

Numerical simulation and analysis of characteristics of atmospheric diffusion in coastal area of a site

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Abstract. A Weather Research and Forecasting Model (WRF) and random walk model have been used to numerical simulate and analysis the characteristics of meso-micro scale wind field and atmospheric diffusion in coastal area of a sit. The results indicated that the atmospheric dispersion in this area is determined both by synoptic scale system and land-sea breeze circulation. Spatial variation of wind field is not obvious in synoptic scale system situation, which leads to the straight dispersion plume. Temporal variation of wind field, particularly the wind direction transition caused by transient of land-sea breezes is obvious. The method of random walk simulation better reflects the characteristics of the air pollutants transportation and diffusion. The atmospheric diffusion parameters obtained with numerical simulation experiment may reflect well the characteristics of the air diffusion in local area.

1. Introduction

The diffusion and transport of air pollutants are affected by local complex terrain and meteorological processes to a large extent. Topography influence includes the disturbance effect of complex terrain to airflow, letdown flow of mountain, sea breeze circulation caused by land-sea difference, and thermal inner boundary layer near coast [1, 2]. Meteorological processes mainly include the synoptic circulation and meso-and-micro scale weather system. Taking into account the complexity of the problems and the local characteristics of atmospheric diffusion, it is very necessary to analyze the meso-and-micro scale wind field and the transport and dispersion of pollutant which is for the actual condition. A lot of work has been done in this field in China, especially power plants and such projects. Various research methods have been used, such as atmospheric boundary layer sounding, turbulence observation, the field tracer test of atmospheric dispersion [3, 4], wind tunnel experiment [5], numerical simulation by [6, 7]. Subject to the weather uncertainty, the experimental conditions and the theoretical limitation, comprehensive conclusion cannot be reached using the former four methods. Numerical simulation has more advantages in studying the characteristics of the planetary boundary layer and atmospheric diffusion, which is good complement for atmospheric experiments [8].

The NCEP/NCAR global reanalysis data and Weather Research and Forecasting Model (WRF) are used here to simulate the meso-micro scale wind field of coastal area of a site. The wind field will be used to drive the meteorological fields, and simulate the transport and diffusion of the atmospheric pollutant in the area of the site, then analyze the atmospheric diffusion characteristics.



2. Numerical Simulation of WRF Program

NCEP FNL (Final) Operational Global Analysis data are on 1-degree by 1-degree grids prepared operationally every six hours, which is used as initial and boundary conditions in WRF. In order to show the meso-micro scale wind field more accurately, four two-way interactive nested domains were selected when WRF running. The spatial grid resolution of 1km(d04). 3km(d03). 9km(d02) and 27km(d01) are used respectively, and outermost domain covers the land and sea. The output result is the hourly wind field in the typical month of January, April, July and October, which represent the four seasons respectively. Terrain data with the resolution of USGS, and land cover type data with the resolution of 1km×1km are used here. The terrain nearby the site is showed in Fig.1.

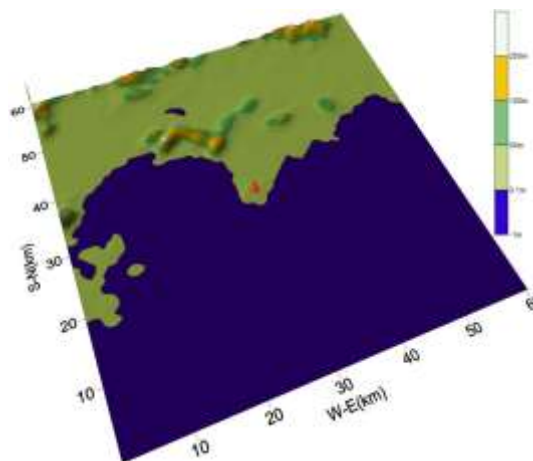


Figure 1. The terrain nearby site

3. Simulated wind field result by WRF

WRF simulated the meso-micro scale three-dimensional wind field at the height of 10m in the area of the site of the typical months. Based on the simulated result, the general characteristics, structures, and the evolution law were gotten as follows.

3.1. Continuous wind field of synoptic system

The system of wind field in spring is the transition field of winter and summer circulation system. The dominant wind direction is mainly east, the wind field distribution is more uniform. The system wind field in autumn as same as spring but the dominant wind direction is north and east. Affected by summer monsoon, southerly wind is dominant in summer. And in winter, Affected by Mongolian high, northeasterly wind is dominant with a higher wind velocity. The typical wind fields of each season are showed in Fig.2.

3.2. Mesoscale local circulation

The local circulation in July 18th is showed in Fig.3. The offshore wind from land to sea was weak at 02am on 18th, and improved until 06am. At around 10am, land breeze transformed to sea breeze gradually. At 02pm, temperature of land rose and the shoreward wind was obvious with increased velocity and land area affected by sea breeze. From 11pm to the next morning, the offshore wind formed again near surface.

Fig.4 shows the North-South vertical cross section of the wind field on July 18th. At 02am, sea breeze circulation started to form. Sea breeze circulation began to form at 02am on 18th July, and low-level offshore winds near the coast began and developed more into sea, and it lasted for about 4 hours. After 10am, affected by land thermal effects and background circulation, there were southerly winds all over the land and obvious upward flows near windward slope. And then during the night, land-sea thermal structure transferred, and northerly winds began to be dominant at low level.

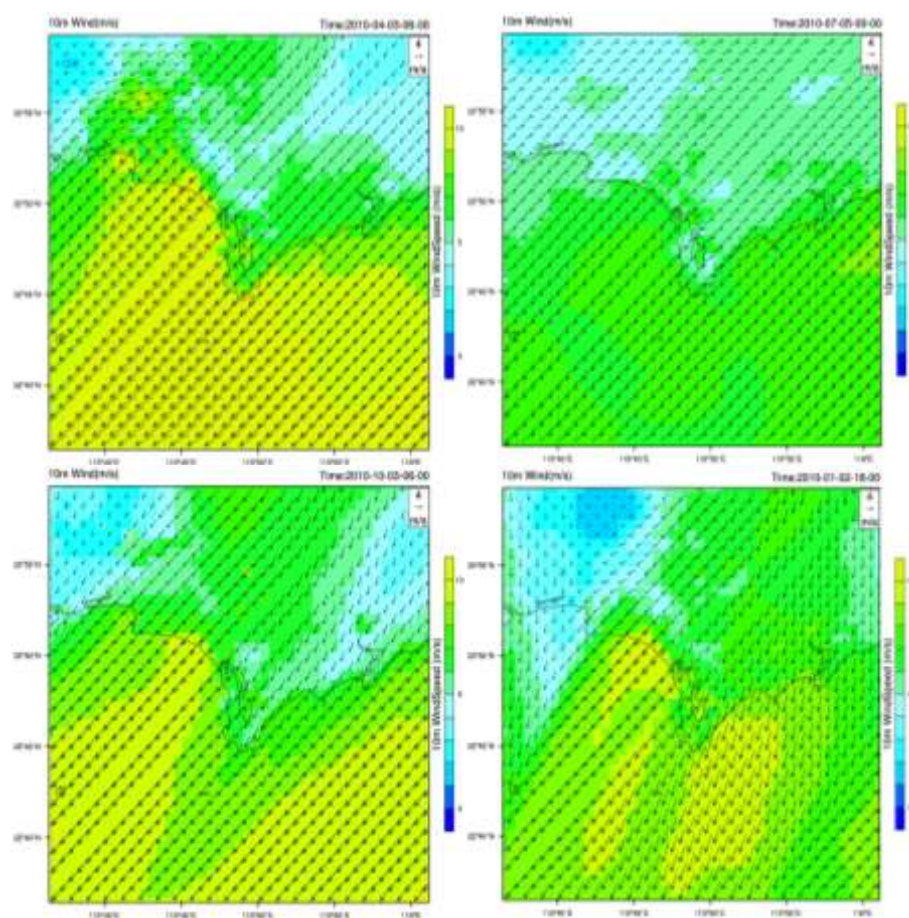


Figure 2. The continuous wind field of the typical synoptic system

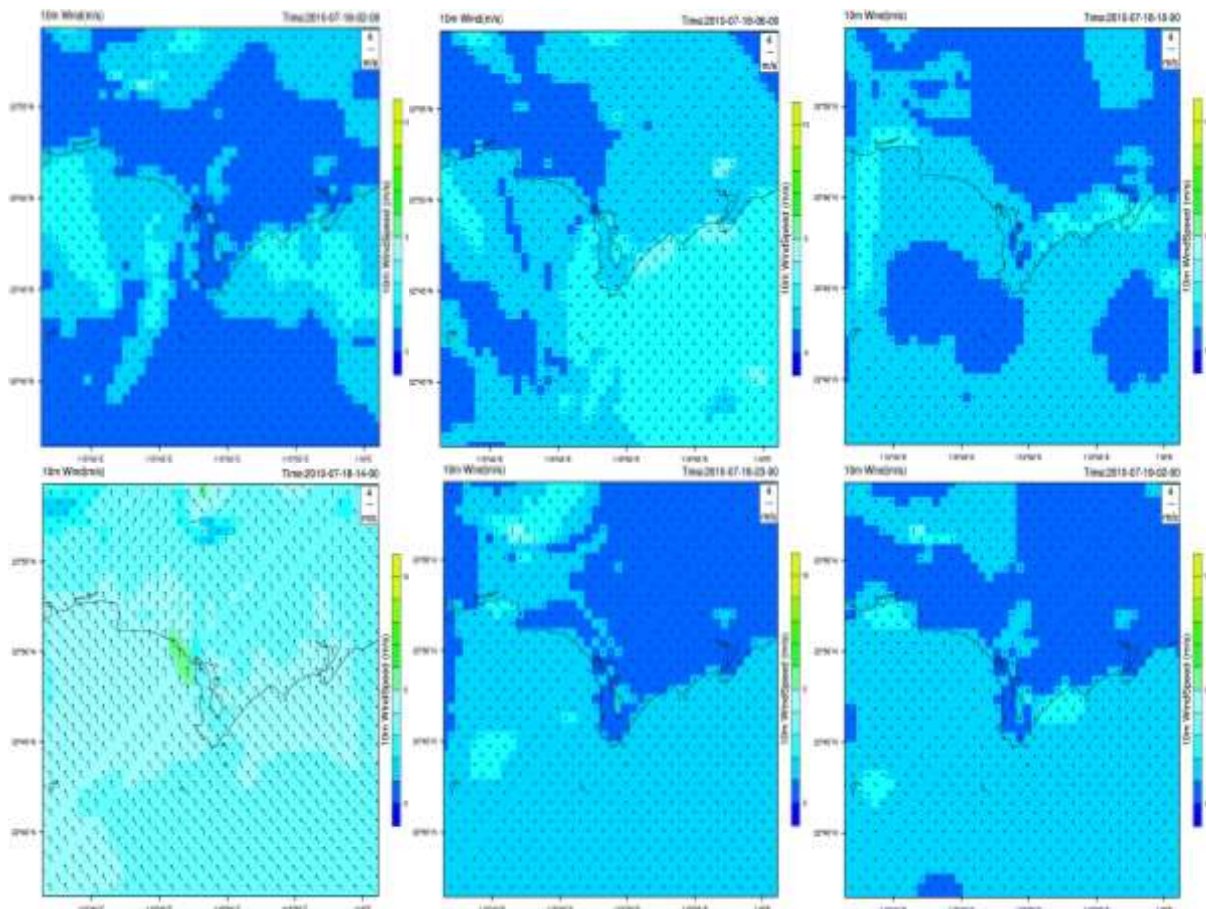
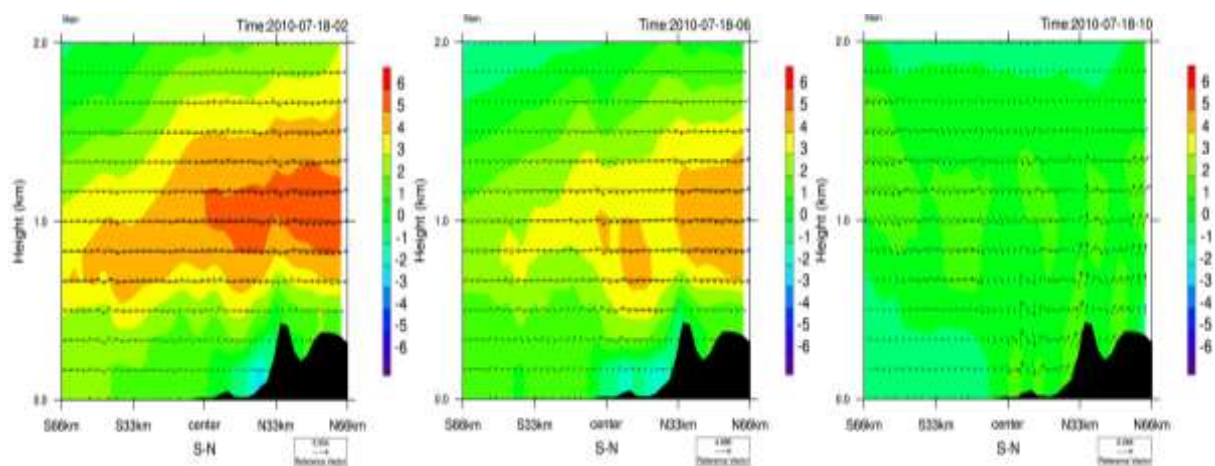


Figure3. The diurnal variation characteristics of the local circulation wind field in Summer



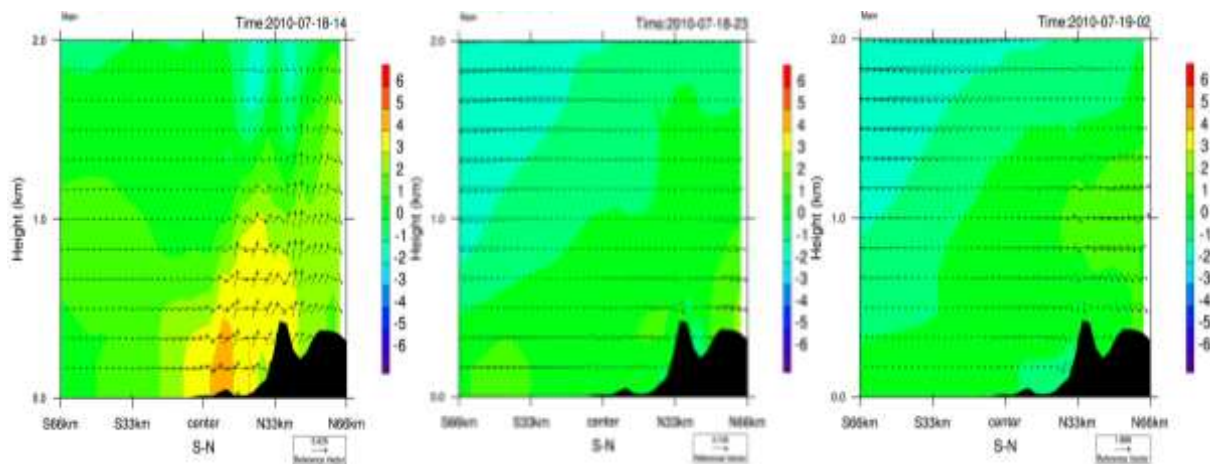


Figure 4. The diurnal variation characteristics of the local circulation vertical wind field in Summer

4. Simulation and analysis of pollutant diffusion

Radioactive pollutants diffusion of the site was simulated by random walk model. The initial wind field of a numerical model was the simulated result of WRF innermost nesting modelling, and the low level wind field had been modified by mass conservation law. The parameters of random walk model were settings as follows. 5km north of the site was set as modelling centre, modelling area was 40km*40km, the horizontal solution was 100m, vertical solution was 10m, and modelling height was up to 800m. Pollution source was set on the height of 10m which was released continuously. The turbulence intensity was used here for model turbulence parameterization, which accorded with the results of the turbulence observation test around the site.

Pollutants diffusion and transportation was mainly affected by background wind field. Northerly winds prevail in winter and autumn, pollutants transport and diffuse from the source to the sea. Easterly winds appear more in spring, pollutants transport to the west. Southwest winds transport the pollutants towards the land. Transportation characteristics of atmospheric pollutants of the seasons were showed in Fig.5. Affected by the mesa-micro scale wind field, transportation of air pollutants appeared obviously diurnal variation which is showed in Fig.6.

Due to the flat terrain of the site, pollutants diffusion appears uniformly distributed. There are east-west hills located 20km north of the site. It caused the higher concentration of pollutants near the windward slope, and lower concentration near leeward slope. Fig.7 chose two examples whose pollutants were transported to NE and NNW respectively. It was more flat in the direction of NE than NNW. In the former case, the distribution was fairly uniform. And it was showed that there were several hills located on the 12km NNW of the source, the pollutants concentration rose on windward slope much more than leeward slope.

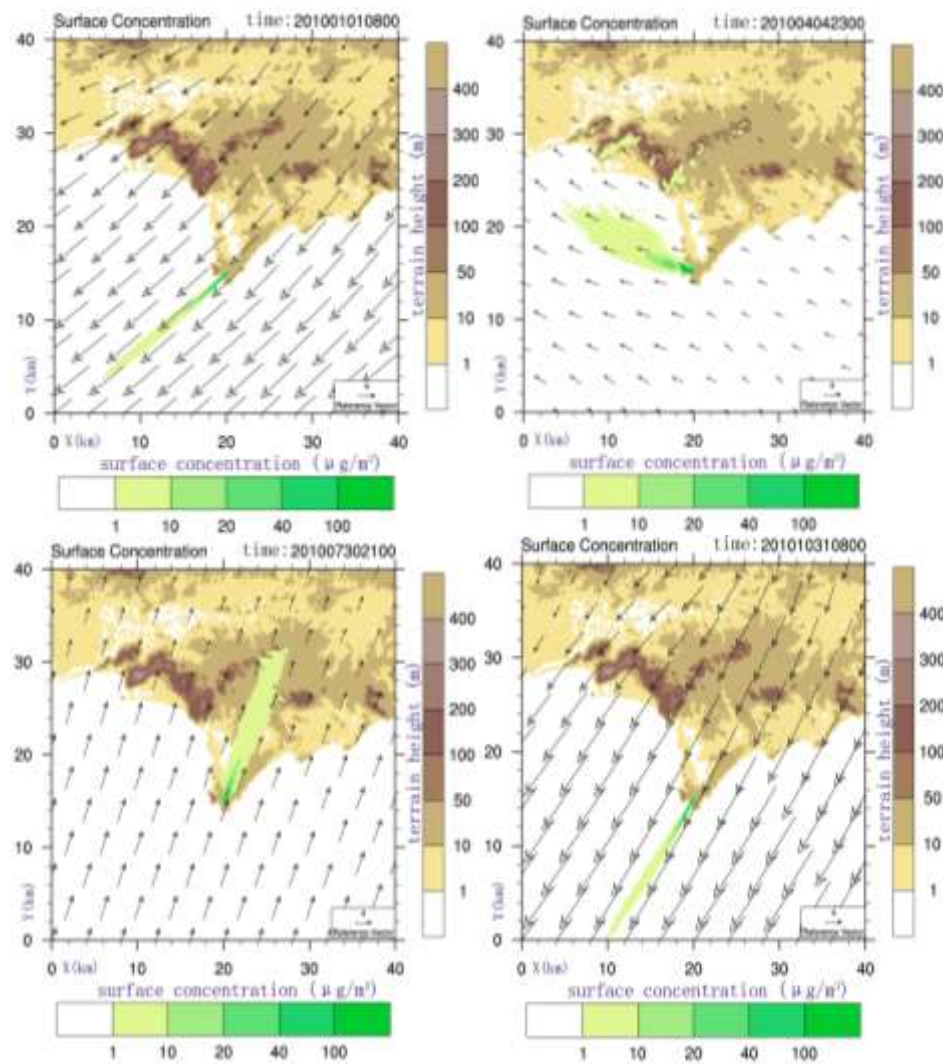
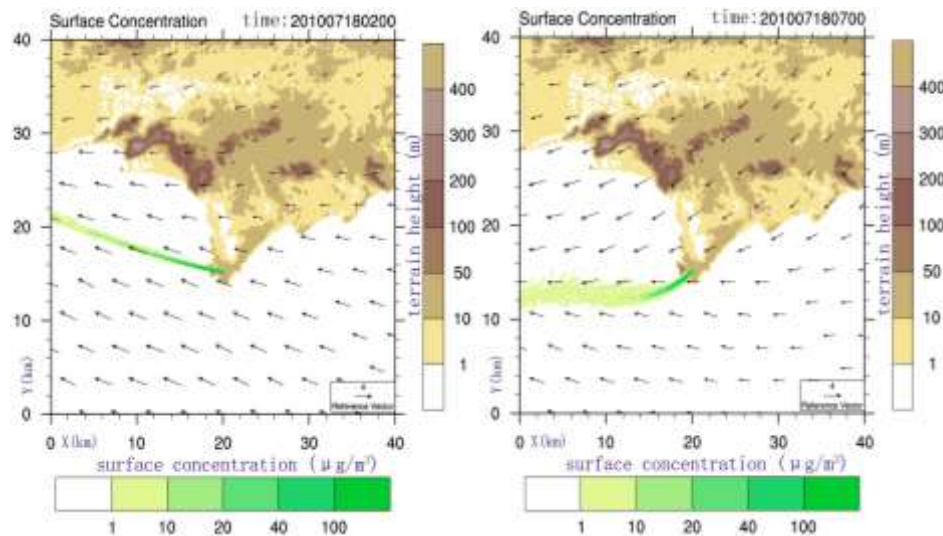


Figure 5. Simulated surface concentration with the system wind circulation in each season



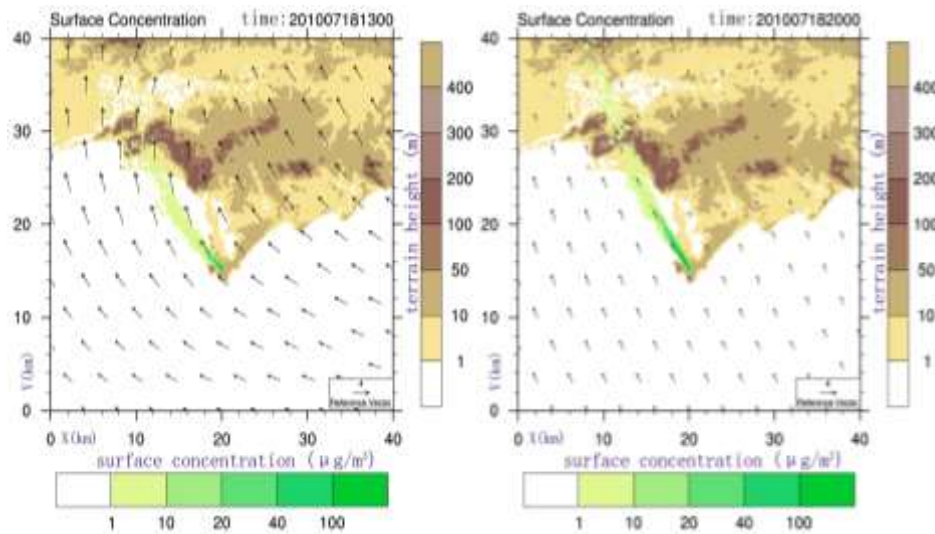


Figure 6. Simulated surface concentration with Summer local wind circulation

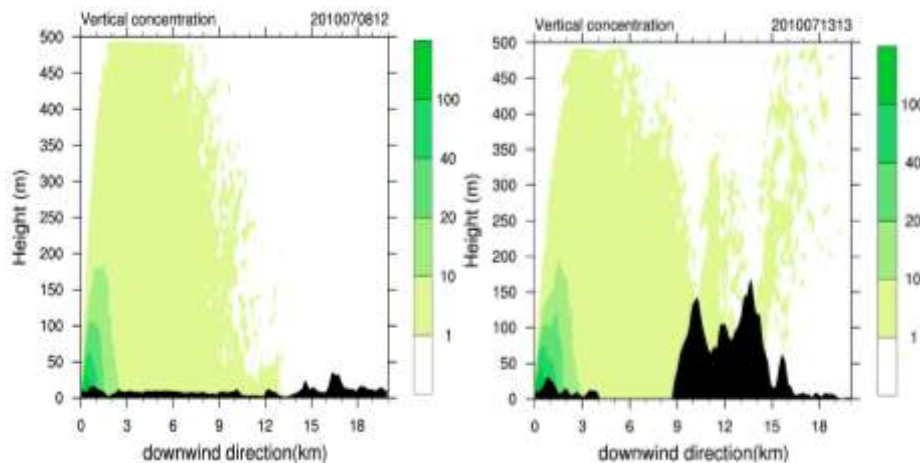


Figure 7. Vertical cross-section concentration fields and corresponding terrain feature

5. Diffusion parameters

The site locates on a peninsula sticking out into the sea. The coastline near the site appears from east to west, so southerly winds could be seen as shoreward winds and northerly winds as offshore winds. We focused on pollutants diffusion on the land and under the southerly winds when wind was weak. Closed several examples of various kinds of stability and statistically analyzed their diffusion parameters. The diffusion parameters were defined here as (1) and (2).

$$\sigma_y = ax^b \quad (1)$$

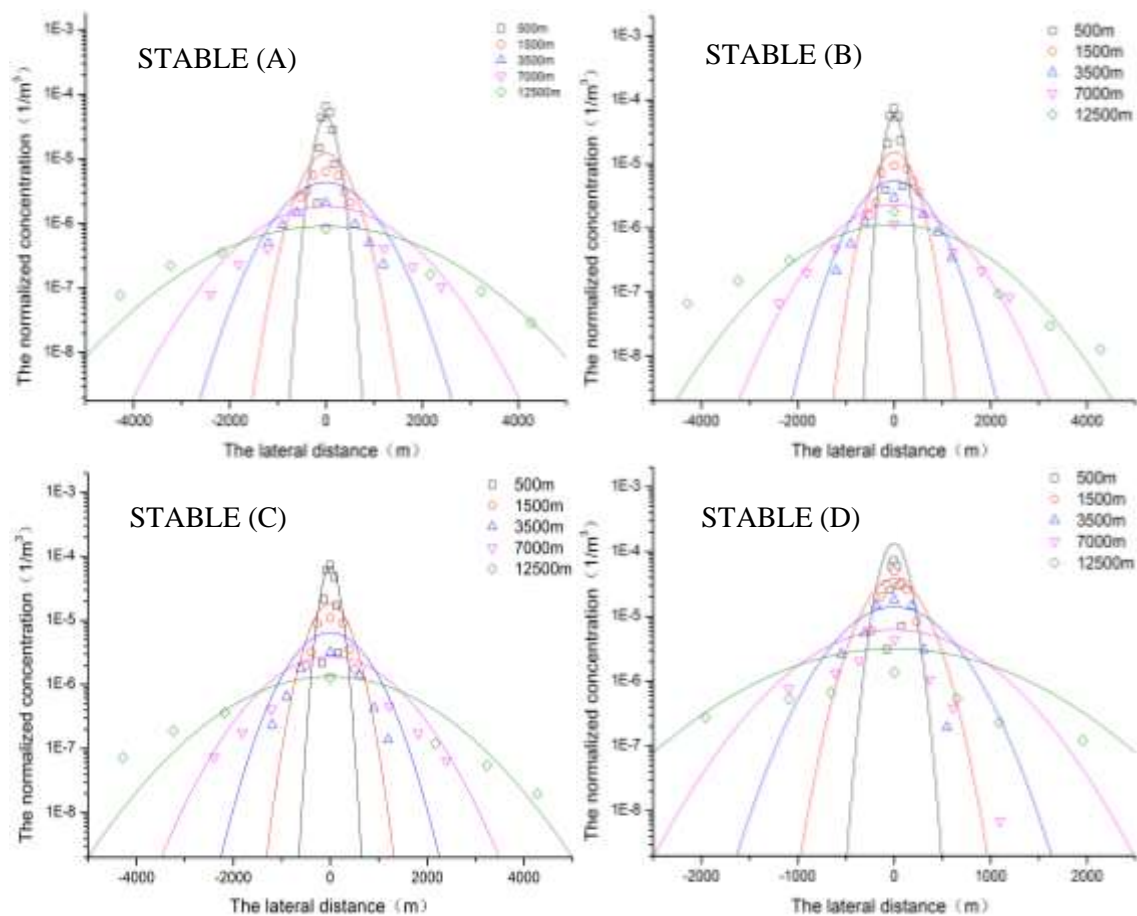
$$\sigma_z = cx^d \quad (2)$$

The Table 1 shows the coefficients of the diffusion parameters obtained from numerical model.

Table 1. The coefficients of diffusion parameters

Stability Coefficient	A	B	C	D	E	F
a	2.094	2.061	1.710	1.560	1.285	1.238
b	0.706	0.681	0.710	0.676	0.700	0.679
c	1.585	1.215	1.163	1.032	0.896	0.993
d	0.520	0.551	0.529	0.494	0.468	0.402

Fig.8-9 showed the lateral normalized concentration distributions compared with Gaussian distributions of different kinds of stability. The concentration distribution obtained from the experiment was according with Gauss normal distribution under the unstable conditions. And under the stable conditions, the distribution was below the Gauss normal distribution curve, especially in near distance. Since background circulation was relatively weak when atmospheric stratification was usually stable, the distribution of atmospheric pollution was mainly affected by the terrain and underlying surface, so the distribution was more complex. The vertical distribution of the downwind of the source varied greatly, especially the region nearby the site, which was according with the general law of atmospheric pollutants dispersion. Generally speaking, diffusion parameters obtained from numerical model experiments reflected well the characteristic of local atmospheric dispersion.



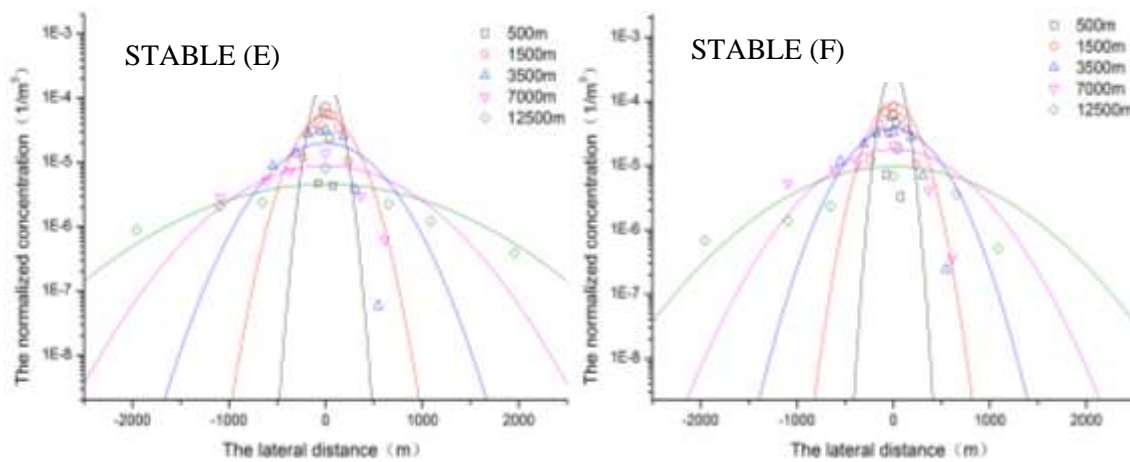
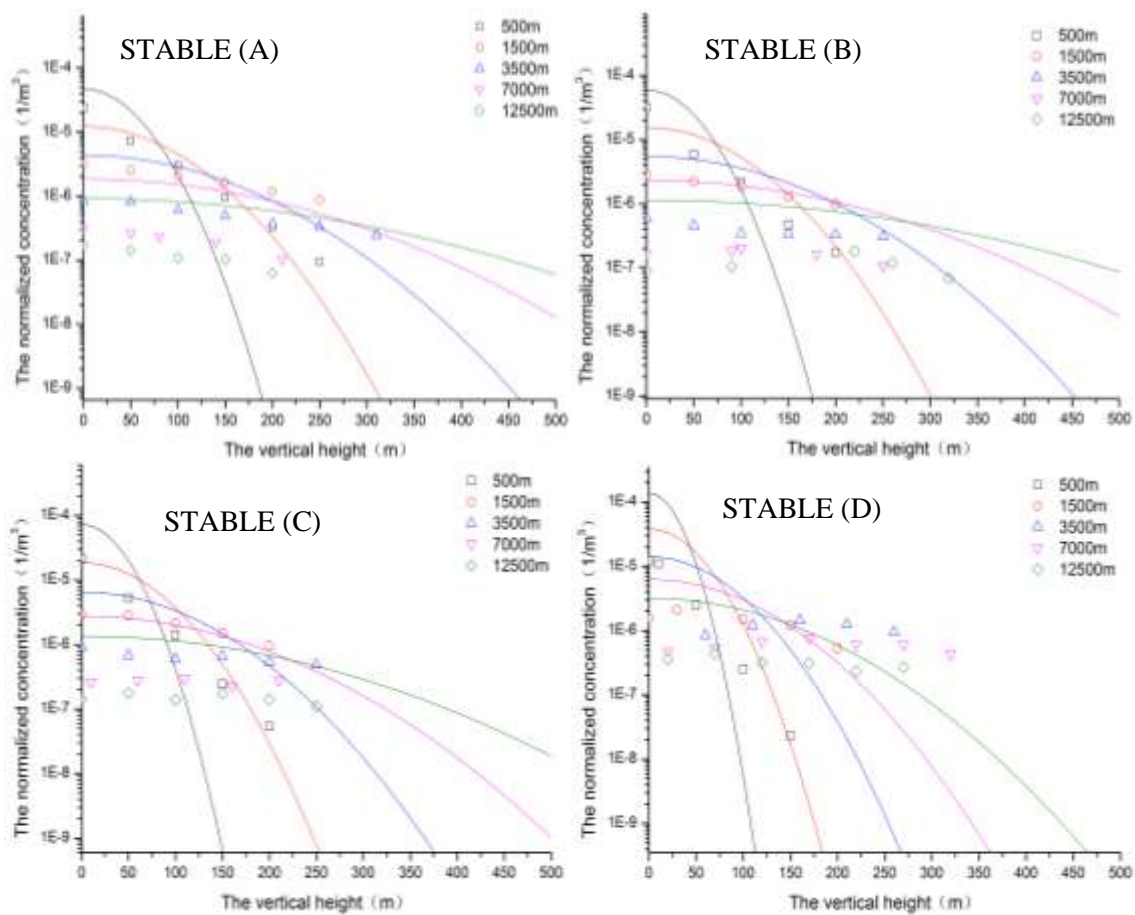


Figure 8. The lateral normalized concentration distribution compared with Gaussian distribution (lines mean Gaussian distribution and scatters mean numerical results in different distances)



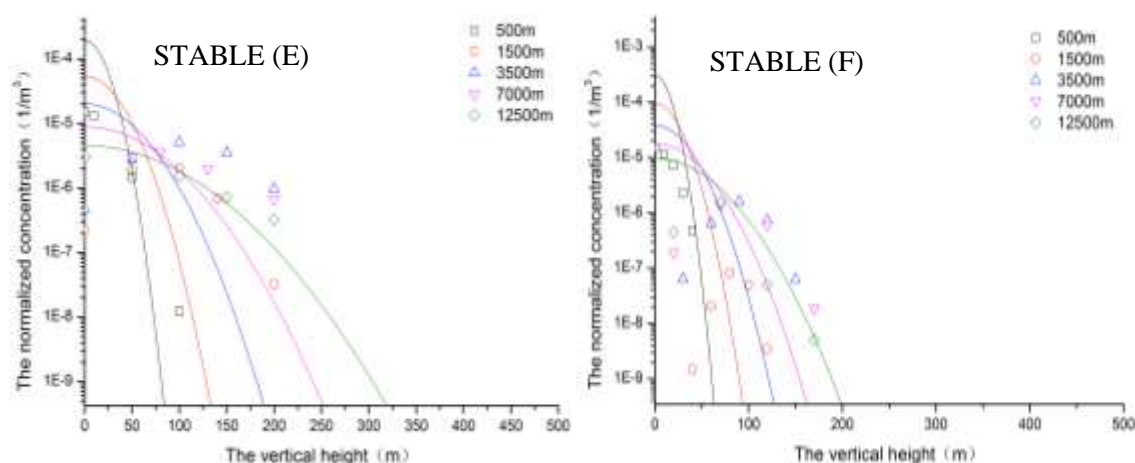


Figure 9. The vertical normalized concentration distribution compared with Gaussian distribution (lines mean Gaussian distribution and scatters mean numerical results in different distances)

6. Conclusion and discussion

In this paper, the wind field of boundary layer and characteristic of atmospheric dispersion in coastal area of a site were simulated and analyzed using WRF and RWM. We find that the site is located at coastal area, meso-micro scale wind field can be broadly classified as systematic wind field and local topographic circulation. The site is affected by synoptic scale system for most of the time, but meso-micro scale circulation still possesses apart of proportion. Under the influence of background atmospheric circulation, pollutant diffusion has significant seasonality characteristics. And under the influence of meso-scale circulation, the transport and diffusion of air pollutants shows diurnal variation, especially in the case of sea breeze circulation. Because the terrain near the site is relatively flat, diffusion of pollutants is relatively evenly. But there are east-west hills located 12km north of the site, which causes higher concentration of pollutants near the windward slope, and lower concentration near leeward slope.

The distribution of air pollutants concentration obtained through numerical simulation accords with Gauss normal distribution, and atmospheric diffusion parameters obtained through numerical model reflect the atmospheric diffusion ability to a certain extent.

The simulation results of wind field reveal the true situation of atmospheric flow field rather well. When simulating surface-layer atmosphere over complex terrain, this numerical simulation optimized the simulated low-level wind field with taking mass conservation law into account. In the research in the future, various physical processes of the WRF model should be focus on, especially optimization and analysis of parameterization scheme for boundary layer simulation, and data assimilation of model initial boundary meteorological field as well, so as to get more accurate results.

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