THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

Source apportionment of ozone under different synoptic patterns in the Pearl River Delta region

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Introduction

- For the Pearl River Delta (PRD) region, the fine particulate matter ($PM_{2.5}$) concentrations remained high during 2004 to 2007 and then **generally declined** with the effective control of $PM_{2.5}$ by the government.
- The $PM_{2.5}$ concentration in the PRD region increased during the 10th FYP period and started to **improve** during the 11th FYP period. **Improvement accelerated** during the 12th FYP period.

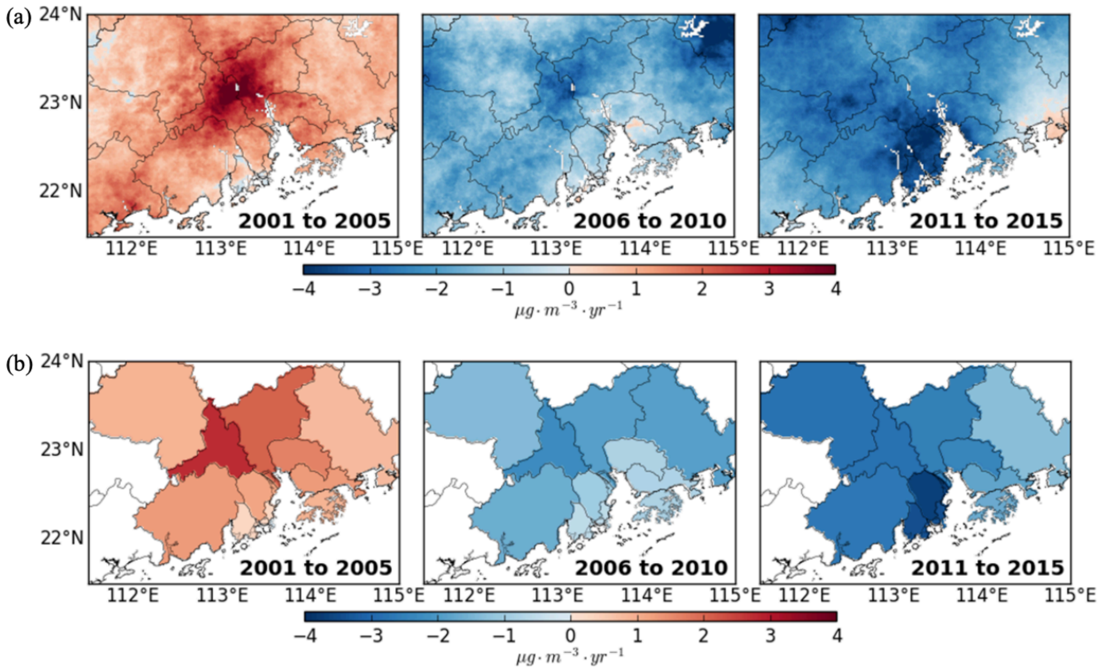


Fig. 1. (a) Spatial distribution of $PM_{2.5}$ trends in the PRD region during the three Five-Year-Plan periods. (b) Mean $PM_{2.5}$ trends for different cities in the PRD region during the three Five-Year-Plan periods.[1]

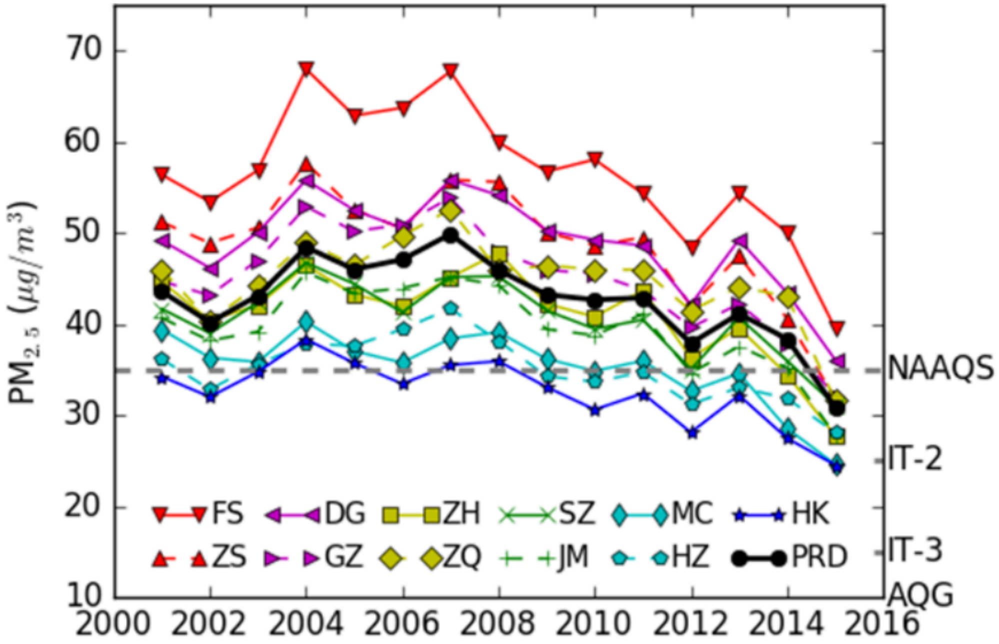


Fig. 2. Inter-annual variations in the spatial mean of the $PM_{2.5}$ concentrations for the PRD region (black line) and different cities (colored lines) from 2001 to 2015. The WHO IT-1, also the current NAAQS (35 μg m^{-3}), IT-2 (25 μg m^{-3}), IT-3 (15 μg m^{-3}), and AQG (10 μg m^{-3}) for annual $PM_{2.5}$ are also labeled.[1]

[1] Lin, C. Q., Li, Y., Lau, A. K., Li, C. C., & Fung, J. C. (2018). 15-year PM2. 5 trends in the Pearl River Delta region and Hong Kong from satellite observation. Aerosol Air Qual. Res, 18, 2355-2362

Introduction

- The pollution problem characterized by **a high concentration of ozone (O_3)** is sequentially emerging.
- In 2017, the other five common air pollutants' concentrations decreased obviously, while the **O_3 increased by 8.4%** nationwide compared with that of 2016.
- In the PRD region, the concentration of **O_3 as the primary pollutant increased significantly**, accounting for 9.3%.

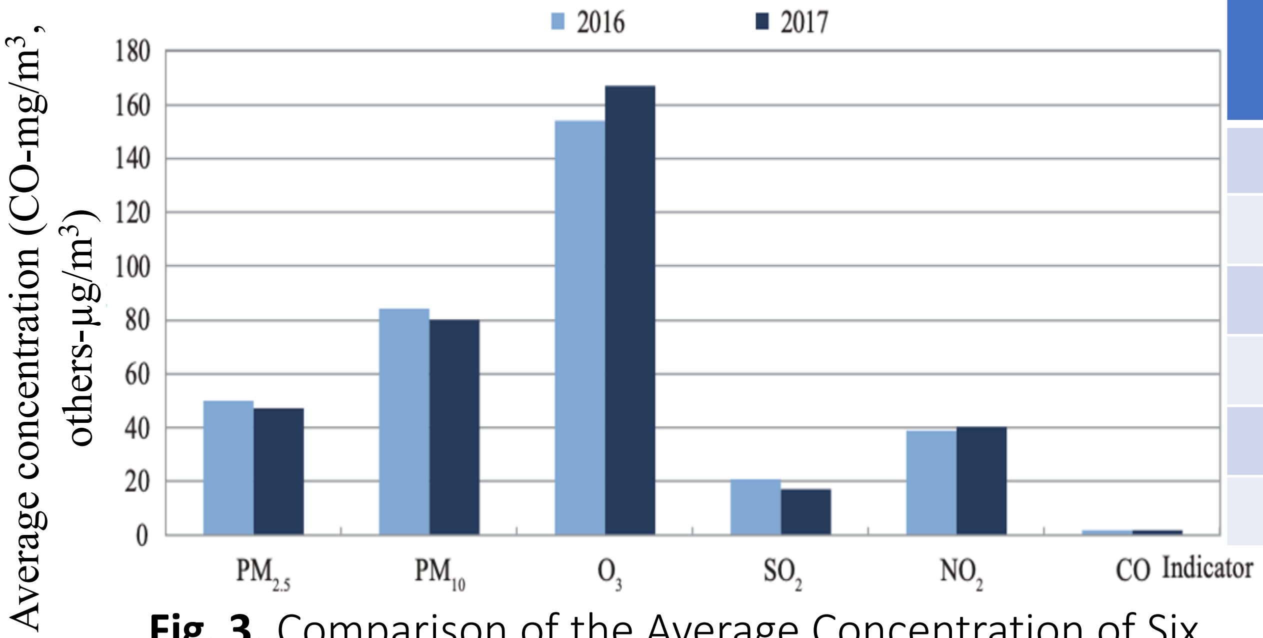


Fig. 3. Comparison of the Average Concentration of Six Pollutants of the 74 Cities between 2016 and 2017.[2]

Indicator	Average concentration (CO: mg/m³, other μg/m³)	Increase from 2016 (%)
$PM_{2.5}$	34	6.2
PM_{10}	53	8.2
O_3	165	9.3
SO_2	11	0
NO_2	37	5.7
CO	1.2	-7.7

Table 1. Average Concentration of Primary Pollutants in the Pearl River Delta in 2017.[2]

[2] Report on the State of the Environment in China, http://english.mee.gov.cn/Resources/Reports/soe/, last access: 2 October 2020)

Method

- **Model:** WRF-SMOKE-CAMx modeling system with Ozone Source Apportionment Technology (OSAT) module
- **Inventory:**
  1. D1 and D2 : the MEIC emission inventory for 2012
  2. D3: the emission inventory for 2015 provided by the Hong Kong Environmental Protection Department
- **Resolution:** 27km (D1), 9km (D2), 3km (D3)
- **Source region:** 10 major cities shown in Fig. 4 and areas outside the PRD region
- **Emission source categories:** area source, mobile emission, industrial point source, power plant point emission, biogenic emission, and marine-ship emission
- **OSAT module:** $\mathbf{C_{O_3}} = \sum_{i=1}^{11} \sum_{j=1}^{7} \mathbf{S(i,j)} + \mathbf{IC} + \mathbf{BC}$

  where C_{O_3} is the total O_3 concentration, $S(i,j)$ represents the contribution of source species j from source region i, IC and BC are the contributions from initial and boundary conditions.

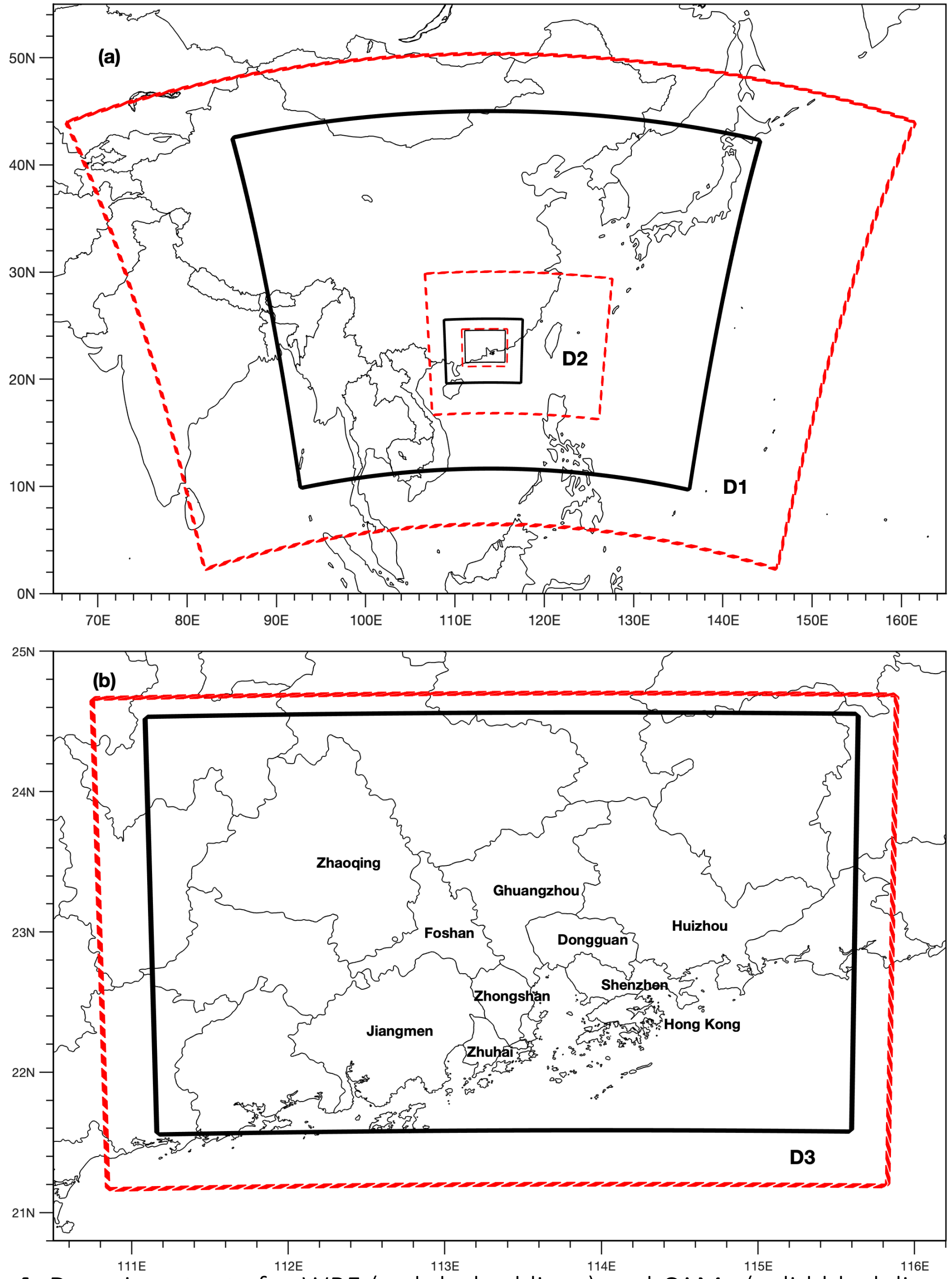


Fig. 4. Domain extents for WRF (red dashed lines) and CAMx (solid black lines), including (a) Domain1 (D1), Domain2 (D2), and (b) Domain3 (D3). Red dots represent the measurement sites. 10 major cities in the PRD region are labeled on the map.

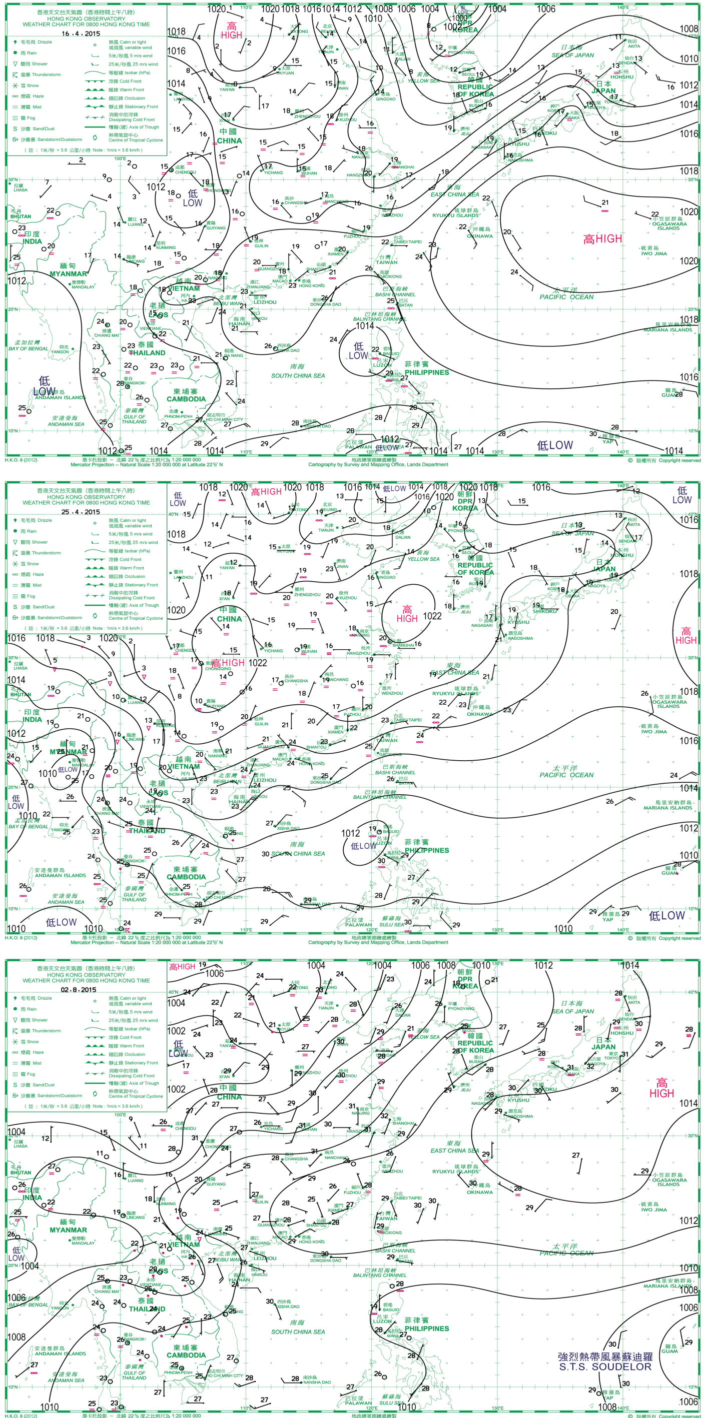
Method

- In the case of relatively stable emissions, the **meteorological condition** is an essential factor affecting ozone pollution.
- **Analysis objects**
  - Ozone maximum daily 8-hour average (O3-8h)
  - Target cities: Huizhou (HZ), Guangzhou (GZ), Foshan (FS), Dongguan (DG), Jiangmen (JM), Shenzhen (SZ), Zhongshan (ZS), Zhaoqing (ZQ), Hong Kong (HK), and Zhuhai (ZH)
  - January, April, August, October in 2015
- **Time period for distinctive synoptic patterns**
  1. Sea high pressure: 20150414 to 20150417
  2. Equalizing pressure field: 20150424 to 20150430
  3. Subtropical high pressure: 20150801 to 20150808

(a)

(b)

(c)



Equalizing pressure field
20150416 8:00(UTC+8)

Sea high pressure
20150425 8:00(UTC+8)

Subtropical high pressure
20150802 8:00(UTC+8)

Fig. 5. Surface weather chart[3] of three synoptic patterns, namely (a)sea high pressure, (b)equalizing pressure field, and (c)subtropical high pressure

[3] Hong Kong Observatory Weather Chart, http://envf.ust.hk/dataview/hko_wc/current/, last access: 5 October 2020)

Monthly Ozone Concentration and Source Apportionment

- In January and October, when northerly wind prevails, the O_3 concentration's contribution was mainly influenced **by the emissions outside the PRD region**, and the contribution can reach more than 80%. For April and August, under the control of weak southerly wind, the emissions contribution outside the PRD region **was reduced to approximately 60-70%.**
- **Mobile, area, and biogenic sources** were the three main sources of ozone. For cities with more motor vehicle ownerships, such as GZ and SZ, the mobile contribution can **be higher than 40%.** For HK, the contribution of ship emissions cannot be neglected. Although the contribution of several sources varied slightly in different months, the overall change was not significant.

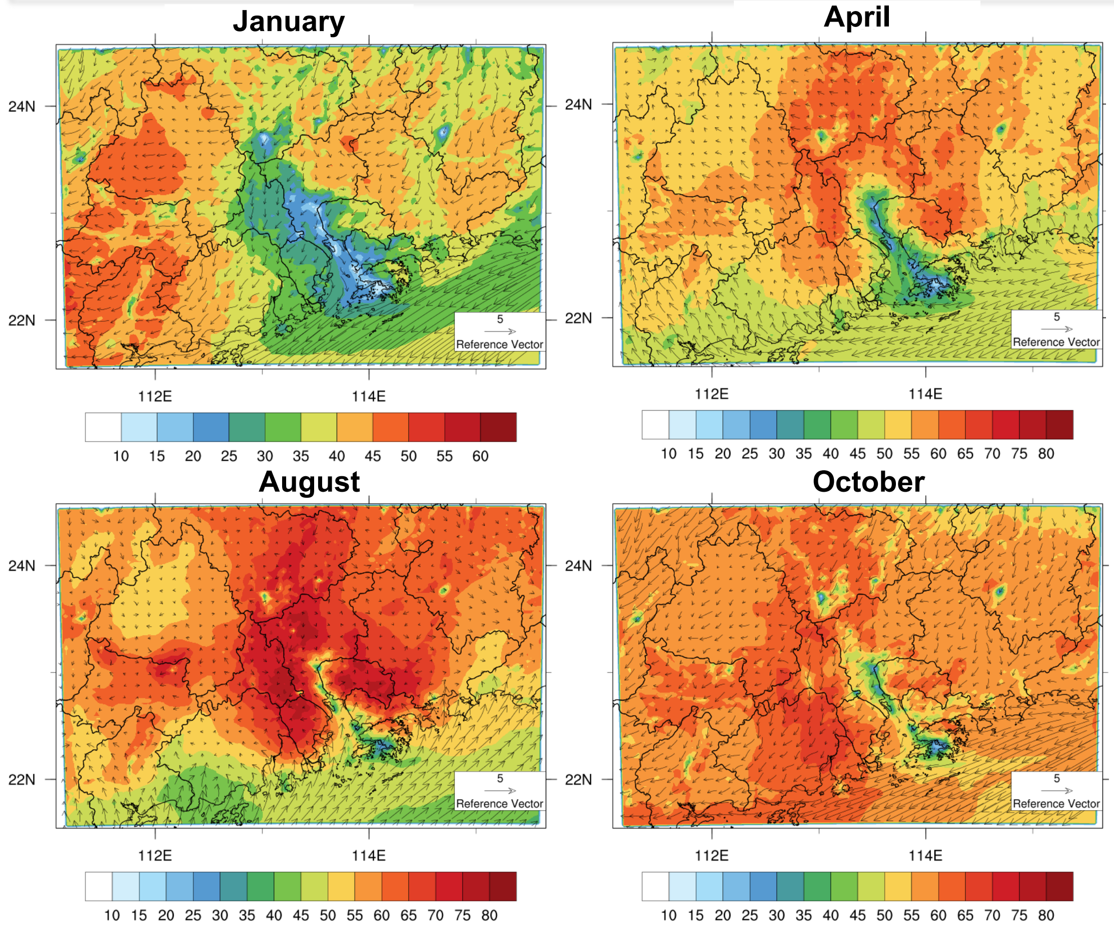


Fig. 6. Monthly O_3-8h concentration spatial distributions with wind fields in January, April, August, and October over the PRD region (Units: ppb)

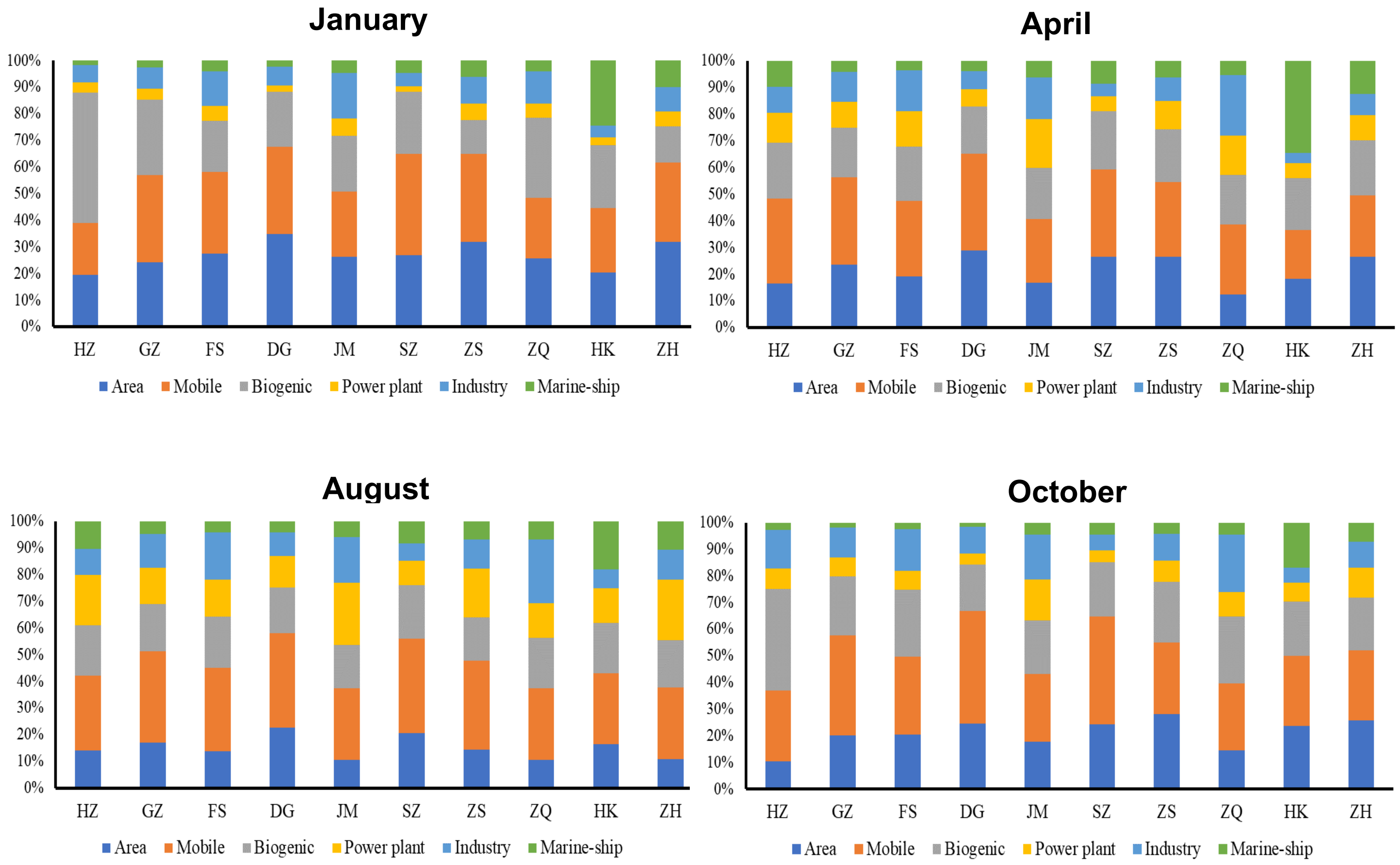


Fig. 7. Monthly source contributions in percentage(%) to O_3-8h in January, April, August, and October in the PRD region

Concentration and Source Category Contribution

- The concentration of ozone **got increased** under three meteorological conditions.
- After the mobile emissions, **biogenic sources** and area sources attribute to the highest contribution under **subtropical high pressure** and sea high pressure, respectively.
- Different weather conditions have a slight effect on source categories.

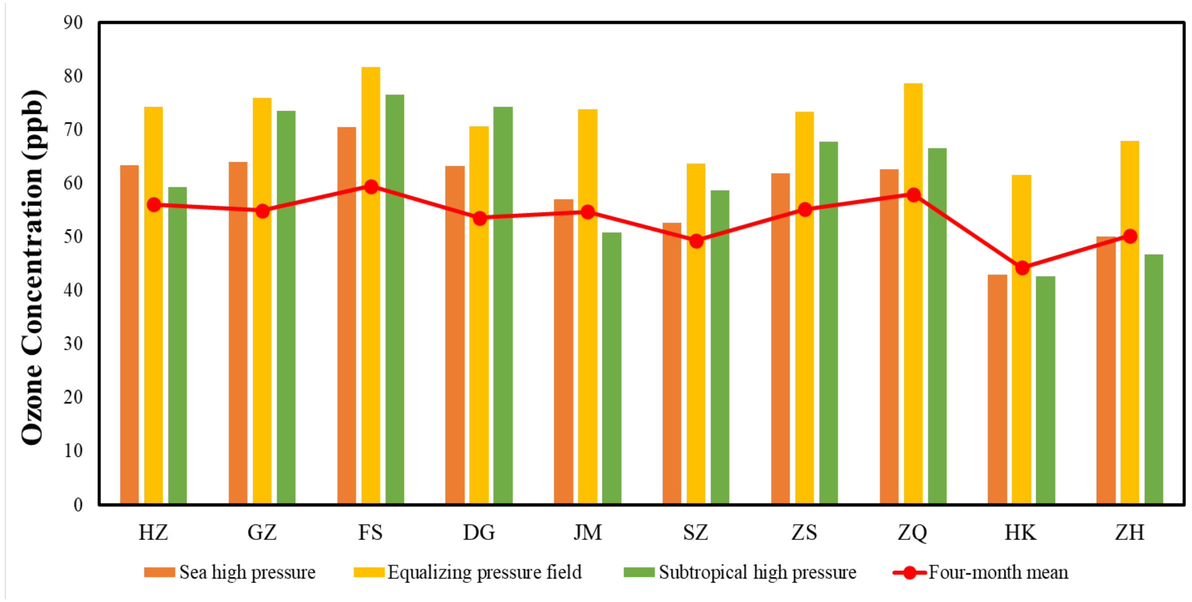


Fig. 8. The average O_3-8h concentrations under three synoptics patterns and four-month average concentrations of different cities in the PRD region (Units: ppb)

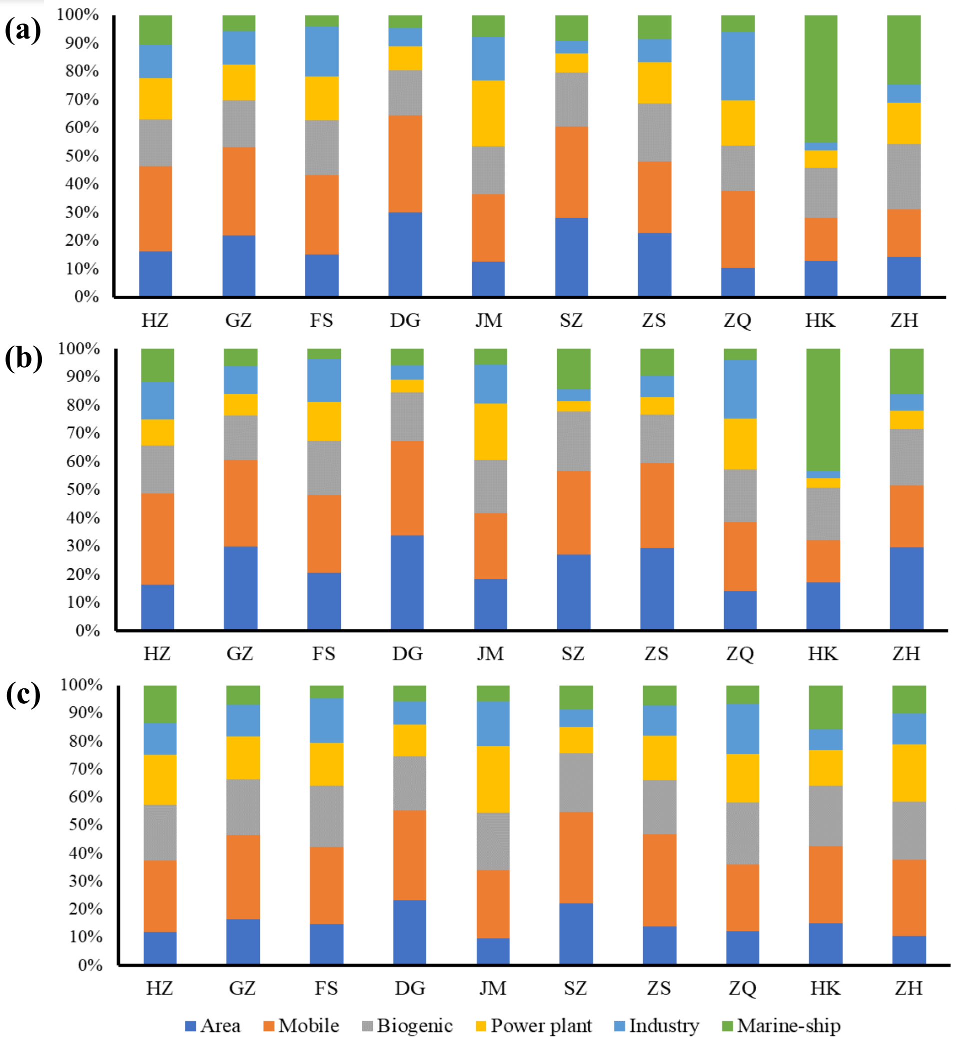


Fig. 9. Source categories' contributions to O_3 in the PRD region under (a)sea high pressure, (b)equalizing pressure field, and (c)subtropical high pressure.

Local, Regional and Superregional contribution

- Three types of source regions are defined
  1. **Local sources:** from a local city
  2. **Regional transport:** from another city within the PRD region
  3. **Superregional transport:** from outside the PRD region
- O_3 had more obvious changes in the high concentration period under different synoptic patterns.
- In the equalizing pressure field, the contribution of superregional transport increased by 6.1%.
- With the effect of **the subtropical high pressure**, the **local contribution increased significantly**, especially in JM (+8.8%) and SZ (+7.3%).

Table. 2. Variations in local, regional, superregional O_3 contribution compared with monthly contributions in 10 cities over the PRD region under sea high pressure, equalizing pressure, and subtropical high pressure synoptic patterns. High conc and low conc represent O_3 daily maximum 8-hour average concentration and other hour average concentration.

			HZ	GZ	FS	DG	JM	SZ	ZS	ZQ	HK	ZH
Sea high pressure	High conc.	Local	1.8%	4.3%	5.7%	4.2%	4.6%	5.3%	3.0%	2.6%	1.7%	2.8%
		Regional	7.6%	7.7%	4.6%	8.8%	-0.5%	1.8%	3.4%	3.2%	-2.2%	-5.3%
		S-Regional	-9.4%	-12.0%	-10.2%	-13.0%	-4.1%	-7.2%	-6.4%	-5.8%	0.5%	2.5%
	Low conc.	Local	0.7%	1.2%	0.6%	1.0%	0.6%	0.6%	0.3%	0.1%	0.6%	0.4%
		Regional	5.0%	5.3%	6.1%	5.8%	3.7%	3.7%	3.9%	4.0%	3.6%	3.7%
		S-Regional	-5.7%	-6.5%	-6.8%	-6.8%	-4.3%	-4.2%	-4.2%	-4.2%	-4.2%	-4.1%
Equalizing pressure field	High conc.	Local	-1.7%	-2.8%	-1.8%	-3.7%	-3.0%	-3.9%	-1.6%	-1.7%	-0.6%	-1.5%
		Regional	-4.8%	-0.8%	-2.8%	-4.7%	-6.6%	-3.8%	-8.0%	-2.2%	-1.0%	-4.2%
		S-Regional	6.5%	3.6%	4.6%	8.4%	9.6%	7.7%	9.6%	4.0%	1.6%	5.7%
	Low conc.	Local	-0.5%	-0.3%	-0.1%	-0.2%	-0.3%	-0.2%	0.0%	-0.1%	-0.2%	0.0%
		Regional	-1.7%	-1.0%	-1.2%	-1.1%	-2.3%	-2.3%	-2.3%	-2.2%	-1.9%	-1.9%
		S-Regional	2.1%	1.3%	1.3%	1.3%	2.6%	2.5%	2.3%	2.4%	2.1%	2.0%
Sub-tropical high pressure	High conc.	Local	7.0%	5.9%	6.0%	6.3%	8.8%	7.3%	5.5%	2.1%	2.4%	4.7%
		Regional	5.9%	11.3%	10.0%	11.2%	5.3%	9.3%	9.2%	16.1%	12.8%	7.8%
		S-Regional	-12.8%	-17.2%	-16.0%	-17.5%	-14.1%	-16.7%	-14.7%	-18.2%	-15.2%	-12.6%
	Low conc.	Local	5.8%	2.5%	1.1%	2.2%	2.1%	2.3%	0.6%	0.4%	1.6%	1.0%
		Regional	9.1%	14.5%	16.2%	15.5%	12.0%	11.9%	13.7%	13.7%	12.8%	13.5%
		S-Regional	-14.9%	-17.0%	-17.3%	-17.7%	-14.0%	-14.2%	-14.3%	-14.1%	-14.4%	-14.5%

Regional Contributions to Guangzhou and Shenzhen

- DG is an important regional source of GZ and SZ under three synoptic patterns. Under the control of the **subtropical high pressure**, the contributions from DG can **reach 22% and 40%** in GZ and SZ.
- **Mobile source** accounts for more than 20% for the regional transported O_3 **under the sea high pressure and subtropical high pressure**.
- The contribution of **area source** is the most significant in **equalizing pressure case**, which can be up to 25%.

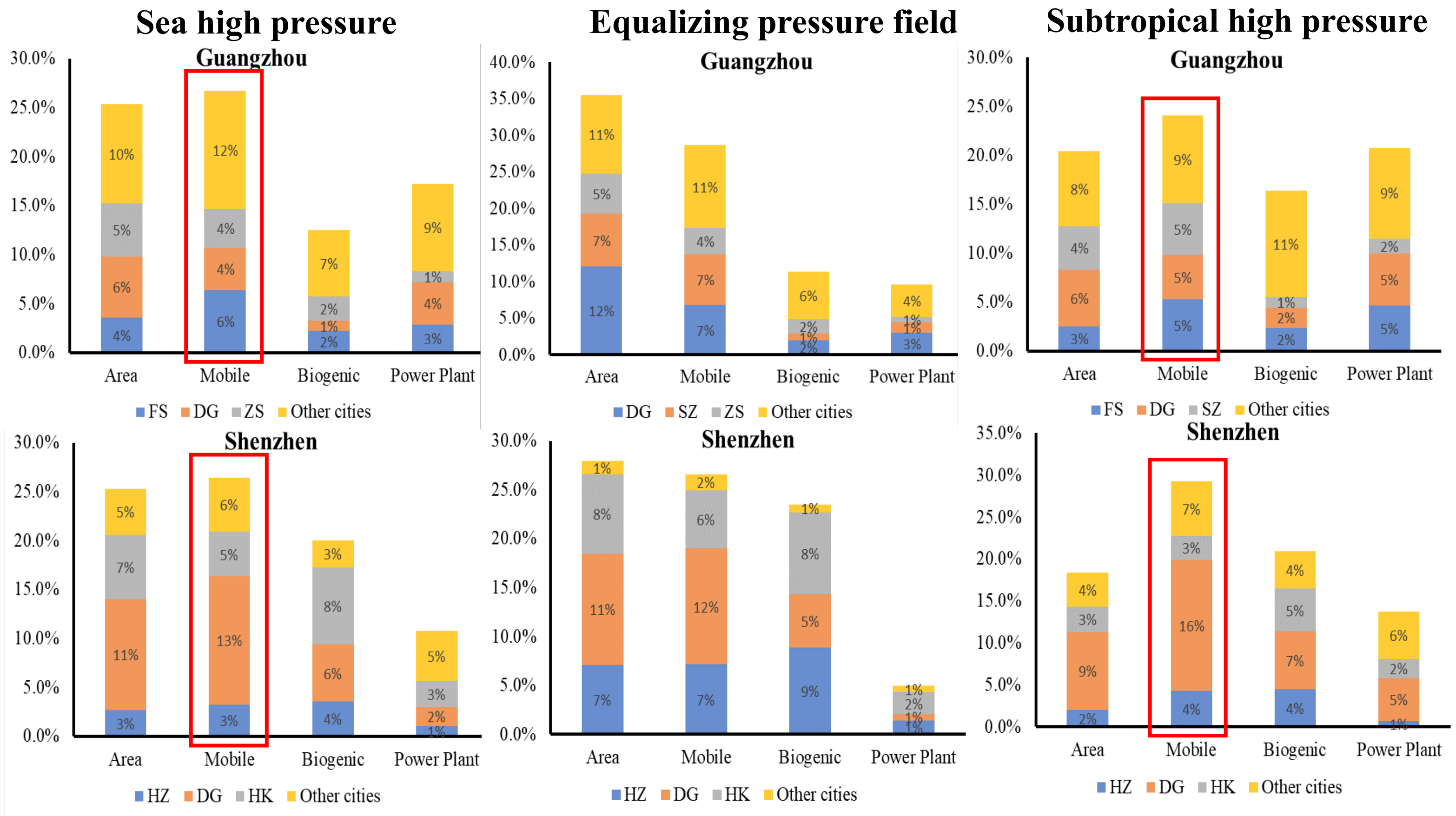


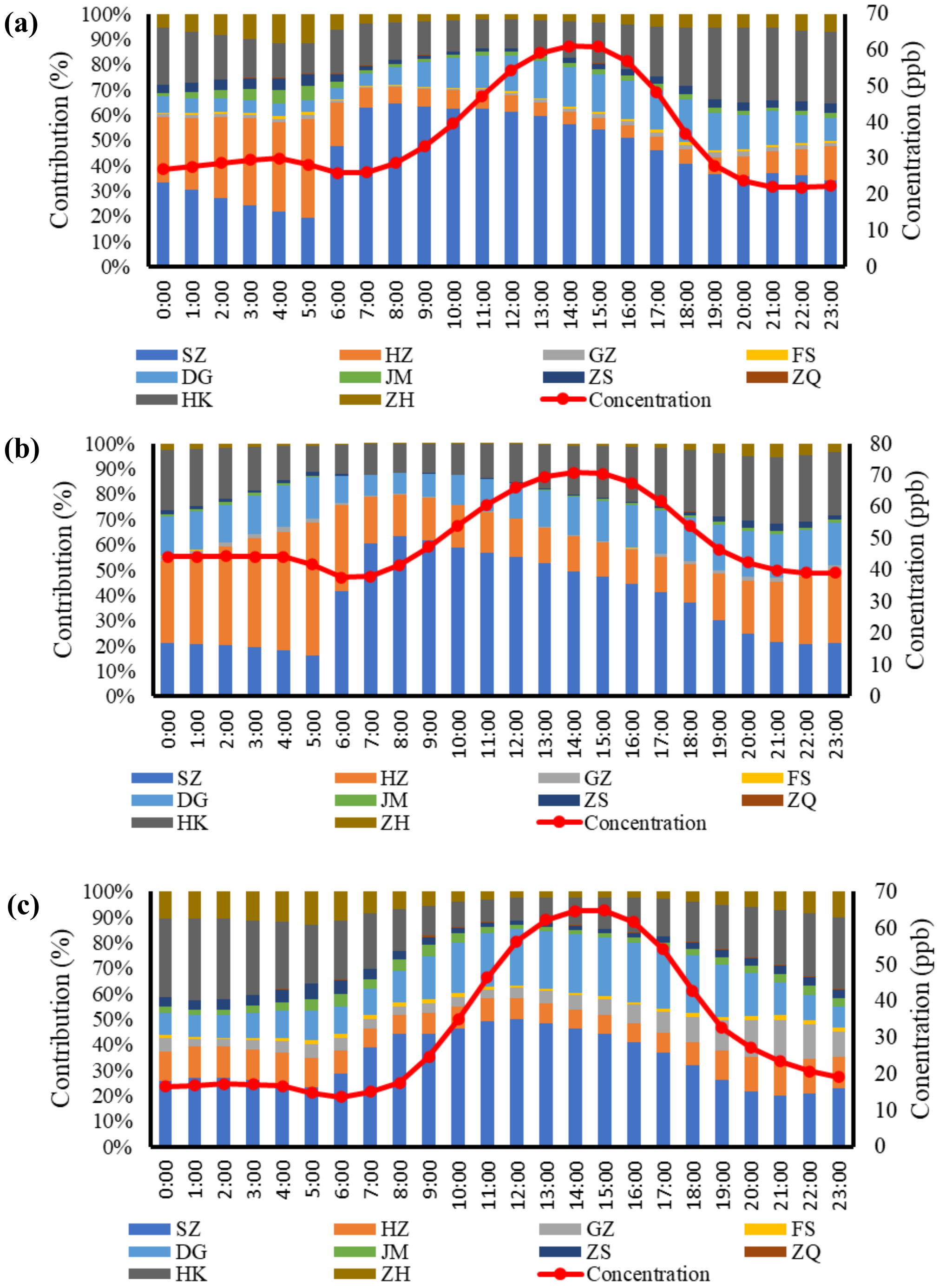
Fig. 10. Regional categories' contributions to Guangzhou and Shenzhen cities in the PRD region under different synoptic patterns. The x-axis is the top-4 regional source categories' contributions. The colored bars represent the top three contributors in neighboring cities for the specific source category. The yellow bar represents the contribution from the rest of the cities.

Table. 3. Regional contributions of O_3-8h from surrounding cities to Guangzhou (GZ) and Shenzhen (SZ) in the PRD region.

	Sea high pressure		Equalizing pressure field		Subtropical high pressure	
	GZ	SZ	GZ	SZ	GZ	SZ
HZ	7.1%	12.1%	0.1%	28.2%	0.2%	13.3%
GZ	-	2.9%	-	0.9%	-	10.5%
FS	17.8%	1.9%	10.9%	0.1%	17.8%	1.9%
DG	20.0%	33.7%	27.4%	30.4%	22.3%	40.9%
JM	13.4%	4.4%	5.4%	1.1%	12.6%	3.5%
SZ	11.3%	-	17.4%	-	13.4%	-
ZS	14.1%	4.5%	12.8%	1.0%	9.0%	3.6%
ZQ	1.1%	0.2%	0.1%	0.0%	1.8%	0.4%
HK	6.4%	32.6%	10.2%	36.3%	8.1%	20.7%
ZH	8.7%	7.8%	6.3%	2.1%	6.8%	5.2%

Diurnal variation in Regional contributions

- The hourly variation of O_3 concentration had similar characteristics with **a single peak** with the maximum in the daytime.
- In the **equalizing pressure field**, the contribution from SZ increased sharply from 5:00 to 8:00. The stable atmospheric stratification near the surface leaded to the **rapid accumulation of O_3 precursors**.
- Under the control of **subtropical high pressure**, the contribution of HZ in nighttime was significantly reduced, which indicates that the weather condition **changes the long-range transport of surface O_3 at night.**



Sea high pressure

Equalizing pressure field

Subtropical high pressure

Fig. 11. Diurnal variation of O_3 concentrations (red lines, units: ppb) and regional contributions to O_3 in Shenzhen city under (a) sea high pressure, (b) equalizing pressure field, and (c) subtropical high pressure.

Conclusion

- The concentration of **ozone increased** under three meteorological conditions.
- Among the six sources in the Pearl River Delta, the contribution of **mobile sources** is outstanding. After the mobile emissions, **biogenic sources** and area sources attribute to the highest contribution under **subtropical high pressure** and sea high pressure.
- In the equalizing pressure field, the contribution of superregional transport increased by 6.1%. With the effect of **the subtropical high pressure**, the **local contribution increased significantly**.
- Our results indicated that **collaborative emission control measures** should be strengthened with the surrounding area. Combined with the meteorological situation, controlling the endogenous emission in the PRD plays a pivotal role in preventing O_3 pollution.

Thank you