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ATMOSPHERIC BOUNDARY LAYER CONCEPT MODEL OF THE PEARL RIVER DELTA AND ITS APPLICATION

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ABSTRACT: Based on the geographical circumstance, climate and the boundary layer meteorology features of the Pearl River Delta, a boundary layer concept model of the Pearl River Delta was built. The concept model consists of four fundamental factors that affect the boundary layer meteorology of the Pearl River Delta and can convincingly explain the reason of the air quality change in the Pearl River Delta. The model can be used to the diffusion capability analysis, the air pollution potential forecasting or haze forecasting, etc.

Key words: boundary layer; concept model; Pearl River Delta

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1 INTRODUCTION

The Pearl River Delta (PRD) is situated on the southern China coast and becomes one of the three main city-clusters in China. Occupying only 0.4% of the whole country's territory in area, it is home to about 3% of the nation's population and creates nearly 10% of the nation's GDP. Due to the rapidly urbanization and industrialization in the past two decades, a large increase in emissions of major air pollutants has contributed to deteriorating regional air quality, as evidenced by a trend of decreasing visibility in many cities in the PRD[1,2].

Previous studies have shown that the emissions from cities and the transport pattern in the boundary layer have contributed to the ozone pollution observed in PRD [3]. However, there are very few researches on the meteorological characteristics of the boundary layer in PRD[4-7]. Based on the analysis of geographical circumstance, climate and the boundary layer meteorological features of PRD, a boundary layer concept model of the PRD was built in this paper.

2 THE GEOGRAPHICAL CIRCUMSTANCE OF PRD

Lying in the central southern part of Guangdong province, China, the PRD belongs to the subtropical monsoon climatic zone, with the Nanling Mountains on the north and the South China Sea to the south and surrounded by hills to the east, west and north. This geographical circumstance has significantly impacts on the regional air quality. Fig.1 shows the geographical

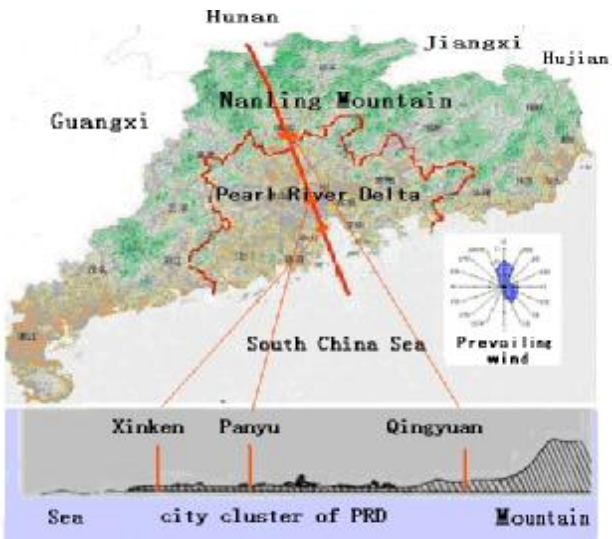

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Fig.2 Frequency variation of wind direction of different seasons in the Pearl River Delta

circumstance and the schematic section along the prevailing wind of PRD.

3 METEOROLOGICAL CHARACTERISTICS OF THE BOUNDARY LAYER OF PRD

PRD has a mild climate, plentiful sunshine and rainfall. Fig.2 shows the PRD wind direction frequency variation of hourly meteorological data in Spring (Mar. – May), Summer (Jun. – Aug.), Autumn (Sept. – Nov.), Winter (Dec. – Feb.) and all the year around from the statistics of nine weather stations from 1995 to 2000.

The weather system influencing the PRD can be divided into land weather system and sea weather system[5]. According to the meteorological data from nine weather stations and some boundary layer radiosonde data from 1995 to 2000 in PRD, the regional climate, weather, wind, temperature, stability, mixing height and other characteristics of the boundary layer in PRD has been analyzed synthetically[7]. PRD

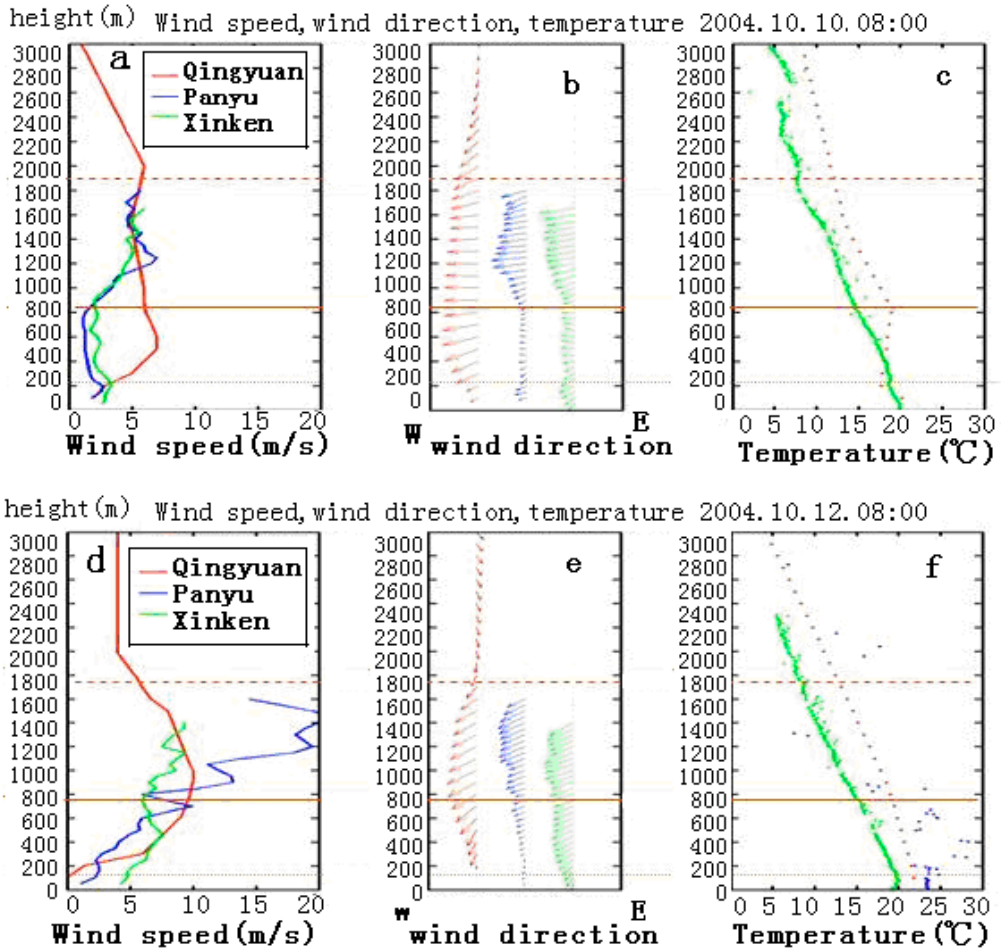

Fig.3 Typical profiles of real-time wind speed , wind direction and temperature in Pearl River Delta, autumn real-time wind speed (a), wind direction (b) and temperature(c), 8 am Oct. 10th, 2004 real-time wind speed (d), wind direction (e) and temperature(f), 8 am Oct. 12th, 2004.

is affected by monsoon markedly, with low mixing height, rather high frequency of inversion and comparatively stable stratification. Moreover, PRD is also influenced multiply by sea-land breezes, heat island circulation and the downdraft across the Nanling Mountains, and complicated underlying surface also exerts an conspicuous impact on the atmospheric boundary layer in PRD[7].

During the Program of Regional Integrated Experiments of Air Quality over Pearl River Delta (PRIDE-PRD2004), we conducted a meteorological observation experiment on the boundary layer in PRD from October 1st to 30th, 2004 with the baseline balloon, mini-temperature-sonde and radiosonde observations in three locations which lie along the north-south section of the prevailing wind in PRD: Qingyuan, Panyu and Xinken (See the geographical positions in Fig.1). Fig.3 gives an example of the real-time typical profiles of wind speed, wind direction and temperature.

From Fig.1, we can see that the wind and temperature profiles obtained from Qingyuan, Panyu and Xinken locations can respectively represent the characteristics of three typical underlying surfaces for the boundary layer in PRD, namely, near-mountain area, city cluster of PRD, and sea shore. Analysis on the observed wind and temperature profiles, such as Fig.3, indicates that there exists a three-layer construction in the boundary layer of PRD in autumn: at high altitude about 1800m, there is obvious downdraft and subsidence inversion (b, c, e of Fig.3); in the intermediate layer between 800 m and 1800 m, the stratification is close to neutral stability and can be regarded as the residual boundary layer; at the height about 800 m, there is evident wind shear (a,b,d,e of Fig.3) with inversion lid, and the height can be regarded as the boundary layer height of PRD. It is found that the PRD boundary layer height can be determined by traditional methods through the height of inversion lid.

In order to confirm the boundary layer characteristics obtained from the real-time observation of PRD, a simulation analysis was conducted using the MM5 mesoscale model to simulate the north- south section wind field of PRD[8]. Fig.4 gives typical simulation results at 08:00 on Oct. 9th, 2004 (with strong system wind) and 20:00 on Oct. 10th, 2004 (with weak system wind), and the boundary layer height is determined by wind shear in the simulation.

From the MM5 simulation analysis, such as that in Fig.4, it is found that when the system wind is strong, local circulation does not appear; when the system wind is weak, local circulation such as sea- land breezes, city heat island circulation and mountain-valley (downdraft) wind will appear in PRD.

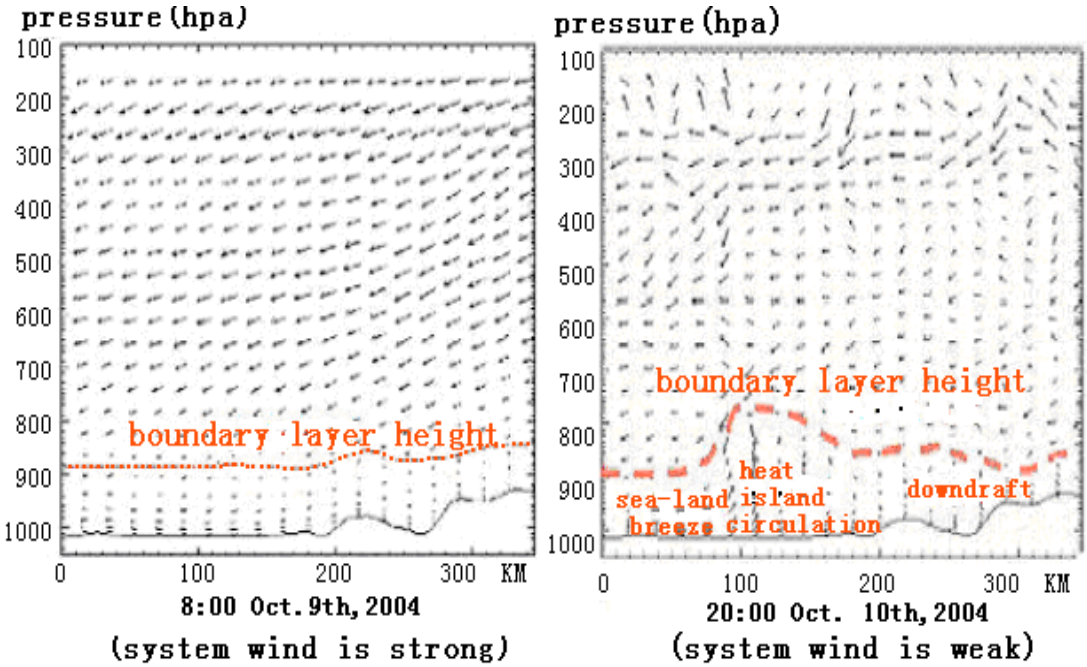

Fig.4 Pearl River Delta south-north section wind field and boundary layer height simulated by MM5.

4 ATMOSPHERIC BOUNDARY LAYER CONCEPT MODEL OF PRD

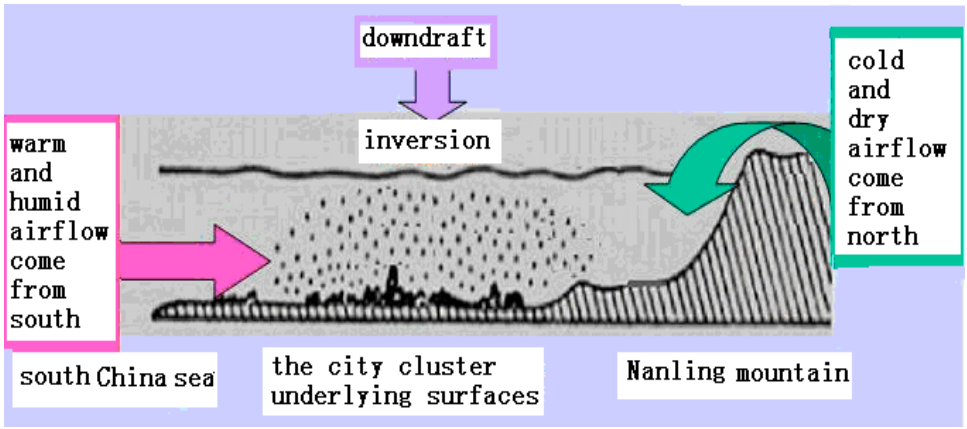

Fig.5 The atmospheric boundary layer concept model of Pearl River Delta.

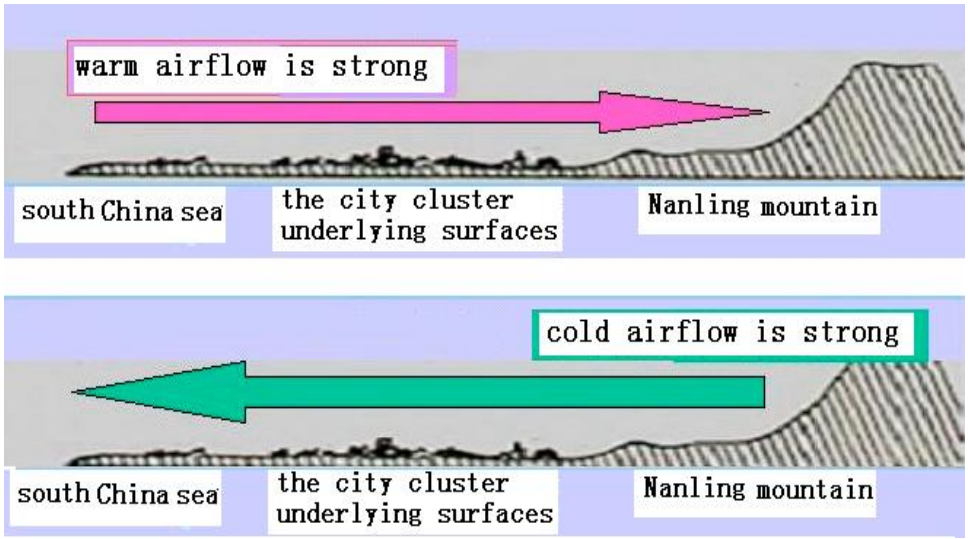

Fig.6 Strong wind(warm or cold air flow is strong) improves the air quality in Pearl River Delta.

From the above data analysis and model simulation, we can summarise the main boundary layer characteristics of PRD, the atmospheric boundary layer structure of PRD is governed by four main factors: the warm and humid airflow from the South China Sea, the cold and dry airflow from the north, the upper inversion with downdraft and the underlying surfaces of the city cluster. Fig.5 shows the concept model for the schematic atmospheric boundary layer of PRD.

The concept model for atmospheric boundary layer comprehensively reflected the general mechanism about PRD boundary layer meteorology and can convincingly explain the reason of air quality change in PRD.

5 APPLICATIONS OF THE CONCEPT MODEL

From the principle of air pollution meteorology, it has been known that when air pollutants are emitted into the atmosphere, they will be transported with wind, diffused by turbulence, transformed and eliminated by physical and chemical processes. In a large region such as PRD, in some time of the year, the emission amount of air pollutants does not change dramatically, but the air quality will vary dramatically due to the variation of meteorological condition of the boundary layer. The atmospheric boundary layer concept model of PRD built in this work can explain the relationship between regional air quality and boundary layer meteorological condition and determine the nature of the emergence of high air pollution index and haze episodes, etc.

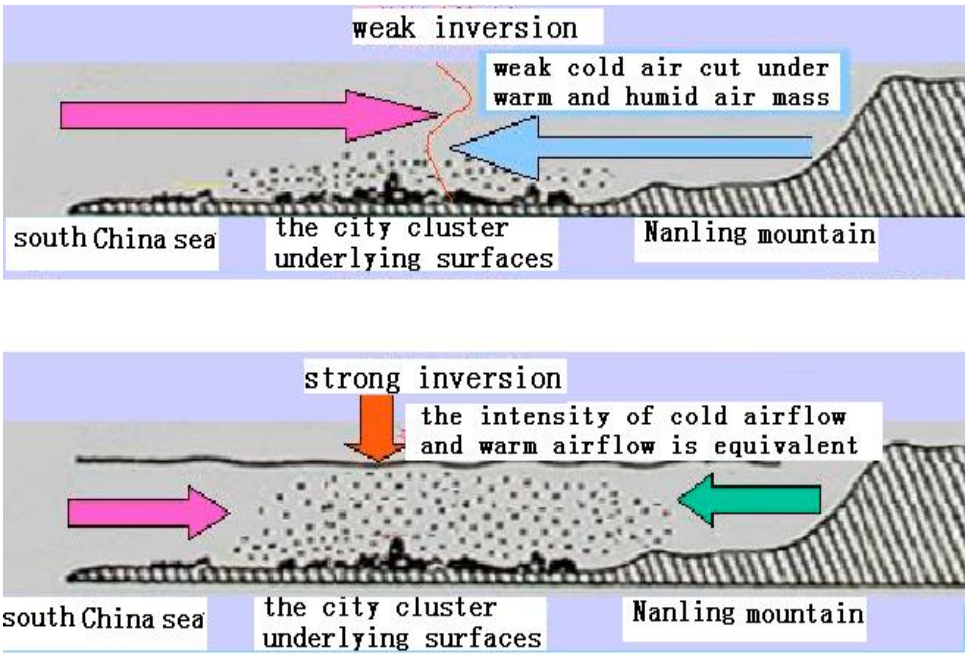

Fig.7 Weak wind (the intensity of cold airflow and warm airflow is equivalent) and inversion layer causing higher regional air pollution level in Pearl River Delta.

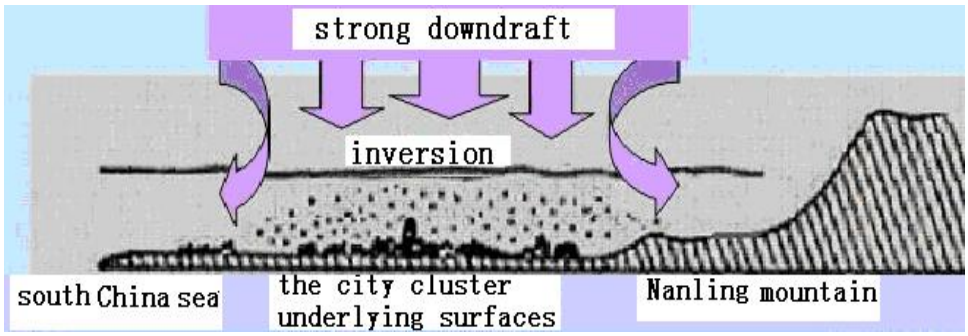

Fig.8 Large-scale strong downdraft causing higher regional air pollution level in Pearl River Delta.

Low regional air pollution level or low air pollution index in PRD mainly appears in summer and windy days. Fig.6 can explain the reason why the regional air pollution level or air pollution index is low. As long as the wind speed is high, the pollutants will be transported and spread with wind without accumulation and the regional air pollution level or the air pollution index will be low. In summer, the prevailing wind in PRD is from the south, the air advection is vigorous and diffusion condition is favorable, so the air quality will be improved. If the cold air across the Nanling Mountains is strong enough, the advection and diffusion condition will also be favorable and will carry away the pollutants and improve the air quality.

High regional air pollution level or high air pollution index arises primarily in the days when the wind is weak, with upper layer inversion exists and poor diffusion ability. Fig.7 indicates that two kinds of circumstances will cause high regional air pollution level or high air pollution index. One is that when the cold air from the north is weak and the shallow cold air is proceeding from the north to the south, the cold air across the Nanling Mountains cut in the lower part of the deep warm and humid air mass owing to the mountain terrain effect and forms weak inversion in the boundary layer, the wind speed is relatively low, and this process will cause regional air pollution in PRD. The other one is that when the intensity of the cold and dry air from the north is comparatively equivalent to the intensity of the warm and humid air from the ocean, the wind speed in the boundary layer will be quite low and the diffusion condition will be very poor. In

addition, the inversion layer is like a huge lid that makes it impossible for the pollutants to diffuse upwards, the pollutants have to accumulate in the urban area, which will form serious regional air pollution episodes. These two circumstances occur frequently in spring and autumn, which explains why the period from October to next April is favorable for haze in PRD.

Fig.8 shows that strong downdraft can also form serious regional air pollution episodes in PRD. When the upper air is controlled by strong downdraft (e.g. the downdraft before the landing of typhoon) or the long-lasting downdraft (subtropical high pressure system), large-scale inversion forms easily, weak wind appears, diffusion ability becomes poor, and pollutants could not diffuse upwards; in addition, under the effect of downdraft, the pollutants at higher layers will be brought to lower layers and accumulate at the surface layer, which will increase the surface layer air pollution level or air pollution index rapidly. From the end of October to the beginning of November in 2003, an extremely severe air pollution episode happened in the PRD region (with the air pollution index reaching 303 in Guangzhou on Nov.2nd, which is the highest in history). The reason is that the region is affected by the downdraft surrounding the typhoon Melor (0319) before its landing[1].

6 SUMMARY

Based on data analysis, model simulation and boundary layer characteristics summarize of PRD, a concept model for the atmospheric boundary layer of PRD was built. The concept model reflects the general mechanism, consists of the fundamental factors affecting the boundary layer meteorology of PRD and can convincingly explain the reason of the regional air quality change, diffusion capability analysis and the air pollution potential forecast and haze forecast, etc.

REFERENCES:

[1] WU Dui,TIE Xuexi, LI Cheng-cai, et al. An extremely low visibility event over the Guangzhou region A case study [J]. Atmospheric Environment，2005, 39: 6568-6577.

[2] JIANG Luan, CAO Chun-yan. Climate characteristics of haze and its factors in Shenzhen [J], 2004. Guangdong Meteorology, 2004, (4): 14-15.

[3] DING Ai-jun, WANG Tao, ZHAO Ming, et al. Simulation of sea-land breezes and a discussion of their implications on the transport of air pollution during a multi-day ozone episode in the Pearl River Delta of China [J]. Atmospheric Environment, 2004, 38 (39): 6737-6750.

[4] Liu Jialing, Huang Zhixing. The vertical characteristics of temperature and flow field of atmospheric boundary layer of Pearl River Delta [J]. Journal of Tropical Ocean, 1993, 12 (2) : 17-24.

[5] LI Qiong, LI Fujiao, YE Yan-xiang, et al. Relationships between weather types and pollution potential and pollution concentration in Pearl River Delta [J]. Journal of Tropical Meteorology, 1999, 15(4): 363-369.

[6] WU Yan-biao, DU Yao-dong, SONG Li-li, etc. Analysis on structural characteristics of temperature field of the atmospheric boundary layer of Pearl River Delta [J]. Shanghai Environmental Science (Web version), 12th , 2003.

[7] FAN Shao-jia, ZHU Wei, WANG An-yu, et al. Research on meteorological characteristics of the boundary layer of Pearl River Delta [J]. ACTA Universitatis Sun Yat-sen, 2005, 44(1): 99-102.

[8] FAN Qi, Wang An-yu, FAN Shao-jia, et al. Numerical simulation research on one radiation fog in Pearl River Delta [J]. Meteorological Science, 2004, 24(1): 1-8.