel experiments.

Each coordinate system has the strength and weakness. For example, the Cartesian coordinate system is suitable for a single or a few number of buildings to produce accurate solutions if appropriate grid structure is selected.

Treating buildings as part of terrain in a terrain-following coordinate provide high grid resolutions along the walls of all the buildings. Although wind distributions in the horizontal planes appear to be reasonable, the vertical structure of the flows such as separation and wakes behind the buildings are not simulated as accurate as using the Cartesian coordinate system.

In the future, additional tests will be conducted, where a steady state boundary condition will be replaced by the time dependent boundary conditions resulted from diurnal heating and cooling of the ground by solar heating and long wave radiation cooling.

4. REFERENCES

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