CityZen

megaCITY - Zoom for the Environment

Collaborative Project

7th Framework Programme for Research and Technological Development

Cooperation, Theme 6:

Environment (including Climate Change)

Grant Agreement No.: 212095

Deliverable D1.7.2, type R

Evaluation of current state of modelled ozone,

PM and deposition fields

Due date of deliverable: project month 22

Actual submission date: project month 35

Start date of project: 1 September 2008 Duration: 36 months

Name of lead beneficiary for this deliverable: PKU

Scientist(s) responsible for this deliverable: Yuanhang Zhang

Contributing authors : Xuesong Wang, Wei Lu, Min Hu, Yuanhang Zhang

Project co-funded by the European Commission within the Seventh Framework Programme (2007-2013)		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Evaluation of the current state of modelled ozone, PM and deposition fields in the Pearl River Delta, China

Xuesong Wang, Wei Lu, Min Hu, Yuanhang Zhang

College of Environmental Sciences and Engineering, Peking University, Beijing, China

Introduction

The Pearl River Delta (PRD) region is one of the most developed regions in southern China. It is made up of three megacities regions (i.e., Guangzhou, Shenzhen and Hong Kong) and numerous small cities. It accounts for about 4% of the total population in China and contributes about 19% of China's gross domestic product in recent years. The large amount of energy consumption caused by rapid economic growth and intense human activity in PRD region gives rise to great pollutant emission and finally causes air quality deterioration. Based on recent air quality studies, we can generally draw a conclusion that it is a mixture of primary and secondary pollutions in PRD region (Chan and Yao, 2008). A recent series of field campaigns in the PRD region, namely PRIDE-PRD, organized by Peking University has helped us to gain insight and achieve a more specific understanding of air pollution and radiative process in this region (Zhang et al., 2008). An important conclusion, which can be drawn from these campaigns, is that the major pollutants, such as ozone (O_3) and particulate matter (PM) in the PRD region often co-exist as a regional problem.

O_3, as a secondary pollutant, has drawn intensive attention from many researchers. When studying O_3, the short-time O_3 episodes are often concerned. From the previous studies in the PRD region, we have obtained some results on the meteorological conditions associated with O_3 episodes (Ding et al., 2004; Huang et al., 2005), the chemical sensitivities of O_3 to precursors (Wang et al., 2005; Zhang et al., 2008; Wang et al., 2010) and the relative importance of different atmospheric processes to ozone concentrations (Wang et al., 2010; Lam et al., 2005). Relatively fewer studies have aimed at explaining long-term ozone budget and transport characteristics and chemical production rate in the PRD region. On the other hand, as another critical pollutant in this region, PM has not been studied intensively in the PRD region, except at Hong Kong. The key issues associated with PM over PRD include the concentration of carbonaceous species, the formation of secondary particulate matters, the hydroscopic properties of particulate matters and the optical properties of particulate matters (Cheng et al., 2006; Hagler et al., 2006; Huang et al., 2006; Zhang et al.,2008).

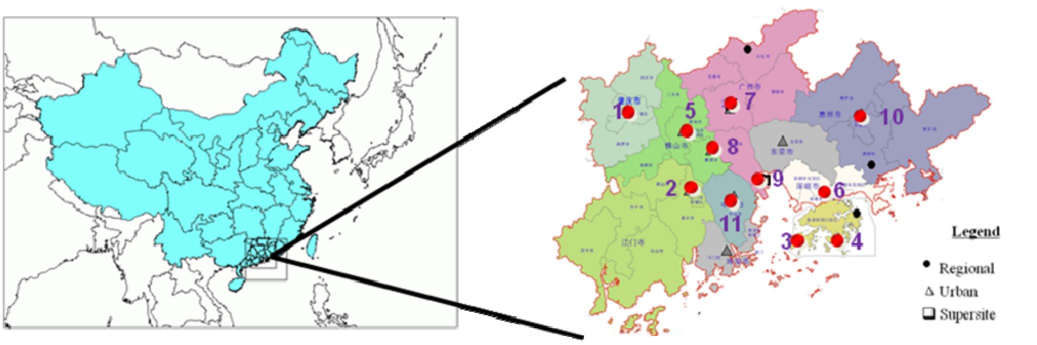
The previous studies on O_3 or PM in PRD often focused on a few episodic days or a certain typical pollution seasons. In this report, we summarize the modelling results on O_3 and PM for a whole year to discern the seasonal variations and inter-annual variations of air pollution in PRD.

Modeling method

We use CMAQ (version 4.5.1) with the State Air Pollution Research Centre version 99 (SAPRC-99) chemical mechanism to simulate the distribution of O_3 and PM_{10} and the deposition fields of sulphate and nitrate in the Pearl River Delta region in south China during the whole year of 2006. The modelling results of Jan, Apr, Jul and Oct are shown to represent the seasonal variation.

The modelling domain with a horizontal grid spacing of 36km covers the entire China (Figure 1a).The grid has 13 vertical layers from the surface to an altitude of 17km above the ground, with 7 layers below 1000m and the surface layer of about 19m. The results covering the PRD region are extracted to represent the current state of air quality in PRD.

The fifth-generation Pennsylvania State University/National Centre for Atmospheric Research Mesoscale Model (MM5 version 3.7) is used to simulate the meteorological fields to drive CMAQ. The Intex-B emission inventory (Zhang et al., 2009) with 0.5°×0.5°resolution is used for the modelling domain as anthropogenic emission and the non-agricultural open fire emission is provided by Peking University (Song et al., 2009). As for the biogenic NOx and VOC, the Biogenic Emissions Inventory System version 3.09 (BEIS 3.09, Vukovich and Pierce, 2002) with a Chinese plantation survey dataset (Pearl River Delta environmental protection planning committee, 2006) is used to estimate the emission amounts.



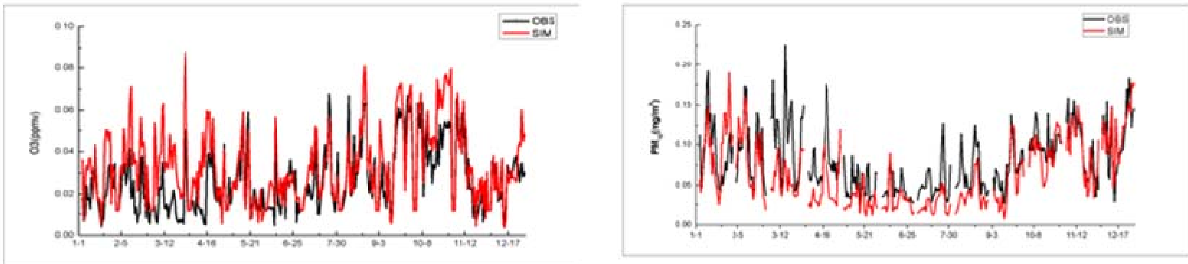
(a) (b)

Figure 1. (a) the 36 km domain for CMAQ simulation; (b)the 11 sites which are marked by red dots are used to evaluate the model performances:1-Chengzhong, 2-Donghu,3-TungCung,4-TseunWan,5-Huijingcheng, 6-Liyuan, 7- Luhu, 8-Shunde, 9-Wanqingsha, 10-Xiapu,11-Zimaling.

Figure 1b shows the location of monitoring sites in PRD, the observational data in these 11 sites are used to evaluate the model performances with three statistical measures, i.e., correlation coefficient (COR), normalized mean bias (NMB) and normalized mean error (NME).

Evaluation and seasonal variations of modelled O_3 and PM

The average time series of the observations and modelling results at the above 11 sites for the pollutants O_3 and PM_{10} are presented in Figure 2 to examine the overall model performances. As for O_3, the CMAQ model successfully captured the day-to-day variation for the year 2006 with a COR of 0.76 (see Figure 2a). It can also be seen that for seasonal variation, there are significant spring peak, autumn peak and summer trough for O_3 in PRD. In spring, CMAQ shows the worst performance with a remarkable overprediction of O_3, especially in March. As for PM_{10}, Figure 2b clearly demonstrates that the CMAQ model successfully captured the day-to-day variation of PM_{10} for the year 2006 with a COR of 0.72. For the whole year, the average concentration of PM_{10} is underestimated by 21% with a maximum bias in spring. The CMAQ model successfully captured the values of PM_{10} in winter and autumn, which were the most polluted seasons.



(a) O_3 (8-h average) (b) PM_{10} (daily average)

COR: 0.76, NMB: 0.27, NME: 0.39 COR: 0.72, NMB: -0.21, NME: 0.33

Figure 2.Time series of (a) 8-h $O_3$and (b) daily PM_{10} averaged at the 11 PRD sites for the whole year 2006

When taking seasonal variation into consideration, we take December, January and February as winter season (DJF), March, April, May as spring (MAM), June, July, August as summer (JJA) and September, October and November as autumn (SON).

Figure 3 presents the seasonal variation of surface O_3 concentration in the PRD region. It can be seen that in all seasons, there exist lower concentrations in the central PRD region than in its surrounding areas. In winter, most of the PRD region shows low O_3 due to low temperature and weak solar radiation. In spring, first O_3 peak in a year occursdue to increasing temperature and strengthening radiation intensity. In summer, the O_3 presents a summer trough along the invasion pathway of the East Asia Monsoon because of the great monsoon precipitation caused by the inflow of clean marine air masses. In autumn, relatively dry weather and great downward flow cause the highest O_3 concentration in a year.

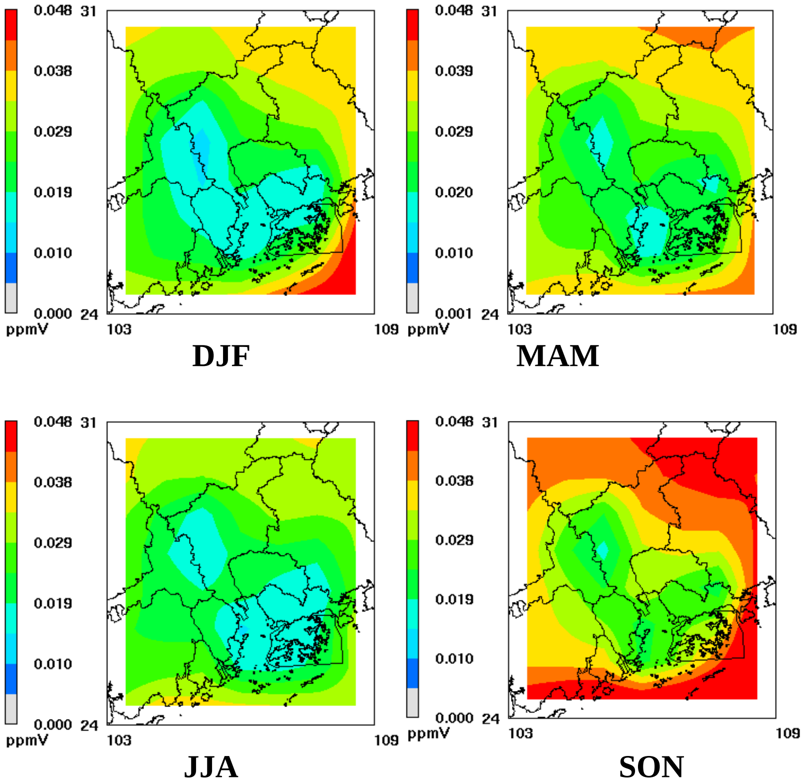


Figure 3 Seasonal variation and spatial distribution of surface O_3 concentration in the PRD region

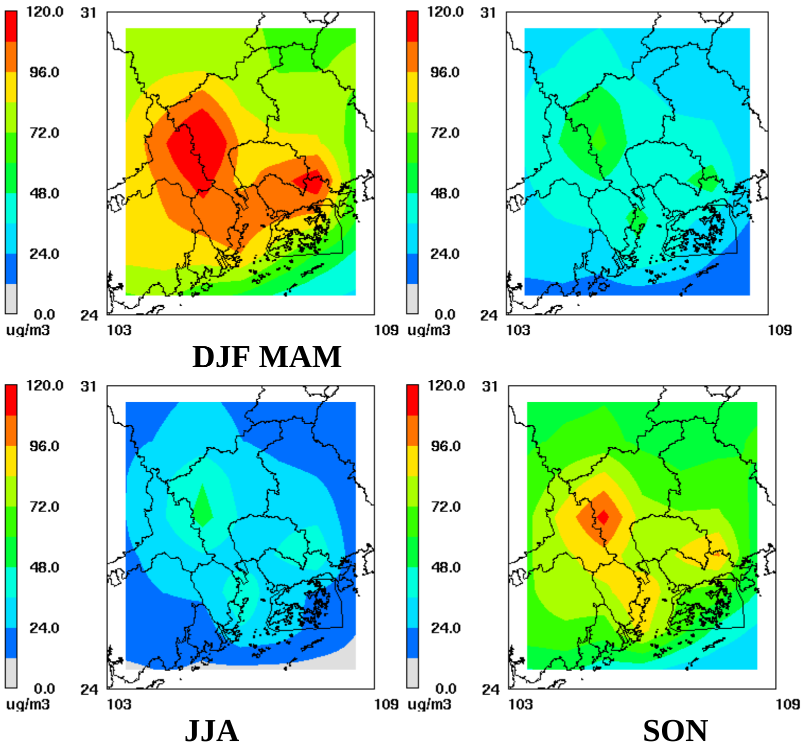


Figure 4. Seasonal variation and spatial distribution of surface PM_{10} concentration in the PRD region

Figure 4 presents the seasonal variations of surface PM_{10} concentration in PRD region. It can be seen that in PRD region, the distribution of PM_{10} shows great seasonal variation and in contrary to O_3, there exist higher concentrations in the central PRD region than in its surrounding areas. In winter, the PM_{10} concentrations are at the highest level due to greater emission from anthropogenic sources, relatively low PBL and not enough precipitation to wash out the particulate matters. In spring, with the advent of the rainy season, the PM_{10} concentration declines, but we can also find relatively high levels in the highly emitted areas such as Guangzhou and Foshan. In summer, the invasion of East Asia monsoon causes the inflow of clean marine air masses together with much precipitation, resulting in the lowest PM_{10} concentration throughout the year. In autumn, the relatively less rainfall and low wind speed favour the accumulation of particulate matters, and as a result, the PM_{10} concentration stays at a high level as well.

Seasonal variation of deposition fields in PRD

SO_2

Figure 5 presents the season variation of SO_2 dry deposition field in the PRD region. The results show that the seasonal variation of dry deposition fields of SO_2 is not very significant except that in winter. Higher dry deposition could be found along the border of Guangzhou and Foshan. In winter, high dry deposition occurs in the Pearl River Estuary region and over the sea, which might be attributed to the strong north winds resulting in relatively high SO_2 concentration in southern PRD areas.

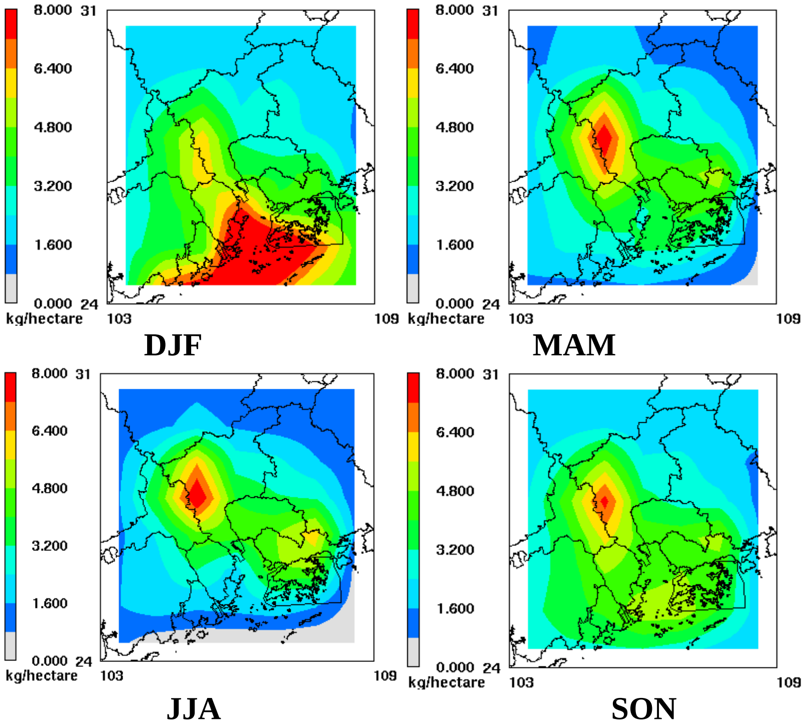


Figure5. Seasonal variation of SO_2 dry deposition in PRD

Figure 6 presents the seasonal variation of SO_2 wet deposition in PRD. The results show spring/summer maximum and winter/autumn minimum of SO_2 wet deposition field. The intensity of SO_2 wet deposition correlates well with its ambient concentration and the amount of rainfall. In winter, weak wet deposition is due to relatively low rainfall in despite of high ambient SO_2levels.In spring, the highest wet deposition is found due to increasing rainfall. In summer, though the rainfall intensity is strong, the SO_2 levels are lower than those in the spring time. As a result, the wet deposition values are lower in summer than those in spring. In autumn, this dry season finally causes low wet deposition intensity.

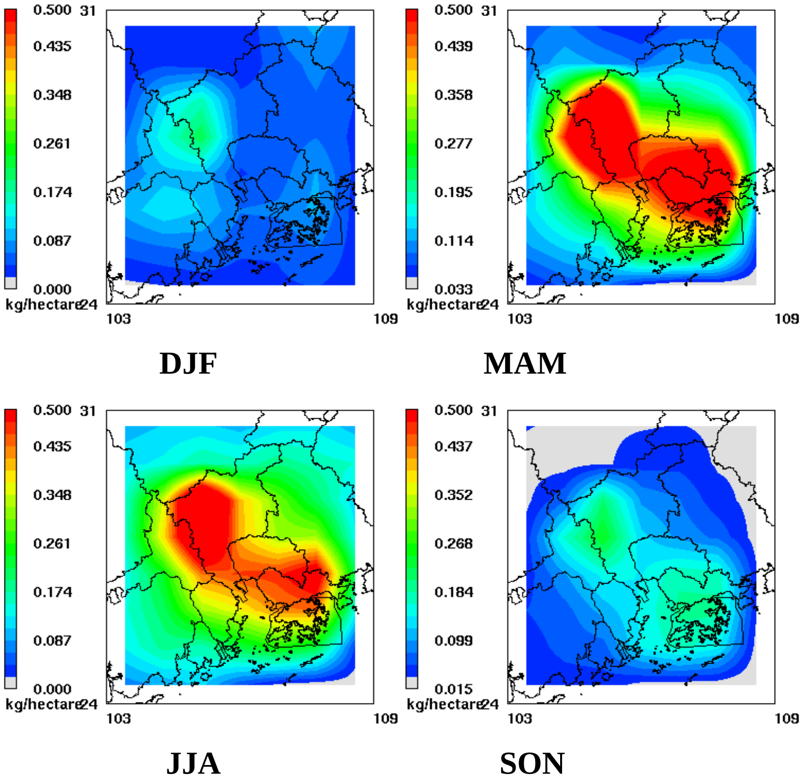


Figure6. Seasonal variation of SO_2 wet deposition in PRD

NO_2

Figure 7 presents the seasonal variation of NO_2 deposition, which is dominated by dry deposition. The seasons with most intensified deposition of NO_2 are summer and autumn. The deposition field correlates with the ambient concentration and the downward dry deposition velocity. In winter, low temperature and relatively weak turbulence result in long residential time of NO_2in the ambient air, therefore, relatively weak deposition is obtained. In summer, the concentration of NO_2 is relatively low but greater turbulence lead to shorter residential time of NO_2 in the air, resulting in higher deposition. In autumn, higher NO_2 concentration and great downward flow cause maximum deposition of NO_2 throughout the year.

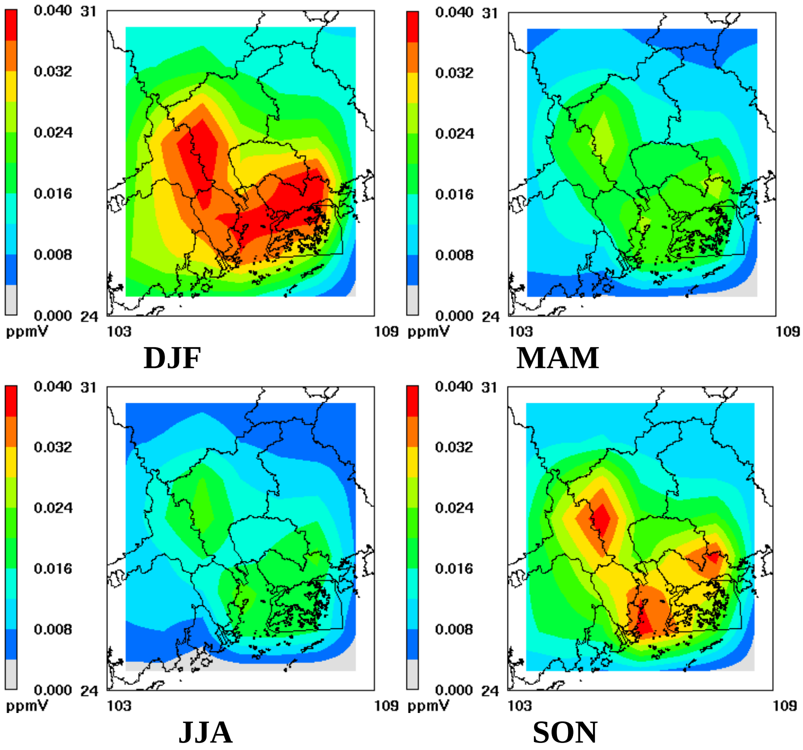


Figure7. Seasonal variation of NO_2deposition fields in PRD

O_3

Figure 8 presents the seasonal variation of O_3 deposition field in PRD. Due to the wet deposition flux is of several magnitudes of orders smaller than the dry deposition field, only the total deposition fields are showed. In winter, relatively low O_3 concentration and relatively long O_3 residential time cause the lowest deposition in the year. In spring, the increasing deposition flux is found due to higher O_3 concentration and short residential time. In summer, although Asia monsoons give rise to the lowest O_3 concentration, strong turbulence and the shortest residential time result in the highest deposition in one year. In autumn, the highest O_3 concentration and the significant downward flow result in a higher deposition field.

PM_{10}

Figure 9 is the season variation of PM_{10} dry deposition field in PRD. It shows no significant seasonal variations. High values are often found in Guangzhou, Foshan and Hong Kong area. This pattern is similar to that of SO_2 dry deposition in the PRD region.

Figure10 presents the season variation of PM_{10} wet deposition field in PRD. It shows significant seasonal variations. The ambient concentration and the precipitation amount or the cloud process would affect the wet deposition flux greatly. Lower wet deposition flux in winter is due to little rainfall though the ambient PM_{10} concentration is high. In spring, the increasing wet deposition is mainly due to the increasing rainfall. In summer, wet marine air gives rise to high precipitation, which causes the highest wet deposition in the year. In autumn, though decreasing rainfall happens, the high ambient concentration also results in high wet deposition field. Compared to dry deposition, wet deposition is a more effective way to clean the particulate matter in the atmosphere.

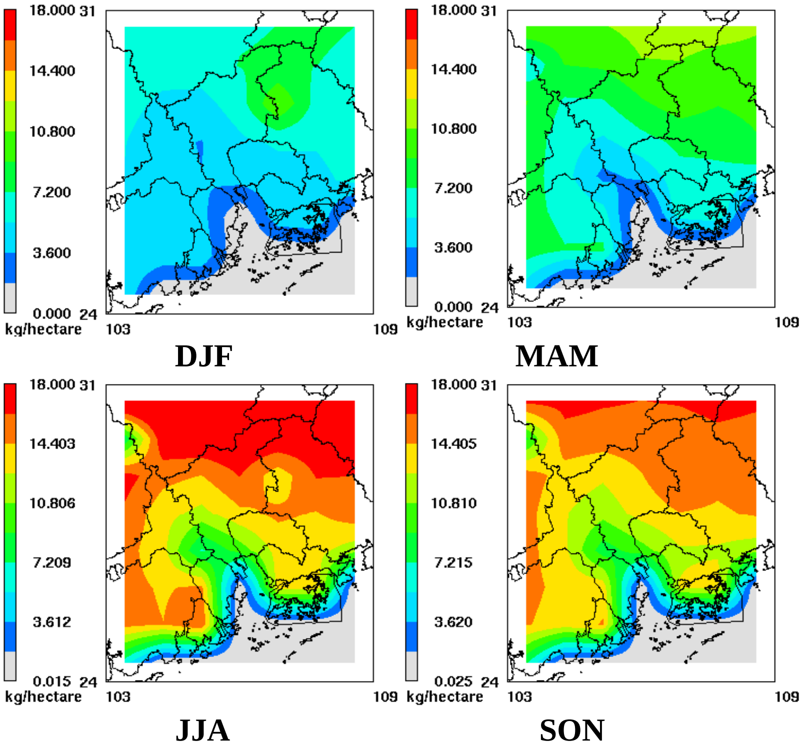


Figure 8. Seasonal variation of O_3 deposition fields in PRD

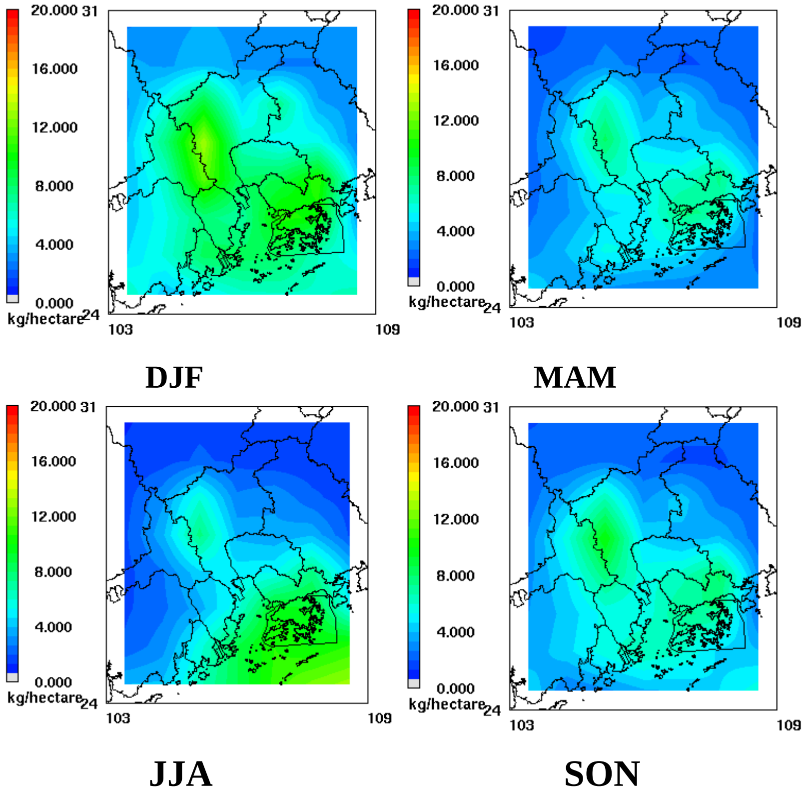


Figure 9. Seasonal variation of PM_{10} dry deposition flux in PRD

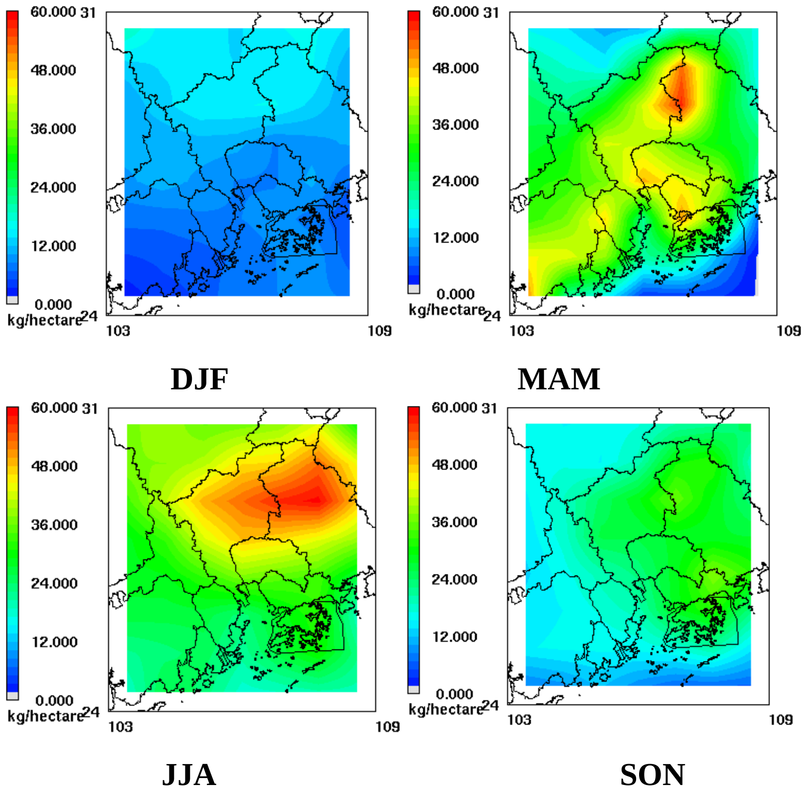


Figure10. Seasonal variation of PM_{10} wet deposition flux in PRD

We also examined the seasonal variation of the dry deposition fields of sulphate and nitrate in PRD. The dry deposition of sulfate shows less significant seasonal variation expect in July. High temperature and high water vapors are favourable to the formation of sulfate, so a high sulfate value can be expect in July. However, more sulfate is removed from the atmosphere by wet deposition, so the dry deposition flux remains low in July. In other months, higher dry deposition can be found in Shenzhen and Hong Kong, which may imply that the atmospheric environment there can accelerate the formation of sulfate. As for nitrate, more significant seasonal variation of dry deposition can be found. Higher dry deposition is obtained in January and October than that in July and October.

Compared to dry deposition, wet deposition is a more effective way to remove the particulate matters from the atmosphere, with higher fluxes in all months. The wet deposition shows significant seasonal variation. It is in a great correlation with the particulate matter concentrations and the amount of precipitation. In April and July, both sulfate and nitrate show great wet deposition flux in PRD due to more rainfall. In January, low precipitation causes less wet deposition. October has also fewer rainy days as in January over the PRD region; however, the ambient particulate matter shows high concentrations in October, resulting in higher wet deposition than that in January.

References

Chan, C.K; Yao X.H.: Air pollution in mega cities in China, Atmos. Environ., 42, 1-42, 2008

Cheng, Y., Lee, S.C., Ho, K.F., Louie, P.K.K.: On-road particulate matter (PM2.5) and gaseous emissions in the Shing Mun Tunnel, Hong Kong, Atmospheric Environment, 40, 4235-4245, 2006

Ding, A., Wang, T., Zhao, M., Wang, T.J., Li, Z.: Simulation of sea-land breezes and a discussion of their implications on the transport of air pollution during a multiday ozone episode in the Pearl River Delta of China, Atmospheric Environment 38, 6737-6750 , 2004

Hagler, G.S.W., Bergin, M.H., Salmon, L.G., Yu, J.Z., Wan, E.C.H., Zheng, M., Zeng, L.M., Kiang, C.S., Zhang, Y.H.,Lau, A.K.H., Schauer, J.J.: Source areas and chemical composition of fine particulate matter in the Pearl River Delta region of China. Atmospheric Environment 40, 3802-3815, 2006

Huang, J-P., Fung, J.C.H., Lau, A.K.H., Qin, Y,: Numerical simulation and process analysis of typhoon-relatedozone episodes in Hong Kong. Journal of Geophysical Research 101, D05301,2005

Huang, X.F., Yu, J.Z., He, L-Y., Yuan, Z.: Water-soluble organic carbon and oxalate in aerosols at a coastal urban site in China: size distribution characteristics, sources, and formation mechanisms, Journal of Geophysical Research, 111, D22212,2006

Lam, K.S., Wang, T.J., Wu, C.L., Li, Y.S.: Study on an ozone episode in hot season in Hong Kong and trans-boundary air pollution over Pearl River Delta region of China, Atmospheric Environment 39, 1967 – 1977, 2005

Ma, J. Z; Ritcher, A; Burrows, J. P.: Comparison of model-simulated tropospheric NO_2 over China with GOME-satellite data, Atmos. Environ.,40, 593- 604, 2006

Song, Y. Di Chang, Bing Liu, Weijie Miao, Lei Zhu and Yuanhang Zhang, A new emission inventory for non-agricultural open fires in Asia from 2000 to 2009, Environ. Res. Lett. 5 (2010) 014014, doi:10.1088/1748-9326/5/1/014014.

Su, H; Cheng Y. F; Cheng P; Observation of night time nitrous acid (HONO) formation at a non-urban site during PRIDE-PRD2004 in China, Atmos. Environ.,42,6219-6232, 2008

Wang, S-L., Zhang, Y-H., Zhong, L-J., Li, J-L., Yu, Q.:.Interaction of urban air pollution among cities in Zhujiang Delta, China Environmental Science 25, 133-137, 2005 (Chinese with abstract in English).

Wang, T., Poon, C.N., Kwok, Y.H., Li, Y.S.: Characterizing the temporal variability and emission patterns of pollution plumes in the Pearl River Delta of China, Atmospheric Environment 37, 3539-3550, 2003

Wang, X; Zhang, Y; and Hu, Y.: Process analysis and sensitivity study of regional ozone formation over the Pearl River Delta China during the PRIDE-PRD2004campaign using the Community Multiscale Air Quality modelling system, Atmos. Chem. Phys., 10, 4423–4437, 2010

Wang, X.M., Carmichael, G., Chen, D., Tang, Y., Wang, T.: Impacts of different emission sources on air quality during March 2001 in the Pearl River Delta (PRD) region, Atmospheric Environment 39, 5227-5241, 2005

Zhang, Q; Street, D. G; Carmichael, G. R. Asian emissions in 2006 for the NASA INTEX-B mission, Atmos. Chem. Phys., 9, 5131–5153, 2009

Zhang, Y. H; Hu, M; Zhong, L.J.: Regional Integrated Experiments on Air Quality over Pearl River Delta 2004 (PRIDE-PRD2004): Overview, Atmos. Chem. Phys., 42, 6157-6173, 2008