Successful air quality management program in central Taiwan?

Pei-Hsuan Kuo; Ben-Jei Tsuang*

Dept. of Environmental Engineering, National Chung-Hsing University, Taichung 402, Taiwan
* tsuang@nchu.edu.tw

Abstract

This paper reviews the changes of the spatial-and-temporal distributions of air pollutants over central Taiwan after 1995, when stationary sources and automobiles were taxed for their airborne-pollutant emissions by Taiwan's EPA. Since then, many control strategies have been implemented for improving regional air quality. SO_2 emission from point sources has been reduced by 50% from 1997 to 2000. Emissions from Highway #1 in 2001 were less than 1997 by 10-64%. As a result, the concentrations of primary pollutants (SO_2, CO, NOx and NMHC) along the highway and the two power plants have reduced. Contour as well as air quality modeling analyses are performed to quantify the source/receptor relationships of primary and secondary pollutants such as SO_2, NOx, CO, NMHC, PM10 and O_3. These analyses prove that the emission reductions from the highway and the power plants cause:1) the concentration reductions of the primary pollutants along the highway and locations near the power plants and 2) possible ozone concentration reduction at 80 km leeward from Tunghsiao Power Plant. Nonetheless, O_3 concentration over the entire region is still in a rise in general, which is most likely ironically connected to NO emission reduction from automobiles. This automobile-NO-emission reduction inhibits surface O_3 to be titrated by NO. The emission inventory and the concentration datasets of the air-quality management history offer a unique opportunity for understanding how well and how bad the current state-of-art air quality models are. It shows the largest discrepancy between modeled and observed concentration change is the impact of high-stack NO emission on surface O_3 concentration.

Introduction and background illustration

Taiwan is a small island located on the western edge of the Pacific Ocean just to the east of China. The Central Taiwan Air Basin (CTAB) includes Taichung County, Taichung City, Miaoli County, Natou County, Changhwa County, Yulin County and Chiayi County (Tsuang et al.,1999; Yu and Chang, 2001). Topographical features of CTAB comprise mainly open terrain on the western side and rugged terrain on the eastern side. Especially, Nantou County, it barricaded on the east side by the Central Mountain Ridge of Taiwan, thus forms a unique feature for the wind pattern in some special meteorological event.

Emission

In 1995, Taiwan EPA has started to tax emission fee from polluters. Since then, many control strategies have been implemented for improving regional air quality. The TEDS (Taiwan Emission Databases, CTCI, 1999) was used as the emission inventories for this study. The inventory contains point, line and area sub-inventory sources. The emission rates of primary TSP, SOx, NOx, CO and NMHC were estimated in 1997 and 2000 respectively. The area and mobile emission Table 1 summarizes the CTCI estimated emissions in 1997 and 2000 over CTAB. SOx emission from point, line and area sources in 2000 were less than in 1997 by 58%, 72% and 30% respectively. NOx emission from point and line source has been total reduced by 14% from 1997 to 2000. Primary particle emission in 1997 was 1% more than in 2000.

Taichung power plant and Tunghisao power plant were the first two largest point sources in central Taiwan (Figure 1a, b). After Taichung power plant installing a de-suffer equipment in June 1999, the SO_2 emission rate in 2000 was only 35.2% of the amount in 1998. Meanwhile, NOx was slightly reduced after July 1999. As to Tunghsiao power plant, SO_2 and NOx emissions from January 2002 were much less than before. Figure 1c shows that the Highway#1, the largest line source, annual emissions in 2001 were less than 1997 by 10-64%. In addition, SO_2, CO, NOx, and NMHC along the two power plants and the highway have reduced (figure not shown). But, the NOx and PM emissions were increased in Nantou County in 2000. It could be seen that the construction of Taichung-Nantou Fast Way played an important role in emissions. Hence, we denoted the years from 1996 to 1998 as “High Emission Years” (HEYs), and the years from 2000 to 2002 as “Low Emission Years” (LEYs).

Spatial and Temporal Distributions of SO_2, CO, NOx, NMHC, and PM

The monitoring data were obtained form 24 air quality stations belong to Taiwan’s

EPA. The distance between observation sites is about 10 km. Because insufficient monitoring stations, we expanded 1 station monitoring data to a 10*10 km grid data to realize the variation of air quality clearly. According to the spatial distribution of SO_2, CO, NOx, NMHC, O_3 and PM10 over CTAB (Figure not shown), it can be seen that for primary pollutants, such as SO_2, CO, NOx and NMHC, the higher concentration areas are located near their sources. For secondary pollutants, such as O_3 and PM_{10}, the high concentration areas are located in the southern leeward areas. Figure 2 and 3 show the wind speed and pollutant concentration changes between HEYs (1996 to 1999) and LEYs (2000 to 2002). The shaded blocks indicated the composite anomalies in 90% statistic confidence intervals between HEYs and LEYs. The black or gray squares displayed that concentrations in LEYs were higher or lower than in HEYs at the same locations

Figure 2 indicates the composite monthly variation in wind speed and wind vector. Because there were almost no shaded blocks, we can explain that the weather condition in HEYs was unrelated to that in LEYs. Thus, we can assume that the weather influence on air quality can be ignored in this study. Figure 3a shows that most of SO_2 reduced areas were located on leeward side of the first two power plants especially during NE monsoon seasons. Thus, the reductions could be related to the reductions of the two plants. Besides, we can find the variation in NOx and CO concentration were similar to line source emissions, which were decreased along Highway#1 and increased in Nantou County (Figure 3c, 3e). In respect to PM_{10} change, Figure 4a, the concentration reduction can be seen in the leeward regions such as in Yulin, Chiayi County; but increases can be also seen in Nantou County. Figure 4c, 4d and 4e show the CH_4, NMHC and THC concentration were decreased on southwest sides of CTAB but increased on the east sides. For secondary pollutant, O_3, we can find that the O_3 concentration was declined at 80 km leeward from Tungshiao Power Plant. Although the concentrations of the precursors of O_3, such as NOx and NMHC, were declined, that of O_3 was still increasing (Figure 4f). It was most likely connected to NO emission reduction from automobiles. This automobile-NO-emission reduction inhibits surface O_3 to be titrated by NO (Chen et al., 2002).

Air quality modeling

The Gaussian Trajectory transfer-coefficient modeling system (GTx) (Tsuang et al., 2002a; Tsuang, 2003a, b; Chen, 2003) is developed to simulate primary pollutants, SO_2, NOx, and CO, as well as secondary sulfate and nitrate aerosol concentrations at receptors, and the level of concentration increase in downwind areas from sources. This model consists of a two-dimensional array of continuous cells that are perpendicular to the wind direction with the terrain following coordinates along a back-trajectory from a receptor. Besides, wind vector, stability class and mixing height among each time interval (1h in the present version) along a trajectory are allowed to change. Surface wind data are obtained from either Central Weather Bureau (CWB/Taiwan) or EPA/Taiwan. The initial concentrations of pollutants at the receptor and the boundary conditions for the concentrations at the beginning of the 24-h trajectory are set at their observed values.

In this study, we used 3-D back trajectory for 24-h of transport arriving at the receptor site at 50m above ground level (agl) to simulate the weather condition during modeling time. The temporal resolution of the observed wind data is 1h and their spatial resolution over land is about 5 km. No sounding data were available. Therefore the lapse rate above a mixing height (MH) is set at the observed temperature gradient between two nearby mountain meteorological stations. One is at 1014m asl and the other at 2413 asl. The aerodynamic roughness of the urban site grid is set at 2.1m measured by Tsuang et al. (2003). The stations we choose during modeling period were the representative stations in Taichuang City (ChungMing station), Changhwa County (Erlin station), Nantou County (Chushan station) and Yulin County (Touliu station). The emission inventories we inputted into GTx were emissions in1997 for HEYs and emissions in 2000 for LEYs.

Comparison with monitoring data

To understand how successful about the air quality management program in central Taiwan is, we compare model results with monitoring data. We choose autumn and winter seasons (Sep-Oct and Nov-Dec) for the comparisons. In these seasons, PM_{10} concentration is often higher than other seasons. The right panels of Figures 3 and 4 show the anomaly of simulated concentrations between LEYs and HEYs calculated by GTx. Figure 3b shows that the modeled SO_2 anomaly between LEYs and HEYs is identical to those observed by monitoring stations. Calculated and observed SO_2 data also show that the concentration-decreased regions located in the southwest CTAB, where also the leeward regions of Taichuang and Tungshiao plants were. In respect to modeled NOx, Figure 3d displayed that modeled NOx concentration, similar to observation, was declined along the Highway#1 in 90% statistic confidence level. Due to the construction of Highway#3 and three East-West Fast Ways, the traffic volume was increased in Nantou County in LEYs. But the model can’t simulate this increase phenomenon in Nantou County during the period. This might be contributed to lack of the emission data after 2000. In respect to CO anomaly, both model and observation do not show regions with anomaly > 90% confidence level between LEYs and HEYs (Figure 3f) over CTAB. Regarding to PM_{10}, the model reproduces the decease of PM_{10} concentration in CTAB in general (Figure 4b). Nonetheless, the model shows the decrease is in 90% confidence level in Chushan, which was not observed in the monitoring network. This indicated more improvements of the models are still required.

Conclusion

From the above analysis, we have found that the spatial distribution of the concentrations of various pollutants can be associated with their emission distributions. SO2 emission from point sources has been reduced by 50% from 1997 to 2000. Emissions from Highway #1 in 2001 were less than 1997 by 10-64%. The temporal distribution of air pollutants, SO_2, CO, NOx, and NMHC, along the two power plants and the highway in LEYs have reduced over CTAB. In addition, GTx model can simulate SO_2, NOx, and CO relationship well during annual September to December, although more refinements or emission data of the models are still required.

Reference

Chen, C.-L.; Tsuang, B.-J.; Pan, R.-C.; Tu, C.-Y.; Liu, J.-H.; Huang, P.-L.; Bai, H-L; Cheng, M.-T., 2002/1: Quantification on source/receptor relationship of primary pollutants and secondary aerosols from ground sources – Part II. Model description and case study. *Atmos. Environ.* 36(3), 421-434.

Chen, C.-L.; Tsuang, B.-J.; Tu, C.-Y.; Cheng, W.-L.; Lin, M.-D., 2002/4: Wintertime vertical profiles of air pollutants over a suburban in Central Taiwan, Atmos. Environ. 36(12), 2049-2059.

Cheng, M.T.; Tsai, Y. I., 2000: Characterization of Visibility and Atmospheric Aerosols in Urban, Suburban, and Remote Areas. Sci. Total Environ., Vol. 263, No. 1, pp. 101-114.

Cheng, W-L; Pai J.-L.; Tsuang, B.-J.; Chen C.-L., 2001/3: Synoptic patterns in relation to ozone concentrations in west-central Taiwan. Meteorology and Atmospheric Physics. 78, 11-21.

CTCI Corporation, 1999. Carrying capacity management plan for air pollutants and estimation of emission inventory over Taiwan. Environmental Protection Administration, Taiwan, EPA-88-FA31-03-03-1059 (in Chinese).

Environmental Protection Agency, Taiwan (EPA/Taiwan), 2000. Air quality management in Taiwan in the past 25 years (1975-2000). Environmental Protection Agency, Taiwan, 385 pp (in Chinese).

EPA-454/B-93-051, PAMS Implementation Manual, March 1994.

Tsuang, B.-J., 2002b: A Gaussian plume trajectory model to quantify the source/receptor relationship of primary pollutants and secondary aerosols: Part I. Theory. Atmos Environ., submitted.

Tsuang, B.J.; Chen C.L.; Liao C.-M., 1999/7: Air basins determined in Taiwan – preliminary results. Journal of the Chinese Institute of Environmental Engineering. 9, 199-208.

Tsuang, B.-J.; Chen, C.-L.; Pan, R.-C.; Liu, J.-H., 2002a: Quantification on source/receptor relationship of primary pollutants and secondary aerosols from ground sources – Part I. Theory. Atmos. Environ. 36(3), 411-419.

Tsunag, B.-J.; Chen, C.-L.; Lin, C.-H.; Cheng, M.-T.; Kuo, P.-H.; Tsai, Y.-I.; Chu, C.-P.; Pan, R.-C., 2002c: A Gaussian plume trajectory model to quantify the source/receptor relationship of primary pollutants and secondary aerosols: Part II. Case Study. Atmos. Environ., submitted.

Table 1 Emission rate (ton yr^{-1}) in 1997 and 2000 over CTAB

	1997				2000				2000-1997 ton yr^{-1} (%)			
	point	line	area	total	point	line	area	total	point	line	area	total
SOx	156822	6999	5250	169071	65349	1937	3687	70972	-91473 (-58)	-5062 (-72)	-1563 (-30)	-98099
NOx	106190	84659	5193	196042	100552	77016	10249	187816	-5638 (-5)	-7643 (-9)	+5056 (+97)	-8226
PM	29448	13415	99616	142479	42274	13752	85526	141552	12826 (+44)	337 (+3)	-14090 (-14)	-927
NMHC	31752	86576	187613	305941	95511	62290	735745	893546	63759 (+201)	-24286 (-28)	548132 (+292)	587605
CO	31318	474280	119581	625179	41253	228041	36953	306247	9935 (+32)	-246239 (-52)	-82628 (-69)	-318932

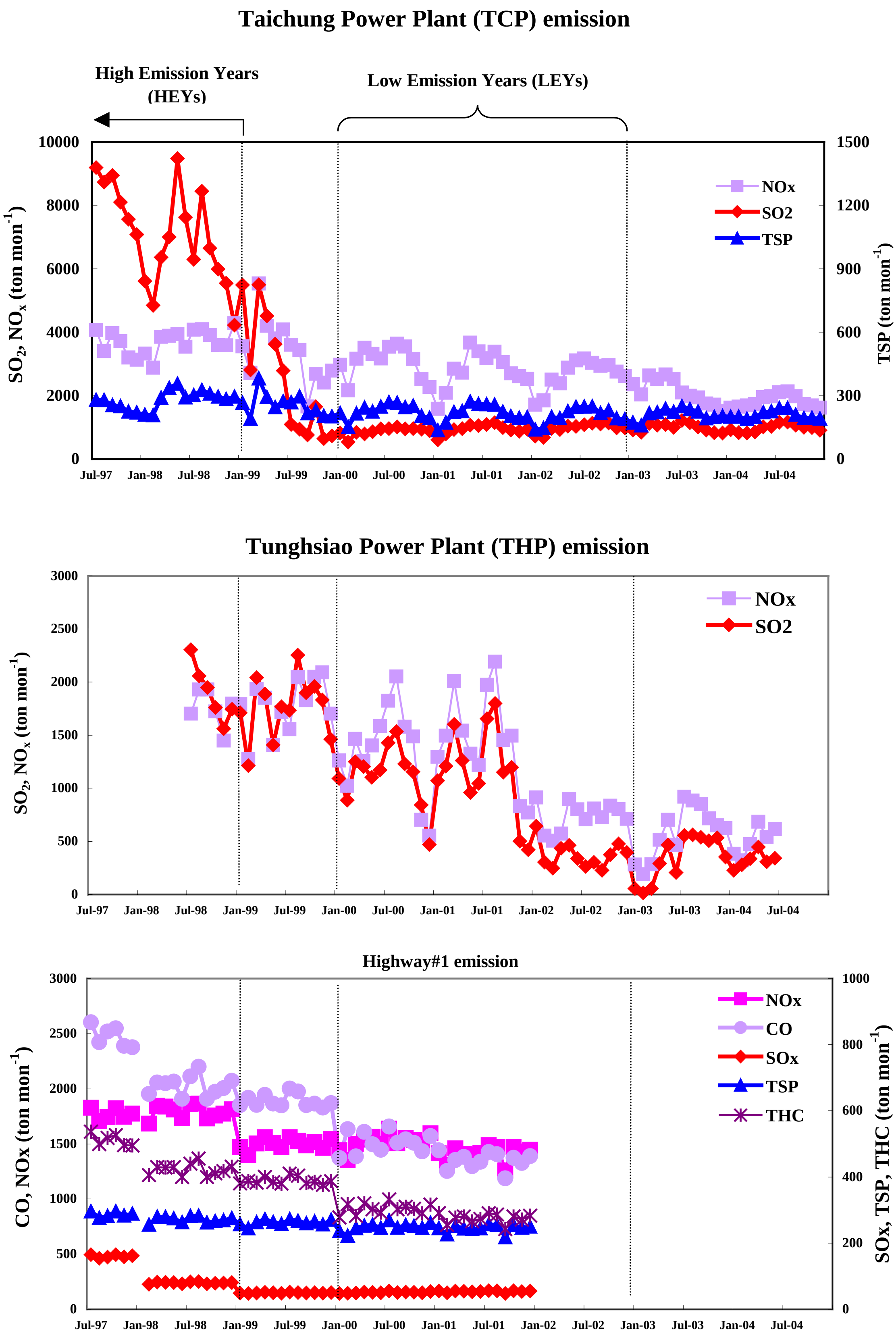

Figure 1. Emission rates from Taichung power plant, Tunghsiao power plant and Highway #1.

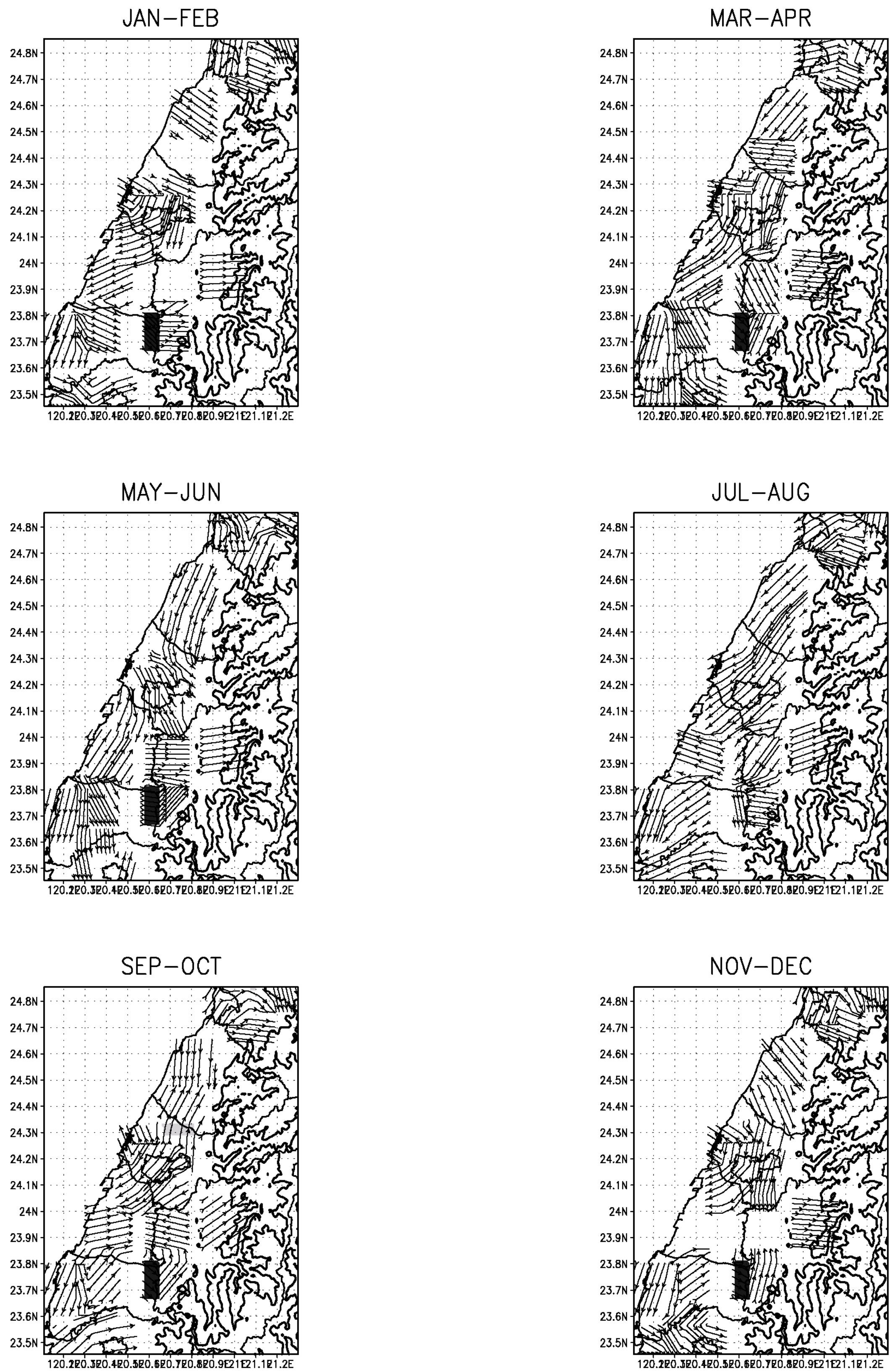

Figure 2. The anomaly of wind velocity and wind vector between LEYs and HEYs. The black shaded indicated the concentration in LEYs was higher than in HEYs within 90% statistics confidence interval.

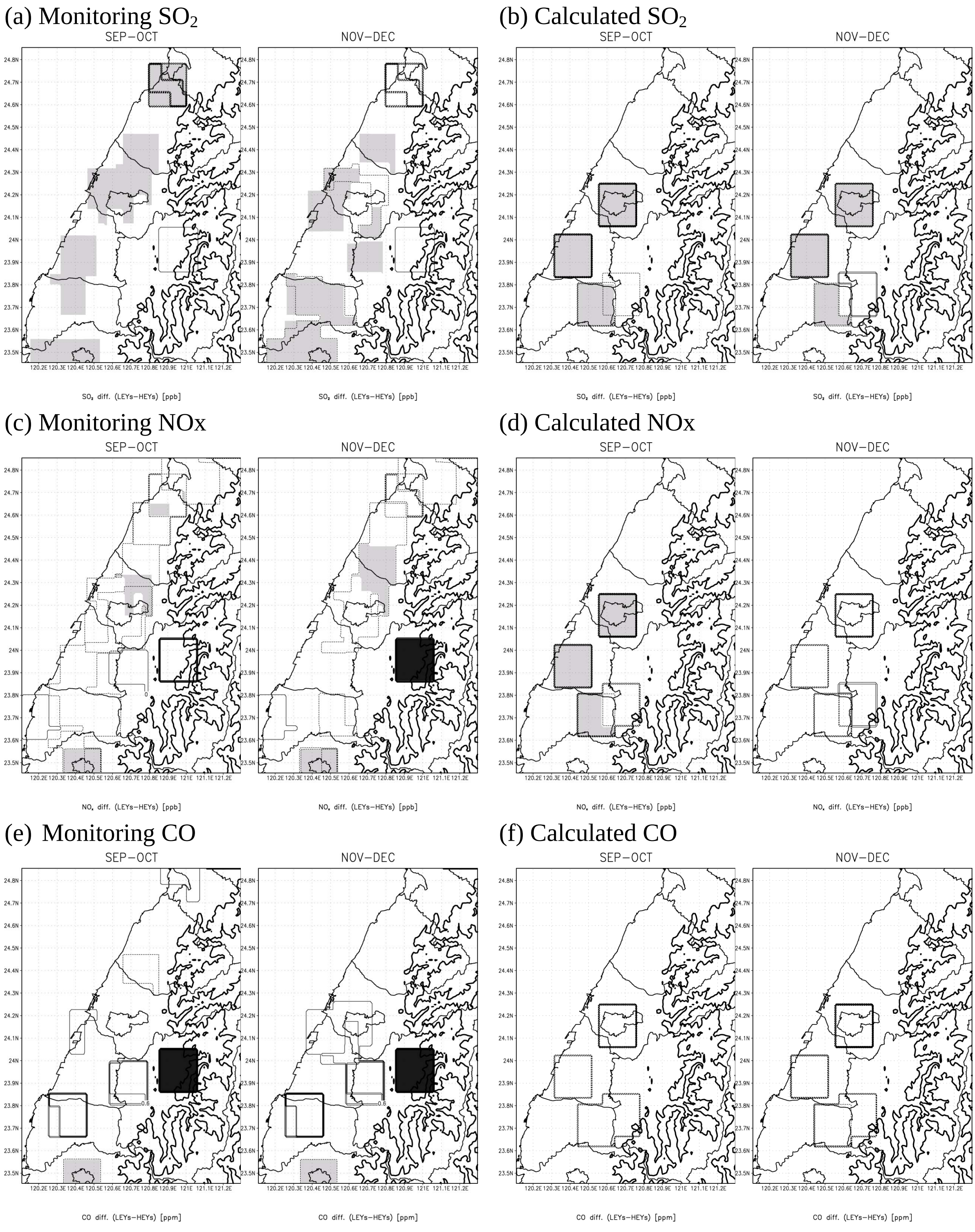

Figure 3. The anomaly of pollutants observed and modeled concentration between LEYs and HEYs. The black shaded indicated the concentration in LEYs was higher than in HEYs within 90% statistics confidence interval. The gray shaded indicated the concentration was lower in LEYs than in HEYs within 90% statistics confidence interval.

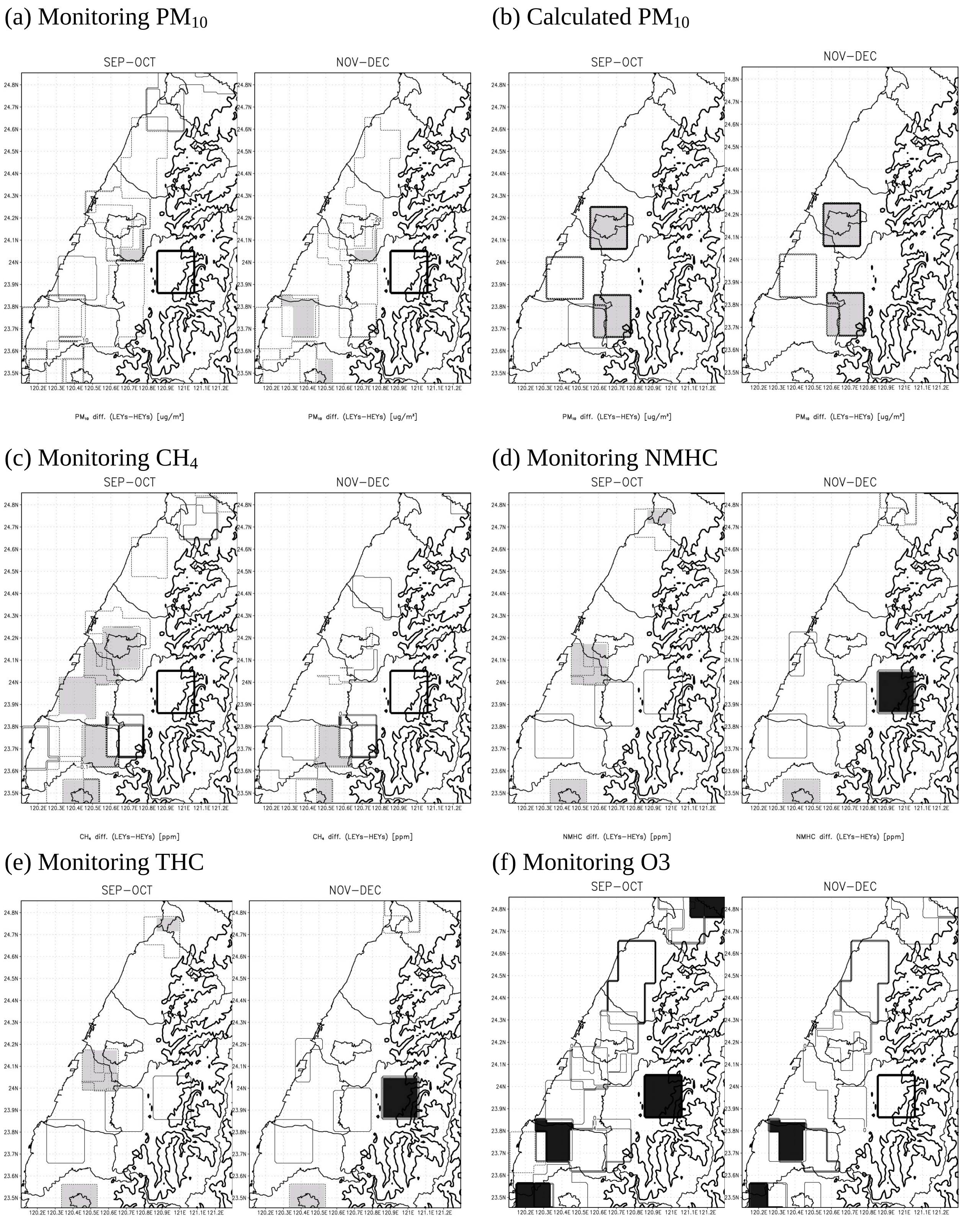

Figure 4. The anomaly of pollutants observed and modeled concentration between LEYs and HEYs. The black shaded indicated the concentration in LEYs was higher than in HEYs within 90% statistics confidence interval. The gray shaded indicated the concentration was lower in LEYs than in HEYs within 90% statistics confidence interval.