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IMPACT OF EMISSION SOURCE UPWIND OF HONG KONG TO THE LOCAL AIR QUALITY

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1. INTRODUCTION

Hong Kong (HK) surrounded by China's largest economic development zone –the Pearl River Delta (PRD) region, faces ozone and visibility degradation problems due to trans-boundary air pollution (Fung et. al, 2005). Recently, monitoring data at Tap Mun (TM) station (see Fig. 1) and source apportionment analysis results suggest a link between air quality deterioration over the eastern part of HK and the adjacent fast-expanding northeasterly industrial sources, mainly Yantian Port and Dayawan Petrochemical Complex (Lau et al, 2008). Given the annual mean dominant wind direction in HK is northeasterly, upwind pollutants have ample chance to be transported to local regions and to accumulate under favorable meteorological conditions. Furthermore, these VOC rich upwind sources might shift the local ozone production balance and trigger more secondary particulate formation, therefore enhancing the ambient ozone and PM2.5 concentration.

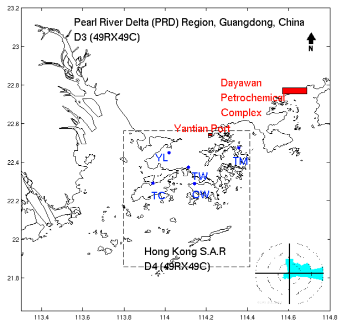

Fig 1. CMAQ domain setting in PRD region (D3) and Hong Kong (D4); the location of Yantian Port, Dayawan Petrochemical Complex (red box); the annual mean wind rose (lower right) and the location of five air quality monitoring stations used for model evaluation (blue dot)

In this study, a compact environmental risk analysis is carried out through the MM5-MCIP-CMAQ modeling system to quantify the impact of upwind sources on local air quality under different scenarios in the near future. A integrated process analysis (IPR) technique is also used to explore the detailed mechanism.

2. METHODOLOGY

2.1 Model Setting

Four nesting domains, zooming down from the outermost one Southern China (D1) to Guangdong Province (D2), PRD region (D3) and HK (D4) with grid resolutions 40.5km-13.5km-4.5k-1.5km, are constructed in CMAQ(V4.6) for the case studies. 20 vertical layers are used with the first layer 17m above the ground. Yamartino mass-conserving scheme, the CBIV mechanism for gas-phase chemistry and the AE4 for aerosol module are selected for the CTM run. Meteorology fields are simulated by MM5 (V3.6) with observation nudging. The base emission inventory is built up by Trace-P (D1-D2), PRD inventory data by HKEPD (D3-D4) and MODIS data (for BVOC, D1-D4) then processed using SMOKE(V3.0). More details regarding model configuration can be found elsewhere (Kwok. et al. 2007).

2.2 Upwind Sources Ingestion

The 2010 projected emission inventories for Yantian Port and Dayawan Petrochemical Complex are estimated by survey or comparable activity data, emission factors and growth factors. CBIV consistent source species are apportioned by utilizing the VOC source profiles from a similar study (Watson et al. 2001) and then brute force ingestion into the base emissions based on actual geographic locations and emission height. Yantian is treated as point source and Dayawan is treated as area source. The total annual emission for Yantian and Dayawan in 2010 account for 15% SO_2, 16% NO_x, 37% VOC, 17% PM, 19% CO of the local base emission inventory.

2.3 Case Selection

Two ozone episodes (Sep2004, Oct2004) and one PM episode (Mar2004) are chosen to model

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the upwind source impact. For each scenario, three runs namely base emission, base emission + Yantian emission and base emission + Dayawan emission are performed. The simulation duration for each case is 96hrs starting form 2:00 LTC with different spinning time. Detailed information is summarized in Table 1.

Table 1. Selected Cases for Upwind Emission Impact Study

Case	Meteor. Condition	Period	Max(O3)	Max(PM2.5)	Spin time
Mar2004	cold front	Mar.1-Mar4	71ppb	145ug/m3	5day
Sep2004	moderate northeasterly wind (speed<5m/s)	Sep.5-Sep8	169ppb	155ug/m3	2day
Oct2004	weak northeasterly wind (speed<2m/s)	Oct.5-Oct.8	155ppb	147ug/m3	5day

3. RESULTS

3.1 Verification of Base emission Case Simulation

Figure 2 summarizes the overall model performance for hourly ozone and PM2.5 simulation in different months. Five HKEPD air quality monitoring stations (see Fig. 1), namely Tap Mum (TM), Tsuen Wan (TW), Central Western (CW), Yuen Long (YL) and Tung Chung (TC), are used to perform model evaluation. The CMAQ system can repeat the general ozone diurnal variation and PM accumulation trend, however the model tends to miss the ozone peak and underestimate the PM2.5 concentration. Generally, the model performance of three cases is acceptable based on evaluation for group of statistic metrics.

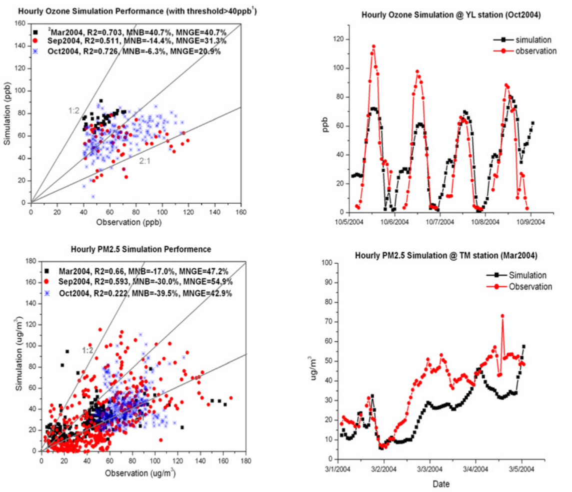

Fig 2. Comparison between simulated hourly ozone (top) and PM2.5 (bottom) compare from base emission source and HKEPD monitoring data for different months

(1. cut-off value 40ppb is applied for model performance statistic evaluation to remove the uncertainty subject to low ambient concentration; 2. the statistic metrics used here are: R2-correlation coefficient, MNB-mean normalized bias, MNGE-mean normalized gross error)

Figure 3 shows the comparison between the satellite retrieved aerosol optical depth (AOD) and the simulated PM10 column sum over PRD region on Oct 9 2:00pm (LTC). Heavy aerosol loading, which lies along the banks of estuary and western part of PRD region, is due to the so called enhanced land-sea breeze convergence zone (Lo et. al., 2007) and calm northeasterly background wind. The model can depict the general spatial gradient pattern well.

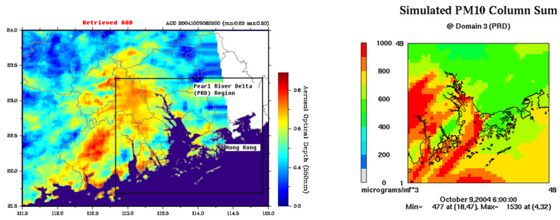

Fig 3. Spatial comparison between satellite retrieved AOD (left) and modeled PM10 column sum (right)

(the black box include area corresponds with the simulated domain 3, the black area is due to cloudiness)

3.2 Impact of upwind Sources

The use of a modeled relative respond factor (RRF) was introduced to gauge the impact from upwind sources on air quality. The RRF for component j at site i is given by:

$$(RRF)_{ij}=([C_{j,\ scenario}] /[C_{j,\ base}])$$

where $C_{j,\ base}$ is the simulated mean concentration at the monitoring sites from the base emission case and $C_{j,\ scenario}$ is the corresponding value from the scenario emission case. Table 2 summarizes the range of RRFs at five receptor stations after adding Yantian or Dayawan emissions under different cases. On average, Yantian emissions tend to increase the ambient ozone concentration by 3.3% and PM2.5 concentration by 14.3% while the increase for Dayawan is 3.6% and 3%. Pollutant concentration enhancement due to upwind emissions is likely to occur when calm northeasterly wind and relatively stable air conditions prevail. In such cases, plumes from Yantian tend to dilute ambient ozone concentrations at night and enhance ozone peaks during the day. The skewed distribution of RRF for ozone by the Yantian source reflects the nonlinearity of ozone chemistry.

Table 2. Range of Modeled Relative Respond Factor at Five Monitoring Site by Considering Yantian or Dayawan Source

Yantian Source[1]:	Ozone[2]			PM2.5		
	Mar2004	Sep2004	Oct2004	Mar2004	Sep2004	Oct2004
CW	[0.919[3] 1.001]	[0.945 1.001]	[0.966 1.059]	[1 1.204]	[1 1.121]	[1 1.104]
TM	[1 1]	[0.995 1.017]	[1 1]	[1 1]	[0.997 1.222]	[1 1]
TW	[0.940 1.003]	[0.887 1.006]	[**0.850** **1.063**]	[1 1.150]	[0.999 1.227]	[0.999 1.088]
TC	[0.913 1]	[0.992 1.011]	[0.876 1.016]	[1 1.067]	[0.992 1.181]	[0.999 1.065]
YL	[0.867 1.004]	[0.925 1.004]	[0.953 1.028]	[0.999 1.154]	[0.999 **1.456**]	[0.999 1.001]
***Dayawan Source*:**	**Ozone**			**PM2.5**		
	Mar2004	Sep2004	Oct2004	Mar2004	Sep2004	Oct2004
CW	[0.984 1.010]	[1 1.006]	[0.996 1.029]	[1 1.016]	[1 1.024]	[1 1.015]
TM	[0.978 1.004]	[0.965 1.078]	[0.974 **1.079**]	[0.999 1.023]	[1 **1.102**]	[1 1.029]
TW	[0.988 1.022]	[0.982 1.007]	[0.993 1.041]	[1 1.022]	[1 1.07]	[1 1.017]
TC	[0.991 1.016]	[0.997 1.010]	[0.996 1.024]	[1 1.019]	[1 1.028]	[1 1.013]
YL	[0.988 1.030]	[0.995 1.006]	[1 1.030]	[1 1.035]	[1 1.035]	[1 1.012]

(1. The RRFs from Yantian source to local five receptors, namely CW, TM,TW,TC,YL. 2. Simulated concentrations less than 40ppb are cut off. 3. Sort the calculated RRF and then average the smallest 20% RRFs and biggest 20% RRFs as the lower and upper bound of the RRF range.)

Figure 4 gives the possibility location and relative frequency for ozone and PM2.5 enhancement due to Yantian or Dayawan sources during the simulation time. Yantian source, which is quite near HK, has a clear and relative isolated high frequency impact region. Any location downwind that lies on the Yantian plume axis (i.e. TW station) might experience significant PM2.5 and ozone increases. On the contrary, the spatial frequency distribution due to Dayawan emissions is relatively smooth. The exception to this occurs when the skirt of Dayawan plume quickly sweeps the eastern part of HK, and in this case, stations like TM may be highly impacted.

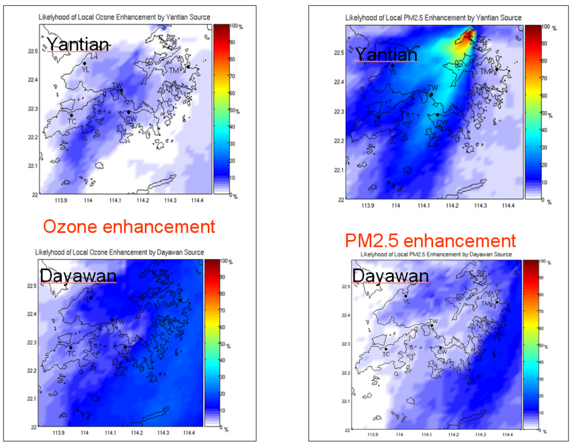

Fig 4. Likelihood of local ozone (left) and PM2.5 (right) enhancement due to upwind emission from Yantian Port (upper) and Dayawan Petrochemical Complex (lower)

3.2 Integrated Process Analysis

A subsequent study of the variation of process terms which affected the ozone budget during the episode was performed. Oct. 6 2004 9:00am-3:00pm (LTC) was selected as the analysis time-frame. During this period, weak northeasterly wind favoured the formation of ozone. Figure 5 gives the process term variation at the source region (Yantian), directly downwind of the station (CW) and at a station less frequently affected (TM) by Yantian emissions. Even though the net ozone concentration in these three station all increased during daytime, the main contributing process term is quite different. The horizontal advection term, vertical advection term and vertical diffusion term dominate the ozone formation in Yantian, TM and CW respectively. The difference is mainly due to flow pattern and the local NOx/VOC ratio. Air parcels tend to rise around the Yantian port and sink around the TM station. The elevated ozone at the downwind CW is because of the significant gradient between upper and surface concentrations. The gradient is so strong that it can compensate for the ozone loss due to the chemical reaction under NOx limited conditions (CW is a road-side station, with abundant NOx emissions). Furthermore, if the circulation around Yantian and TM is maintained and the Yantian emissions increase, we can expect further ozone enhancement by the upwind source.

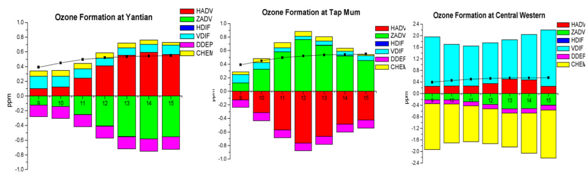

Fig 5. Process term contribute to the ozone formation at Yantian port (left), Tap Mum (middle) and Central Western (right) station
(HADV: horizontal advection term, ZADV: vertical advection term, HDIF: horizontal diffusion term, VDIF: vertical diffusion term, DDEP: dry deposition term, CHEM: chemical term. The dot black line represents the net ozone at that hour.)

4. CONCLUSION

A MM5-MCIP-CMAQ modeling system was set up to model the upwind emission impact to the local air quality under favorable meteorological conditions. We focused our discussion on surface ozone and PM2.5 enhancement. The base emission simulation results compared reasonably well with observation data. The impact from Yantian port and Dayawan petrochemical complex are considered individually under three cases. Modeled relative responds factors are introduced to quantify the possible impact range. The results show that Yantian is far more important than Dayawan in regard to PM2.5 enhancement. During extreme conditions, the ambient PM concentration can increase nearly 50%. Ozone enhancement by the two upwind sources is not significant (<3%) and the upwind source tends to strengthen diurnal variation when the background wind is weak and the air is relatively stable. A simulation based ozone and PM2.5 enhancement map was constructed to explore the ‘hot spots’ for the environmental risk analysis. Tsuen Wan (TW) station, which is located downwind of Yantian emission source, is highly likely to be affected. Integrated process analysis was applied to understand the relative importance of each process term to the total budget. For ozone, the dominant process term is determined by the general flow pattern and local NOx/VOC ratio.

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References

Fung, J. C. H., A. K. H. Lau, J. S. L. Lam, and Z. Yuan, 2005: Observational and modeling analysis of a severe air pollution episode in western Hong Kong, *J. Geophys. Res.*, *110*, D09105, doi:10.1029/2004JD005105.

Lo, J. C. F., Lau A.K.H., Chen F., Fung, J.C.H., Leung, K.K.M., 2007: Urban modification in mesoscale model and the effects on the local circulation in the Pearl River Delta region. *J. Appl. Meteor. Climatol.*, **46**, 457-476.

Huang, J.P.(2005) Numerical simulation study of ozone episode in complex terrain and coastal region. Ph.D. thesis, Mathematic department, Hong Kong University of Science & Technology.

Lau, A. K. H., Yuan, Z.B., Lin, C.B., Zhang R., Yim S. H.L(2008). Study on air quality impact due to emission sources upwind of Hong Kong. Report to EPD HKSAR (AP 06-048).

Kwok, R. H.F., Fung, J.C.H., Lau, A.K.H. and Fu, J. S., Urban effects of Hong Kong and Pearl River Delta region on sulfur cycle. 6th annual CMAS conference, Chapel Hill, October 2007.

Watson, J. G., Chow, J. C. and Fujita, E. M. Review of volatile organic compound source apportionment by chemical mass balance, Atmos. Environ., 2001, 35, 1567-1584.