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APPLICATIONS OF A NESTED GRID MESOSCALE MODEL TO UNDERSTANDING THE IMPACTS OF MESOSCALE FLOW DISCONTINUITIES UPON REGIONAL AIR POLLUTION DISPERSION

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1.0 INTRODUCTION

Regional photochemical grid models (PCGMs) are widely used in regulatory decision making to design emission control strategies. Historically the meteorological inputs to these codes (wind, mixing depth, temperature) were derived from objectively analyzed observations, often collected during a companion field program. As typical photochemical model grid cell sizes gradually decrease to less than 10 km, the use of inputs derived from observational data sets is becoming increasingly impractical. The cost of field monitoring programs is becoming prohibitively higher as modeling domains enlarge, often encompassing over water and mountainous terrains, durations extend to many days, and it is required to obtain mass consistent 3-D wind fields on scales of only several kilometers. Thus, the emergence of mesoscale numerical models (MNMs) as a prime source of PCGM input. Current examples of the use of MNMs to drive PCGMs include the SARMAP modeling effort in the San Joaquin Valley and San Francisco areas, the Denver Brown Cloud II study, and LMOS, the Lake Michigan Ozone Study (Lyons et al, 1991).

Recent sea breeze model sensitivity studies (Lyons et al., 1990) highlighted the strong dependance of the resolution of flow field discontinuities, such as sea breeze fronts, and the resultant mesoscale regions of upward vertical motion and subsidence upon model horizontal mesh size. It should be noted that to resolve a given feature within an MNM one should ideally have four grid cells. Thus model "resolution" is actually four delta x. Sea and river breeze phenomena in the vicinity of the Kennedy Space Center were poorly resolved using 10 km mesh, whereas the model produced wind fields closely resembling the complex observations when the innermost nested grid had a 1.0 km mesh size. Computed vertical motions in the frontal zone exceeded 200 cm/sec, much stronger than most previous modeling studies using coarser grids. Trajectory calculations showed the resulting 3-D mesoscale transport was also highly dependant upon mesh size. This raises the basic issue of what mesh size is required to properly resolve transport patterns in complex 3-D mesoscale wind fields, often with first order flow discontinuities typically found in coastal zones and complex terrain. This paper reports on a series of mesh size sensitivity tests using an MNM linked with a Lagrangian Particle Dispersion Model (LPDM). Particles emitted into a MNM-generated atmosphere are advected by velocity fields composed both of model-resolved synoptic and mesoscale velocities and turbulent (sub-grid) fluctuations computed from normally-distributed random numbers whose standard deviation is determined locally. The issue of mesh size selection is of practical importance. One can not simply decrease mesh size with impunity because the impact upon computational requirements is severe. Typically a 3-D simulation using a 1.0 km mesh requires three orders of magnitude more computer time than the one for the same domain at 10 km. On the other hand, failure to properly resolve the impacts upon plume transport caused by strong mesoscale vertical motions can seriously compromise the validity of the model results.

2.0 EXPERIMENTAL RESULTS

The Regional Atmospheric Modeling System (RAMS), developed at Colorado State University, is a primitive equation, non-hydrostatic code (Pielke et al, 1990). It is here run in a 2-D mode along a 189 km wide east-west plane across Lake Michigan at latitude 42.4°N during mid-July. There were 28 vertical levels in a telescoping grid from 12 to 9600 m AGL. The land surface roughness length was uniform at 20 cm. A silty loam soil with a soil moisture factor (% of saturation) ranging from .38 (at 50 cm depth) to .10 at the surface was used. Water surface temperatures increased from 13°C on the western shore to 23°C on the east side of the lake. Moisture was considered a passive tracer and condensation was not allowed in this case. The model was initialized at local midnight and run for 19 hours. The case selected was typical of those days having high ozone levels along the western shore of Lake Michigan. Table I shows the sounding used, showing a brisk south-southwest flow near the surface. The observed lake breeze was shallow (150-300 meters in depth) and penetrated only about 10 km inland along the western shore. The simulations were conducted using five different horizontal mesh sizes (27, 9, 3, 1, and .33 km) with all other factors being held equal. Figure 1 displays the U and W wind components at 2100 Z (1500 LST). Not unexpectedly, as the mesh size decreases, the resolution of the lake breeze front becomes sharper, and upward vertical motions become stronger. Table II shows that the W values at the 27 km mesh size peak at 23 cm/sec, increasing to 152 cm/sec at 1.0 km and 212 cm/sec at 0.33 km. At the finest mesh, what appears to be noise in the vertical motion field is more likely gravity wave phenomena known to result from disturbance of the regional winds flowing over the "dynamical equivalent mountain" represented by the lake breeze inflow. What are the effects of the decreasing mesh upon pollution transport? The LPDM was configured to release particles from the 3 m AGL level at the rate of 1250 particles/hour for four hours beginning at 1630 Z. Two release points were selected, at the shoreline and 15 km inland (outside of the lake breeze inflow). Figure 2 shows the streaklines resulting from these releases, both in plan and side views. At first glance the resultant plume dispersion shows certain basic similarities. However, for mesh sizes of 3 km or less, the plume material is "trapped" much closer to the western shoreline and shows other characteristics noted in pollution observations in the region. Individual trajectories can be computed by nulling the turbulent component of the winds in the LPDM (Figure 3). In this case, for trajectories released from the two sources at 1630 Z, very different realizations are obtained. Again, only the smaller mesh sizes (1.0 and .33 km) resolve the complete helical vortex signatures suspected to characterize transport in the lake breeze cell.

TABLE I. Soundings used to initialize all five RAMS model runs

Height (m AGL)	Potem (°K)	RH (%)	U (m/sec)	V (m/sec)
9523	338.4	3	0	0
8422	335.0	13	-5.3	-2.8
7437	331.7	36	-7.4	-3.1
6544	328.3	6	-3.3	-3.8
5732	323.9	7	2.3	1.9
4983	321.3	8	3.0	4.0
4287	318.3	9	4.2	2.8
3638	314.7	9	3.7	2.0
3366	311.7	56	4.8	1.3
2540	307.7	54	6.0	-0.6
2460	307.2	66	5.9	-1.0
1921	305.4	68	9.5	0
1407	303.9	88	9.3	2.0
913	303.2	80	8.7	4.1
441	302.4	73	8.2	4.8
302	302.1	71	8.1	5.0
32	298.6	88	7.6	5.7

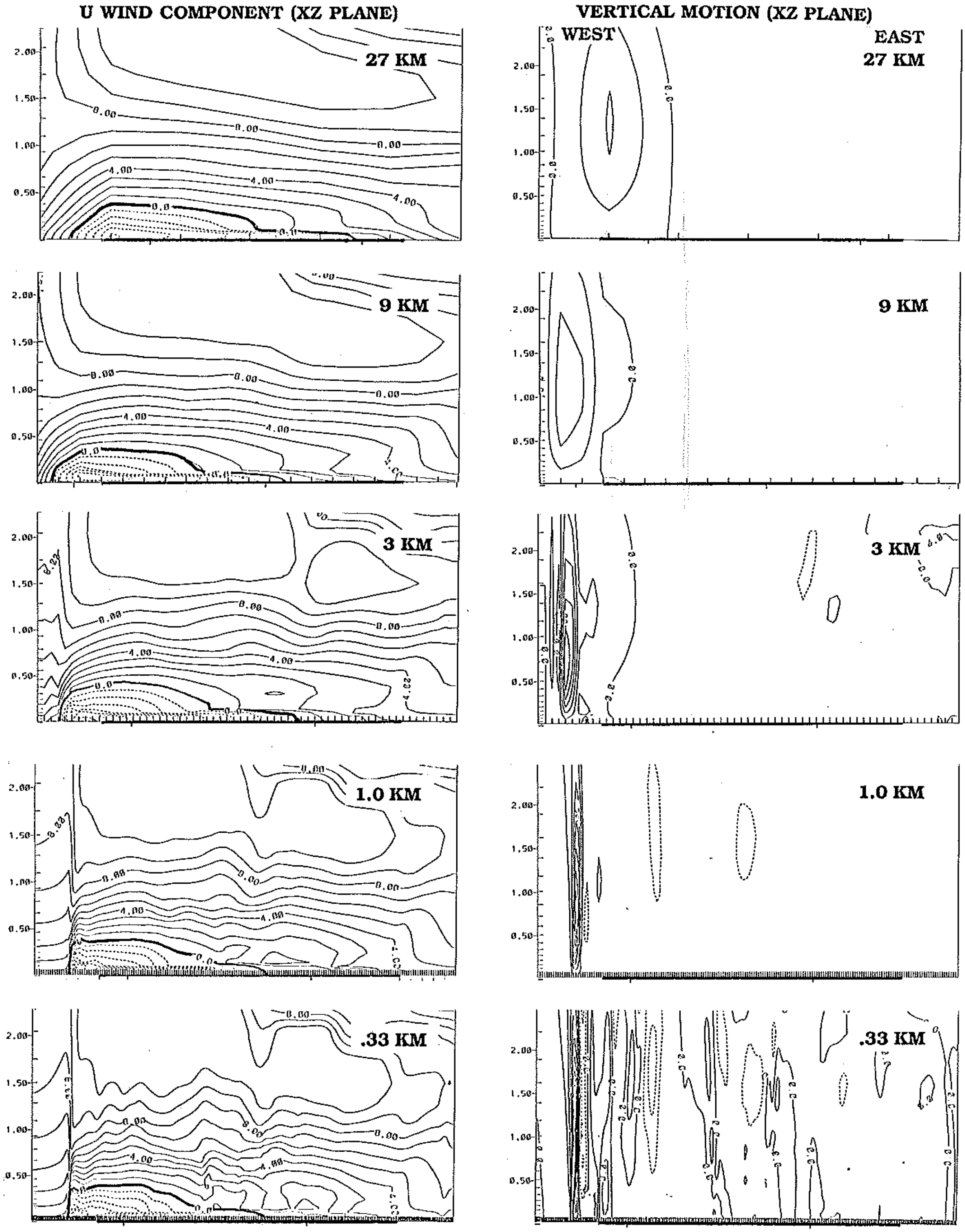

Figure 1. Five 2-D realizations of a lake breeze in a 3000 meter deep east-west plane across southern Lake Michigan using the RAMS model at 27, 9, 3, 1 and 0.33 km horizontal mesh. All frames at 2100 Z (1500 LST). Shown are the U wind component, m/sec (left) and the W vertical motion, cm/sec (right). The lake surface is shown as a darkened line. The top of the lake breeze inflow is indicated by a darkened line, with negative values shown as dashed lines.

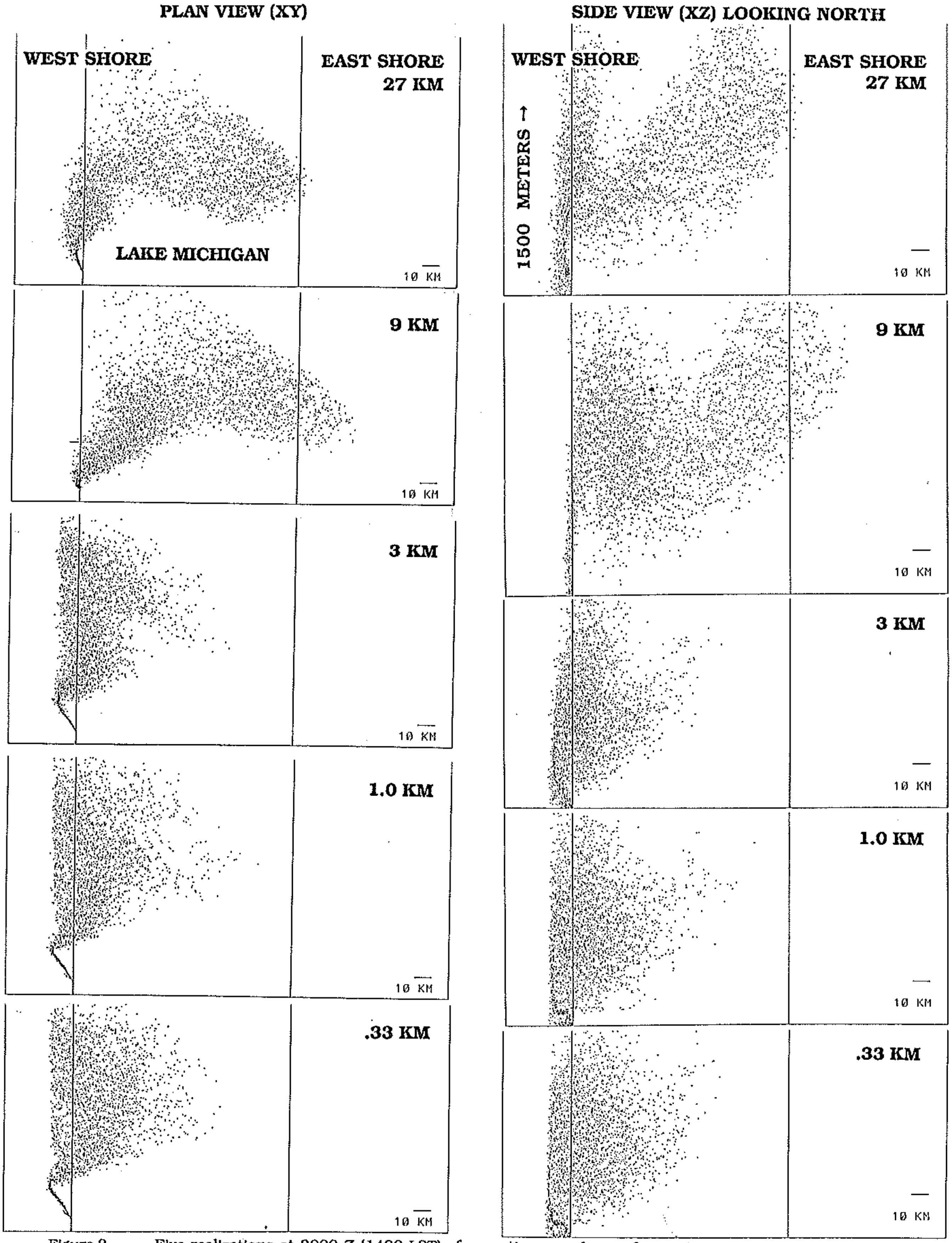

Figure 2. Five realizations at 2000 Z (1400 LST) of a continuous plume of particles released form a shoreline shore, 3 m AGL, beginning at 1630 Z and continuing until 2030 Z, using the Lagrangian Particle Dispersion Model driven by the RAMS prognostic meteorological model. The RAMS model was run with five different horizontal mesh sizes. The XY (plan) view of the plume is shown (left) and the XZ view looking north (right). The XZ section is 1500 meters high and the horizontal width of both views is 189 km.

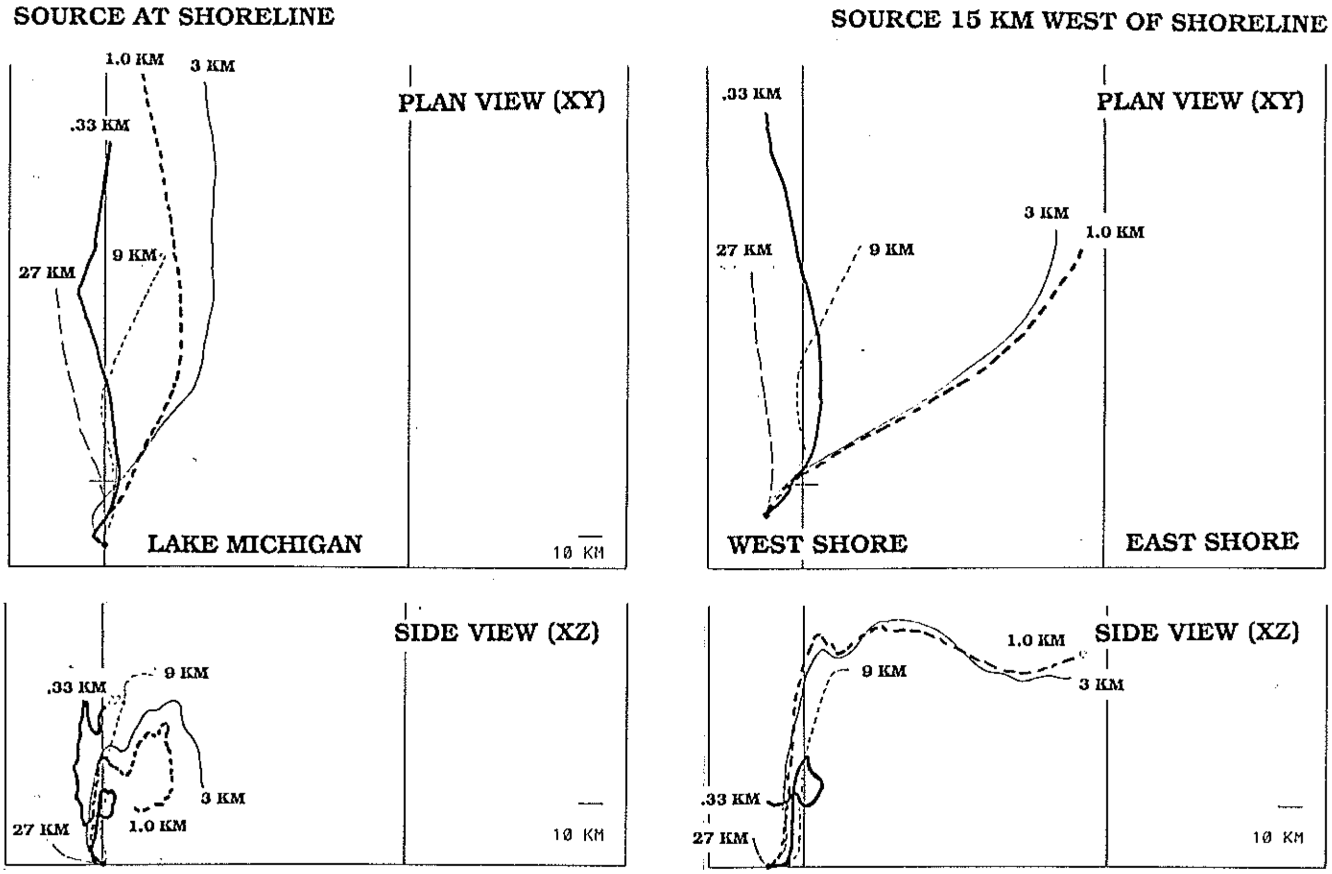

Figure 3. Plan (XY) and vertical (XZ) realizations of particle trajectories released from a 3 m AGL shoreline source (left) and a source 15km inland (right). All trajectories started at 1630 Z and continued until 2100 Z. The horizontal mesh size of the RAMS model used to drive the LPDM which generated the trajectories are indicated. The display domain is 189 km on a side, and 1500 meters deep in the vertical.

TABLE II. Maximum vertical motion (cm/sec) and subsidence as a function of model horizontal mesh size

	Horizontal mesh size									
Time	27 km		9 km		3 km		1 km		.33 km	
LST	up	down	up	down	up	down	up	down	up	down
1000	1	2	3	5	8	10	21	17	39	18
1100	4	3	6	6	15	11	29	13	55	14
1200	7	4	11	8	27	11	48	15	100	17
1300	11	5	19	9	44	10	91	12	181	38
1400	17	7	30	9	60	12	101	13	175	29
1500	21	8	35	10	72	13	135	18	198	30
1600	23	7	33	9	91	10	152	17	212	34
1700	21	7	26	8	59	12	133	17	205	32
1800	17	5	25	7	65	13	106	28	188	60
1900	12	5	14	5	17	10	75	17	144	28
2000	7	4	12	4	15	6	23	13	-	-

3.0 SUMMARY AND CONCLUSIONS

The use of MNMs as input to regional photochemical and acid deposition models is likely to become more widespread. For those domains in which significant discontinuities in the three-dimensional wind field are induced by topography (coastlines, mountains/valleys, land use discontinuities), considerable care must be taken to configure the model so the predicted wind field properly resolves the relevant mesoscale vertical transport processes. Even weak lake breeze fronts appear capable of generating peak mesoscale updrafts in the 100 to 200 cm/sec range which can significantly translocate plumes in the vertical. In the case of the lake breeze regime, it would appear that the desired resolution of the innermost nested horizontal mesh over the coastal zone is definitely less than 3 km. Current regional lake breeze modeling projects (for LMOS) plan using a 1.5 to 1.0 km mesh size. Whether a still finer mesh size is desired will in part be clarified by comparison of RAMS/LPDM model simulations to tracer release observations taken during the 1991 LMOS field program on the western shore of Lake Michigan.

4.0 ACKNOWLEDGEMENTS

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