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The Effect of Mesoscale Flows on Regional Atmospheric Transport in a Complex Terrain

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ABSTRACT

Model results simulated over a complex terrain under a synoptically calm condition, using a three–dimensional (3–D) regional–scale meteorological acid deposition model (RMADM), show that thermally induced mesoscale circulations (MCs): sea–and land–breeze circulations and up– and down–slope flow circulations play a fundamental role in determining how the pollutants being dispersed . Analysis showed that under synoptically calm condition, the role played by the MC would dilute the smoke released during the early stage of the emission; the accumulation, however, would become important if the synoptically calm condition lasts long. Since the structure and intensity of the MCs depend on geography and topographical allocation, land surface coverage, incoming solar radiation intensity and so on, it makes the estimates of source–reception relationship and long–range atmospheric dispersion more difficulty.

It concluded that it is impossible for a pollution model to correctly simulate smokes transport using only the synoptic station data, since the mesoscale information can not be resolved from these datasets.

Key words: Atmospheric transport, Mesoscale circulations, Mesoscale model

I. INTRODUCTION

The impact of pollutants emitted from industrial areas on environment has been increasingly concerned (Shao et al., 1992; Zhou and Li, 1992; Wang et al.,1996). Air Pollution episodes are relatively a common problem in coastal area or / and mountain area. In a calm, stagnant condition synoptic forcing is weak. It can be anticipated that locally induced classical MCs play a fundamental role in pollutant dispersion. The pollutant plume under the influence of synoptic flow might be affected by the MCs and mountain waves if the plumes travel over mountains. Obviously, the impact of MCs on plume transport will not be involved if the computation is based on synoptic data alone, since mesoscale features cannot be resolved from synoptic data. Based on extensive data sets collected in 1970s over mountain areas in China, we have suggested (1978) that transport and dispersion of pollutants are closely related to meteorological conditions: wind and temperature field over mountain area, suggesting that for regional and long–range atmospheric transport over coastal or / and mountain regions, the impact of the MCs on pollutant transport and dispersion must be taken into account under conditions with and without synoptic influence.

The aim of this study is to develop a computational efficient model suitable for engineering, which consists of both regional–scale meteorological model and atmospheric diffusion model for the use in studying the impact of MCs on pollutant dispersion.

II. A BRIEF DESCRIPTION ON THE NEW MODEL

The RMADM is basically a merging of two models: an Eulerian regional acid deposition model (ERADM) designed to simulate the spatial and temporal distributions of pollutants developed by Jia (1993) and a regional–scale biophysical meteorological model constructed by Jia and Ye (1996). For simplicity, the models will not be given in this paper, the reader can refer to the relevant papers in detail.

III. SIMULATION RESULTS AND DISCUSSION

Poor air quality is often associated with high pressure stagnation or thermal low associated with very high temperature in the lower layer of the troposphere. Under these conditions ventilation would be poor, mesoscale flows would dominate. This study investigates the impact of sea–land breeze circulations and mountain–valley circulations on pollutant transport under synoptically poor ventilation condition. As an example, Shandong peninsula is used to perform this study. The topography and allocation of the simulated domain are shown in Fig. 1a. Generally, there are seven mountains, described as from H_1 to H_7 in the order from west to east and valleys associated with these mountains. The geographic conditions suggest that the mesoscale climate in the peninsula is likely controlled by sea–breeze circulations (SBCs) and upslope flow circulations (UFCs) during the day and land breeze circulations (LBCs) and downslope flow circulations (DFCs) at night under nearly calm synoptical flow and clear sky conditions.

Table 1. Numerical Model Levels for θ and q and Initial Profile of q

Z(km)	0.075	0.15	0.275	0.475	0.7	0.95	1.35	2.00	2.80	3.60	4.50	5.75
q(g / kg)	11	10	9	7.5	7	6	5	2	1	0.7	0.3	0.02

Table 2. Input Parameters for Soil Model

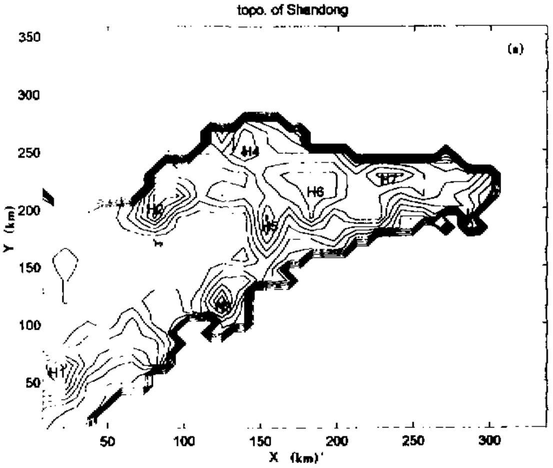
density	specific heat	conductivity
1.45 kg / m^3	1.46 J / cm^{3}K	3.9 cm / s

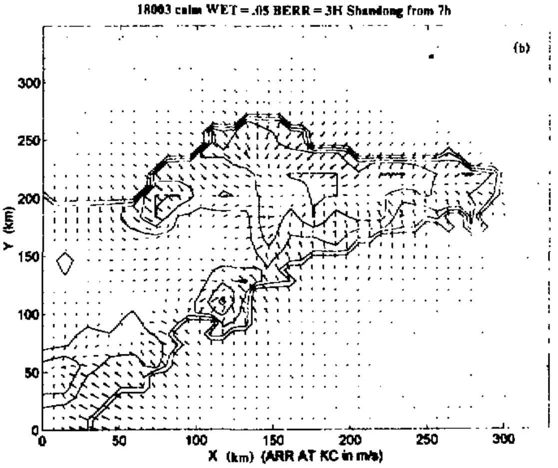
The input parameters were as follows: latitude = 37^{0}N; the simulation domain was 350 km in north–south and 330 km in east–west with grid resolution of 5–min.; the model consists of 16 vertical levels, ranging from $z=0$ to 13 km above sea level; the levels for potential temperature (θ) and specific humidity (q) in the air and the initial profile of q below 6 km are presented in Table 1, which is typical in Shandong peninsula; the initial profile of θ was set to be 3.5 K / km; the synoptic flow was set to be 0.5 m / s, coming from the south, in order to separate the impact of MCs on the dispersion; there were 6 levels in soil model with constant grid interval of 5 cm; the input soil parameters are described in Table 2; the initial wind fields were obtained by running the 3–D model to a nearly steady state with the given profiles of θ, q and other input parameters; the simulation was run 24 hours beginning at 0700 local standard time (LST) with time step 60 s . The source is at the level of $z=210$ m near Yantai city ($x=200$ km, $y=240$ km in Fig. 2a).

1. *Simulated Meteorological Fields*

Under synoptically calm situation, the horizontal temperarure difference in planetary boundary layer (PBL) is generated by absorbed different solar heating during the day and by different longwave radiation cooling at night between land and sea and between mountain and plain. SBCs (LBCs) and UFCs (DFCs) will be thermally forced during the day (at night). The flow fields are dominated by SBCs (or LBCs), UFCs (or DFCs) and their interaction.

In the morning hours, the simulated MCs are weak with maximum horizontal wind -0.9 m / s at 1000 LST (Fig. omitted). At 1600 LST, a convergence zone was formed in the central part of the peninsula as shown in Fig. 1b (the solid lines stand for topography with larger interval for Figs. 1b, 1c as compared with that in Fig. 1a). The maximum wind computed reached 5.9 m / s at this hour. By comparison of the wind speeds over south slopes of mountains H_1, H_2 and H_3 with that over the north, the wind intensities over the mountain slopes facing the sea were stronger than that of the mountain slopes facing the plain. Since the topography of mountains H_1, H_2 and H_3 looks like axis-symmetrically distributed with the axes running in NE–SW, suggesting the strong MCs developed over slopes facing the sea result from the interaction between SBCs and UFCs (UFCs are supported by SBCs). During the next several hours, the stronger UFCs developed over the slopes facing the sea will overcome the blocking by the opposite UFCs and penetrate into the opposite slope. Six hours later (at 2200 LST, see Fig. 1c), the convergence zone has developed into a convergence line because of the collision by the winds flowing from south or southwest in the southern peninsula





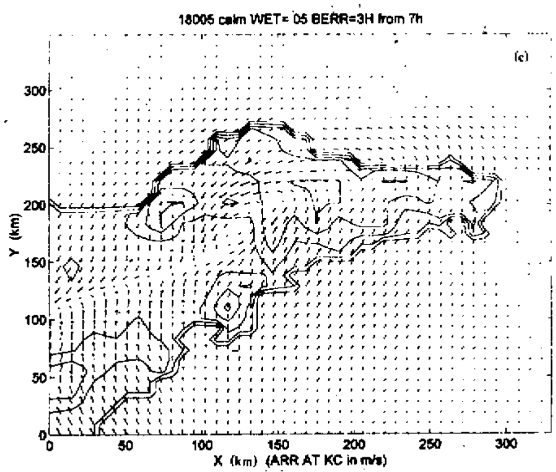


Fig. 1. (a) Topography of Shandong peninsula; (b) Numerical model simulated terrain-followed X-Ycross-section of horizontal wind vector at level $z=210$ m at 1600LST; (c) As in (b) but for 2200 LST.

and from northeast in the northern peninsula, respectively. Notice that a cyclonic circulation located at $x=130$ km, $y=170$ km was generated as shown in Fig. 1c.

As opposite to the daytime hours, the flows are controlled by LBCs, DFCs and their interaction. Generally, the winds came from southwest over the northern coast areas and from northwest over the southern coast areas (Figs. omitted).

2. *Impact of MCs on Pollutant Dispersion*

As far as air quality over a complex terrain is concerned during a weakly synoptic forcing period, it is important to understand how smokes released will be transported by MCs.

During the first 3 release hours, the smoke emitted from Yantai was transported eastwards by west wind. In the next 3 hours, the wind direction gradually changed from W to NW, which brought plumes to south-east. From 1400 to 1600 LST, the wind direction gradually switched to NE as shown in Fig. 1b, which blows the smoke towards southwest. The above mentioned wind field structure resulted in pollutants distributed as shown in Fig.2a by solid lines. In the afternoon, the MCs resulted from an interaction between SBC and UFC, were well developed, the winds flowed from NE over Yantai area (see Fig. 1b) and turned to east wind at about 2200 LST as shown in Fig. 1c. By the impact of MC, smoke emitted from Yantai was transported to southwest during the afternoon hours and to west in the evening, resulted in concentrations at 2200 LST distributed as in Fig. 2b. Notice that the gradients of concentration were sharp in the southern bounds as compared to that in the northern bounds. As compared Fig. 2b with Fig.1c, the sharp contrast was corresponding to where the convergence line located. As indicated in Section 2.2, the convergence line resulted from the collision of two headed-on MCs moving from south and north, respectively. The upward motion in the convergence zone of a UFC will be enhanced by the collision. The enhanced upward wind over the convergence zone will bring smoke to the height as high as 3.5 km above sea level and over the ridge area, as presented in Fig. 2d. The upward transported smoke will be brought back by the return flows of the MC in the upper layer of the PBL between 1.5 km -

2.5km as shown in Figs.2d and 2e, where Figs. 2d and 2e are the north–south and west–east cross–sections through the source point, respectively.

At night, SBCs and UFCs developed during the day were decayed and LBCs and DFCs were evolved as mentioned above. The valley flow collecting downslope flows was supported by LBC. The smoke blowing to west of the H_4 and H_6 during the day will be divided into two

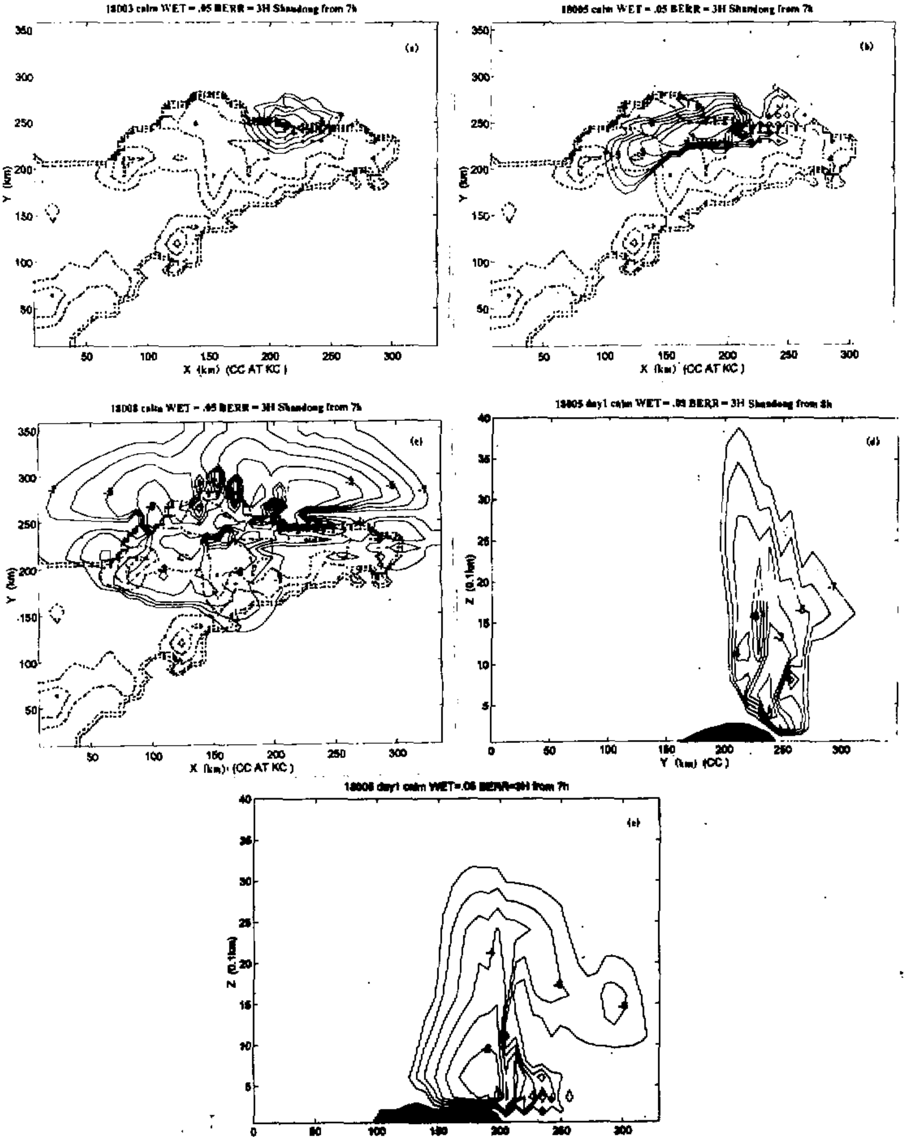


Fig. 2. Simulated terrain–followed X–Y cross–section of $\log_{10}C$ (solid lines) at: (a) 1600 LST; (b) 2200 LST; (c) 0700 LST; (d) Y–Z and (e) X–Z cross–sections at 2200 LST. All plots are through the source point. The dash–circle lines in (a,b,c) are the topography.

parts by valley wind: one was brought to east of Laizhouwan through the valley between H_2 and H_4, the other through the valley between H_2 and H_5 went down to the plain and then passed through the valley between H_3 and H_5 blowing to the southern coast area. Concentration ridges were formed based on the above reason as illustrated in Fig. 2c. Fig. 2c also indicates that the smoke newly released from the source at night will be transported to north and northeast by LBC supported by DFC near Yantai area to form a high concentration area. Notice also that there were diverse MCs thermally forced during the day and at night over the topography associated with different scales, in turn creating diverse convergence and divergence zones with different scales and intensities. The smoke transported in a complex wind field will result in a complex distribution of concentration as shown in Fig. 2c.

IV. CONCLUSION

Model results simulated over a complex terrain under a synoptically calm condition using a 3–D RMADM show that thermally induced MCs (SBCs, LBCs, UFCs, DFCs) play a fundamental role in determining how the pollutants being dispersed. Analysis suggested that under synoptically calm condition, the MCs provide an opportunity for the smoke moving horizontally and vertically. The smoke can be brought to 3.5 km and above in the convergence zone by updraft. Therefore, the role played by the MCs dilutes the smoke. The upward pollutants can be brought back into the return flows aloft. When the backward pollutants reach the divergence zone, they will be transported downward by downdraft, resulting in accumulation. The accumulation, however, would become important if the synoptically calm condition lasts long. Generally, in the early release time, smoke is transported by the local circulation system. Several hours later, the newly emitted smoke will continuously be transported by the local wind system, for the early release smoke, however, having been flowed to surroundings during the past period, they will be impacted by those MCs the pollutants located. Since the thermally forced MCs are changed day and night; their structure and intensity depend on the geography and topography allocation, land surface coverage, incoming and outgoing solar longwave radiation intensity and so on, and the above mentioned mechanism in diluting the pollutants will bring a complicated situation in estimating source–reception relationship and long–range atmospheric dispersion under a complex terrain.

The analysis suggests that it is impossible for a pollution model to correctly simulate smoke transport using synoptic station data only. Since the mesoscale information cannot be resolved from these dataset.

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