THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

Worsening urban ozone pollution in China from 2013 to 2017: The roles of meteorology and anthropogenic emission

Yiming Liu and Tao Wang

Department of Civil and Environmental Engineering

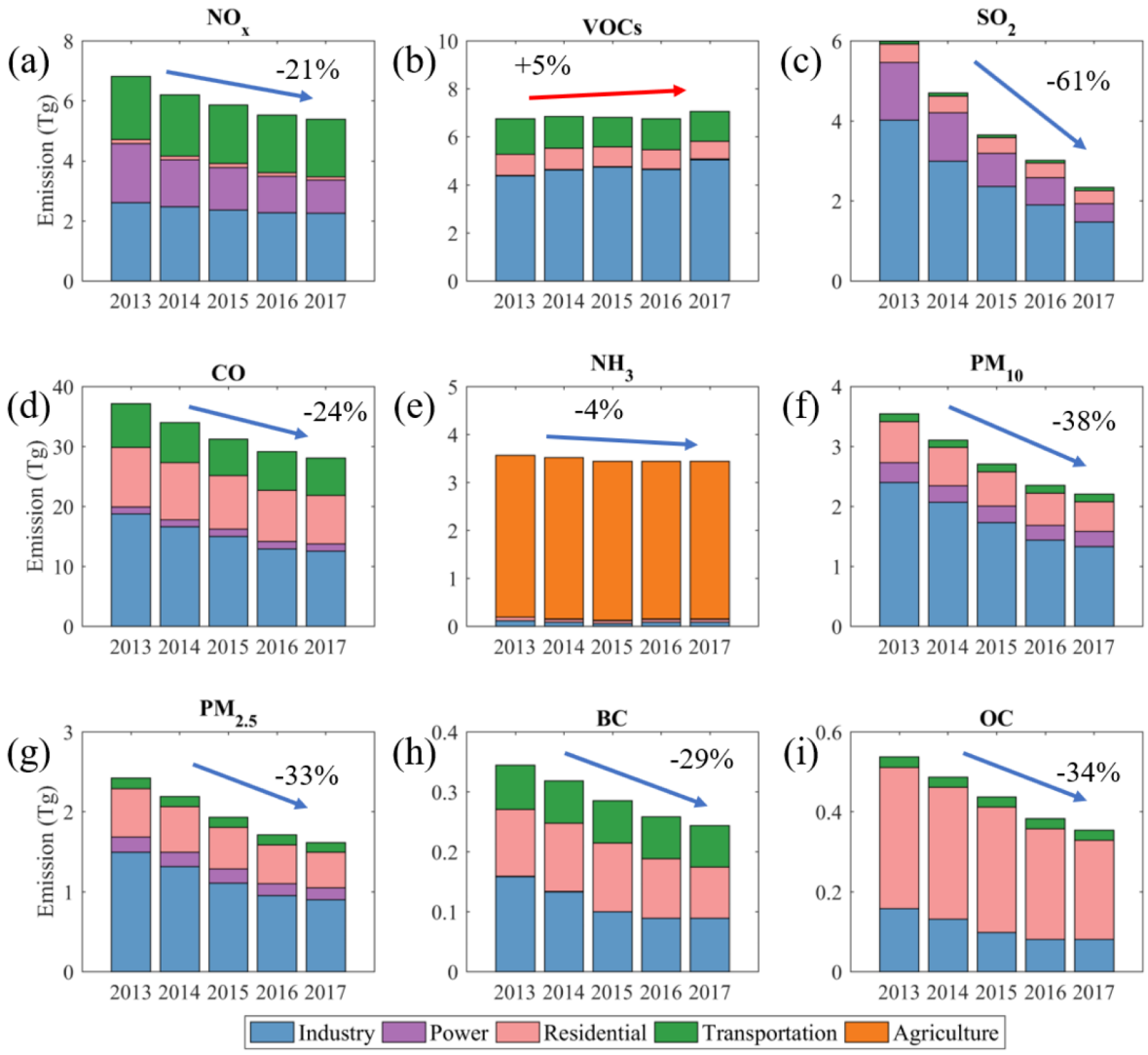
The Hong Kong Polytechnic University

EGU online meeting

07 May 2020

Email: tao.wang@polyu.edu.hk (Tao Wang), yming.liu@polyu.edu.hk (Yiming Liu)

2013-2017 anthropogenic emissions in mainland China

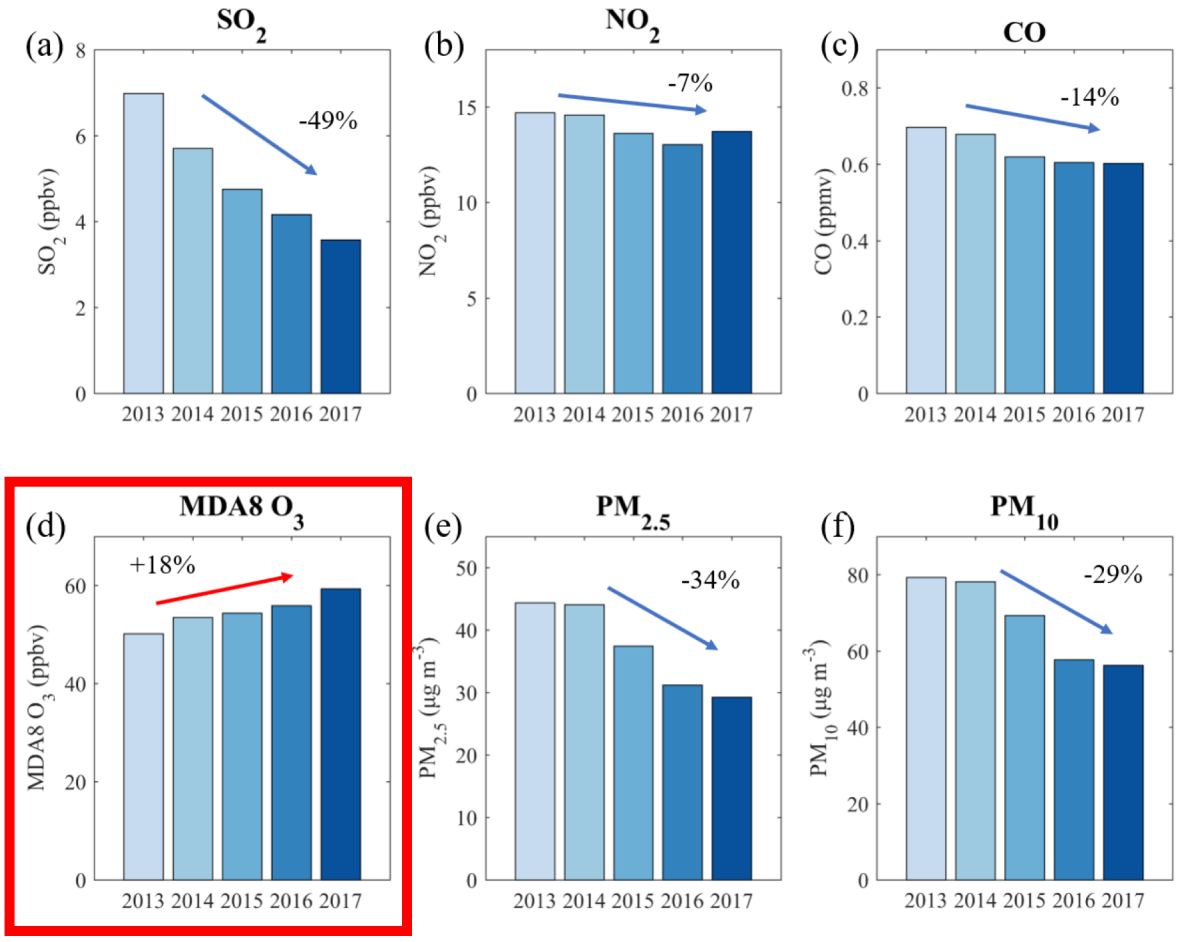


Except for VOCs, the anthropogenic emissions of other species has decreased since 2013.

Data from MEIC (http://www.meicmodel.org/)

Variations of pollutants concentrations in China

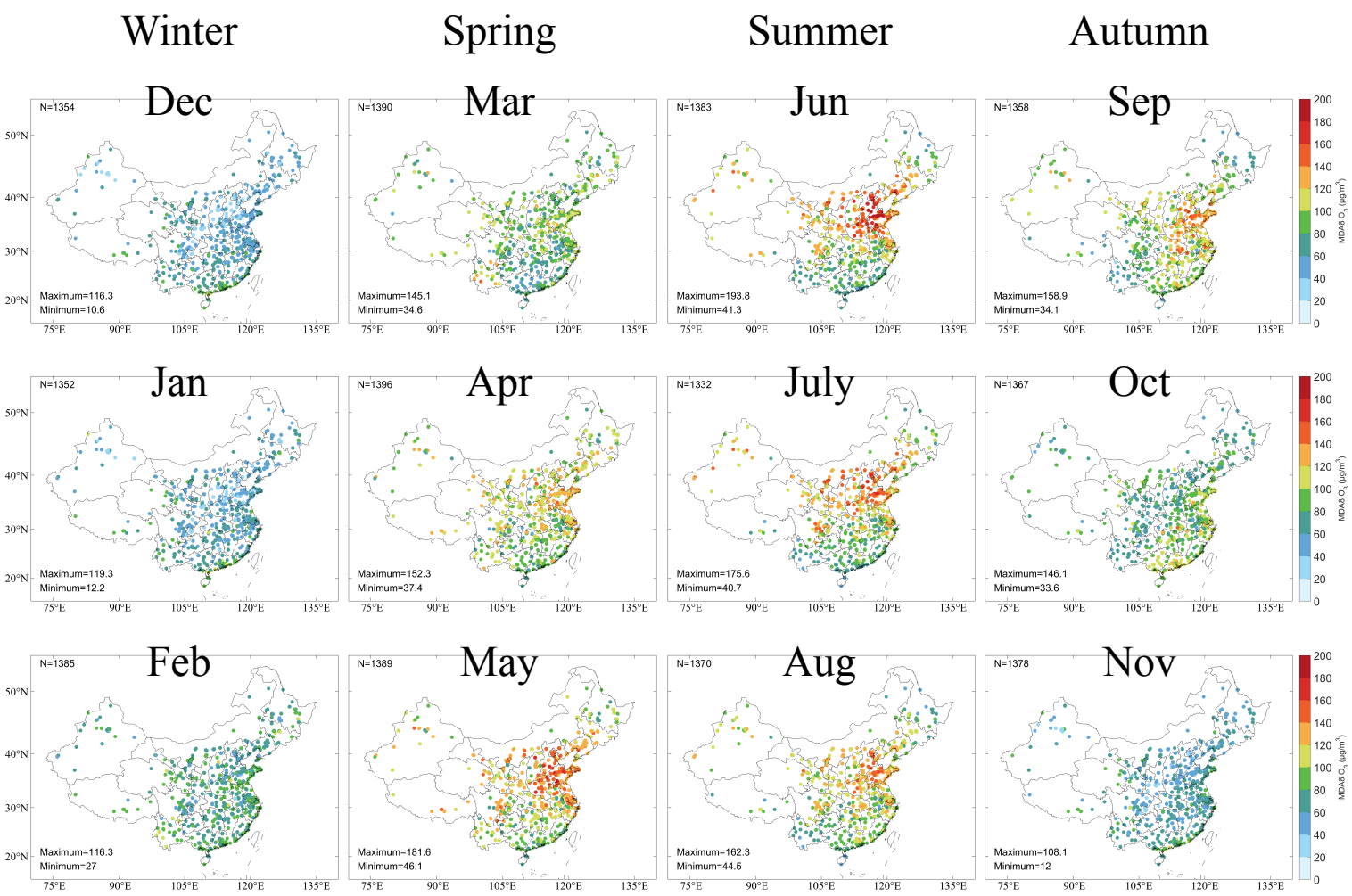
After 2013, primary pollutants concentrations decreased but ozone concentration has been increasing.



74 cities in summer across China

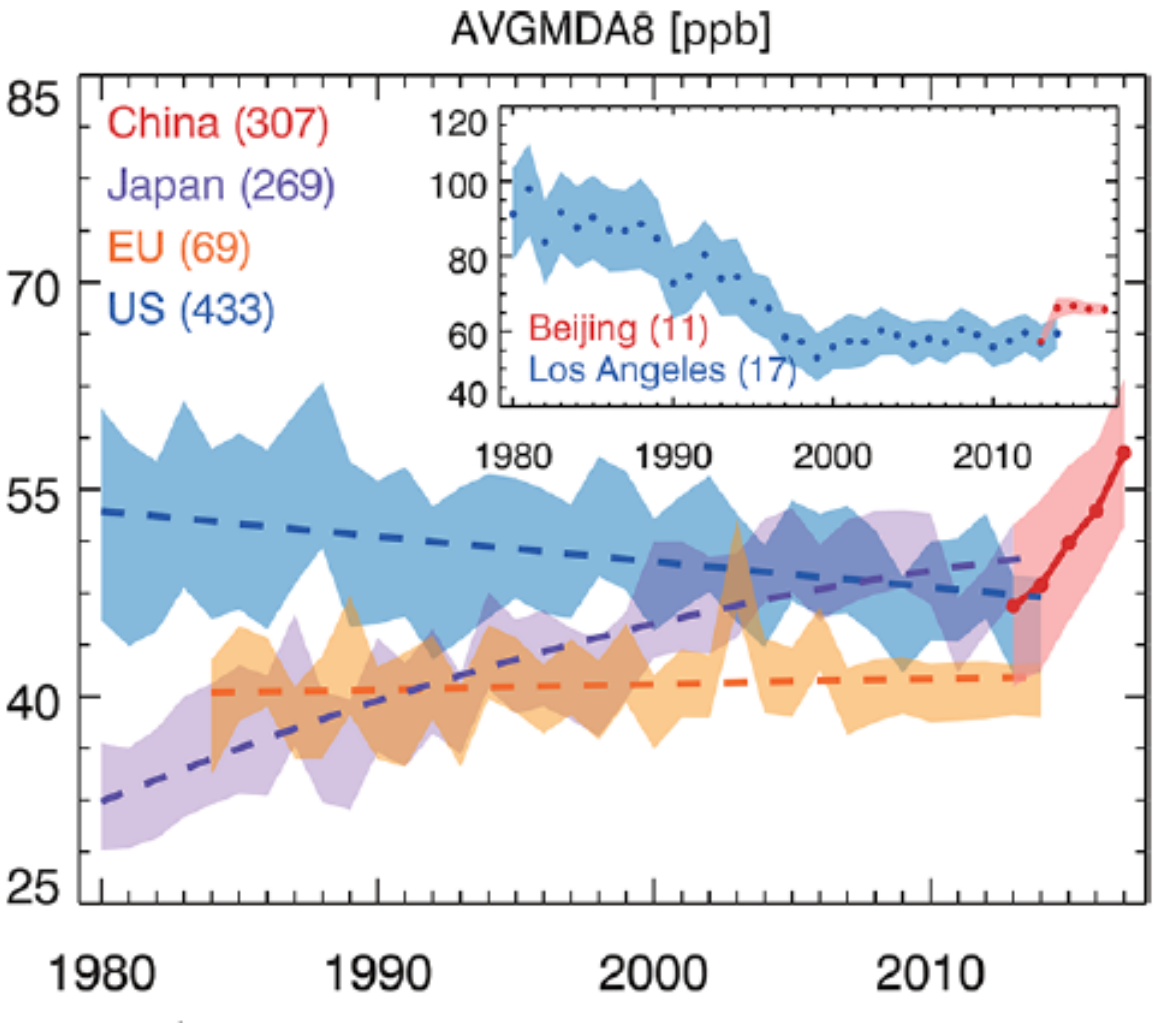
(Data from MEE)

Observed MDA8 O_3 concentration in each month



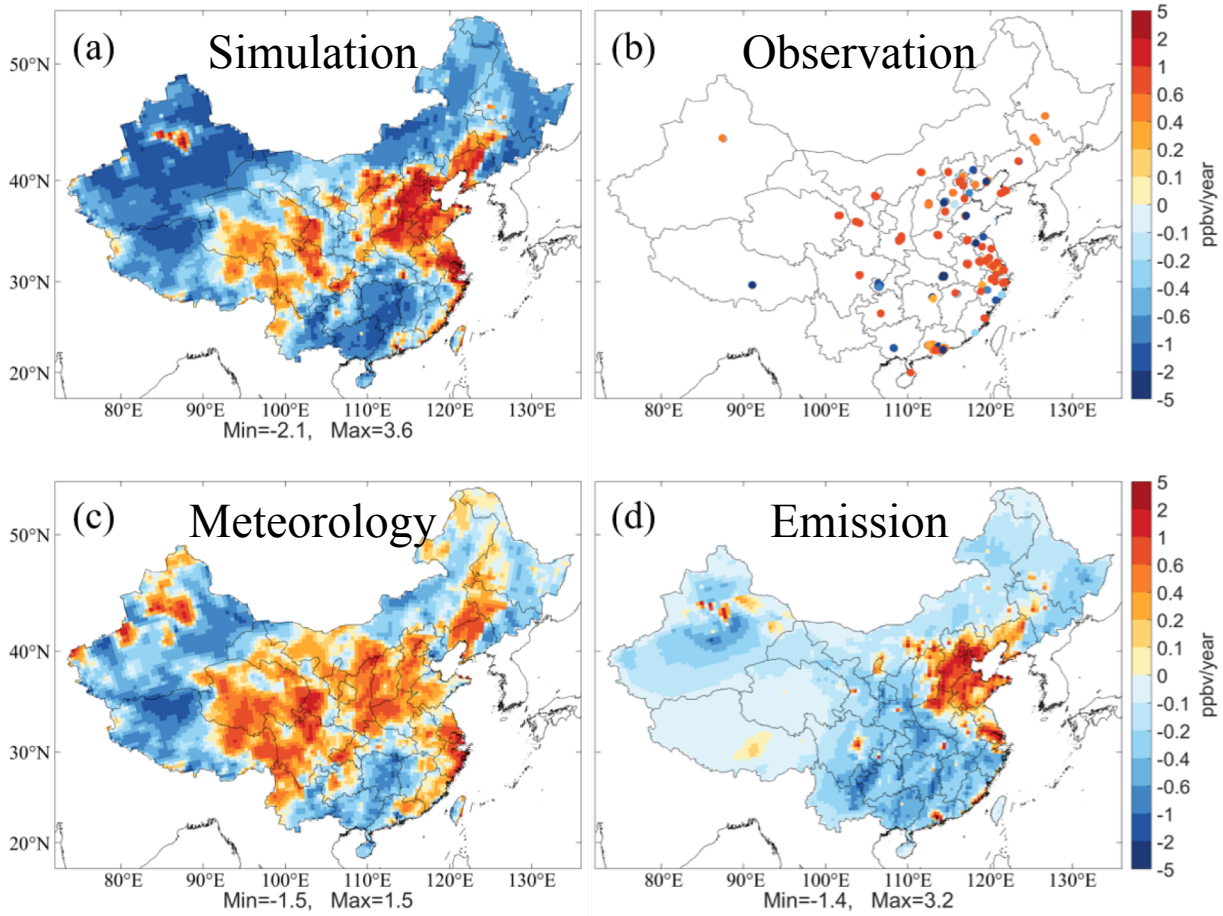
Averaged during 2013-2017

Decrease in Europe and U.S. but increase in China



(Lu et al., 2018, ESTL)

Ozone variation due to meteorology and emission



Trends of MDA8 O_3 in summer during 2013-2017

Model: WRF-CMAQ (5.2.1 latest version)

Domain: 36km×36km, 23 layers

Mechanism: SAPRC07TIC, AERO6i

Meteorological initial and boundary conditions: NCEP FNL

Chemical boundary condition: MOZART

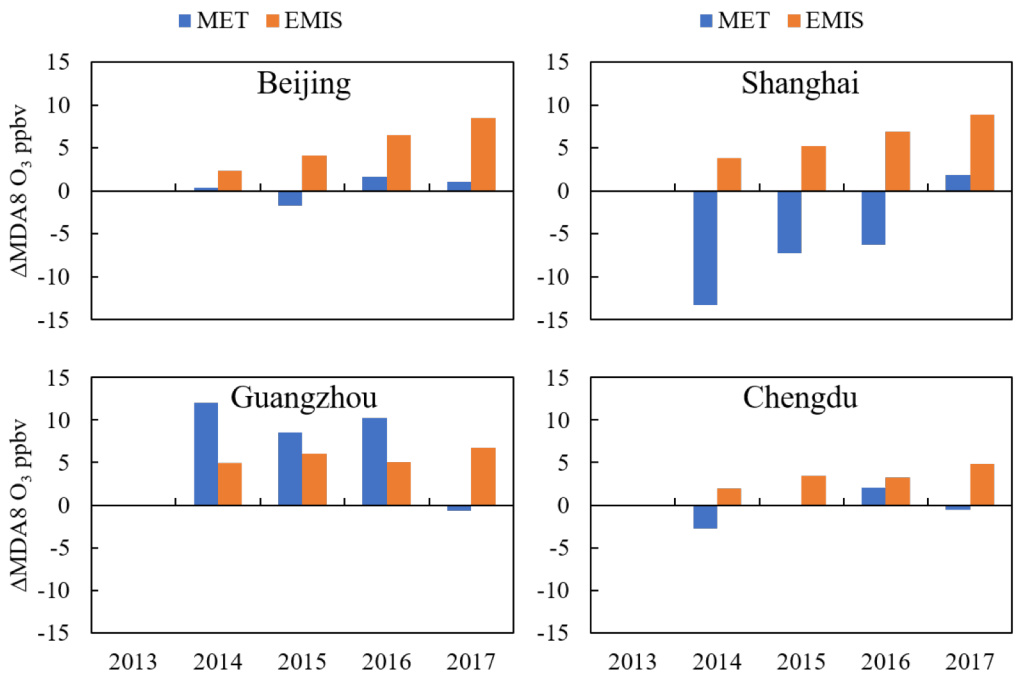
Emission: MEGAN (biogenic emission), MEIC (anthropogenic emission), MIX (outside China), EDGAR (global ship emission)

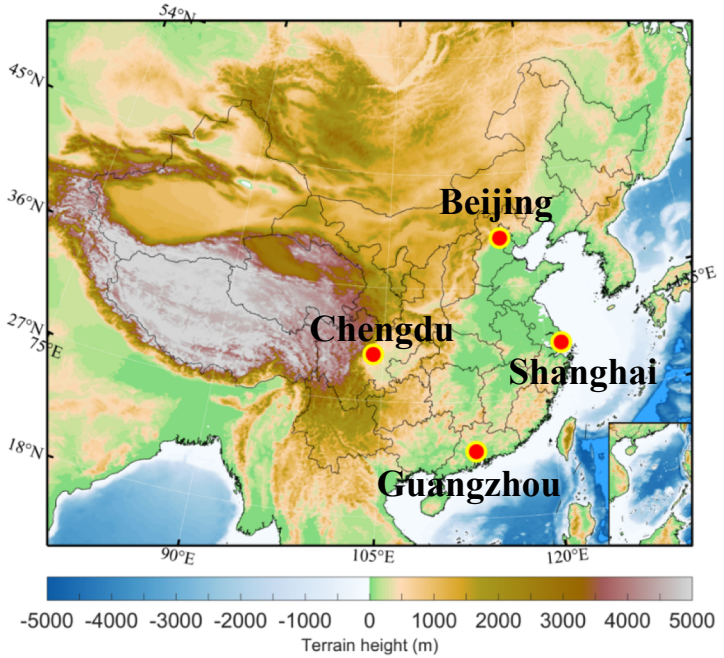
Modeling period: Summer of 2013-2017

- Ozone increase in western and central China due to meteorology variations.
- Ozone increase in NCP due to emission changes.
- Rural ozone deceases due to emission changes.

(Liu and Wang, 2020 @ ACPD)

Changes of MDA8 O_3 compared to 2013

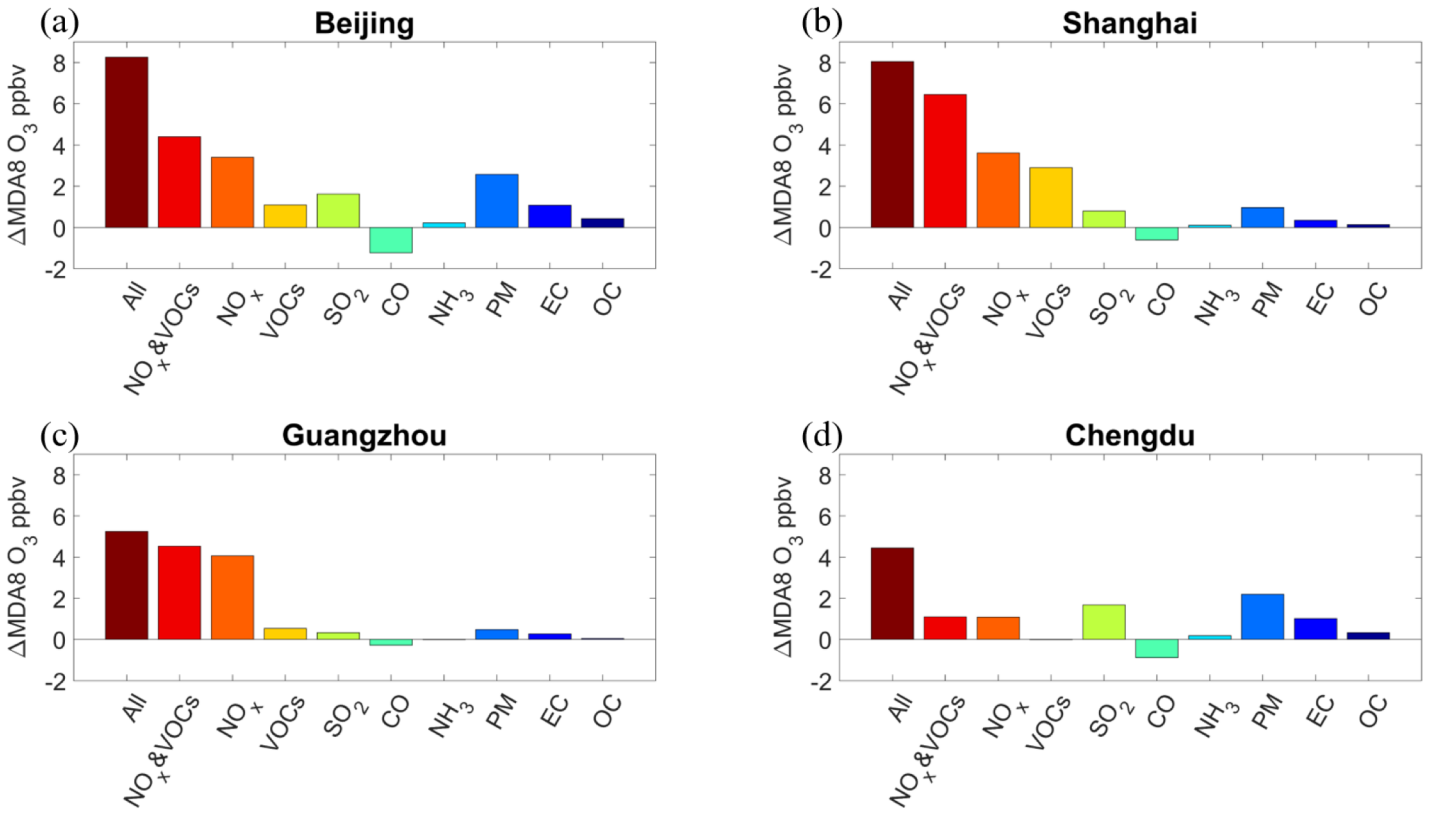




- Meteorological impacts on ozone depend on regions and years.
- Emission impacts shows a nearly linear increasing trend.

(Liu and Wang, 2020 @ ACPD)

Response of MDA8 O_3 to changes in emissions



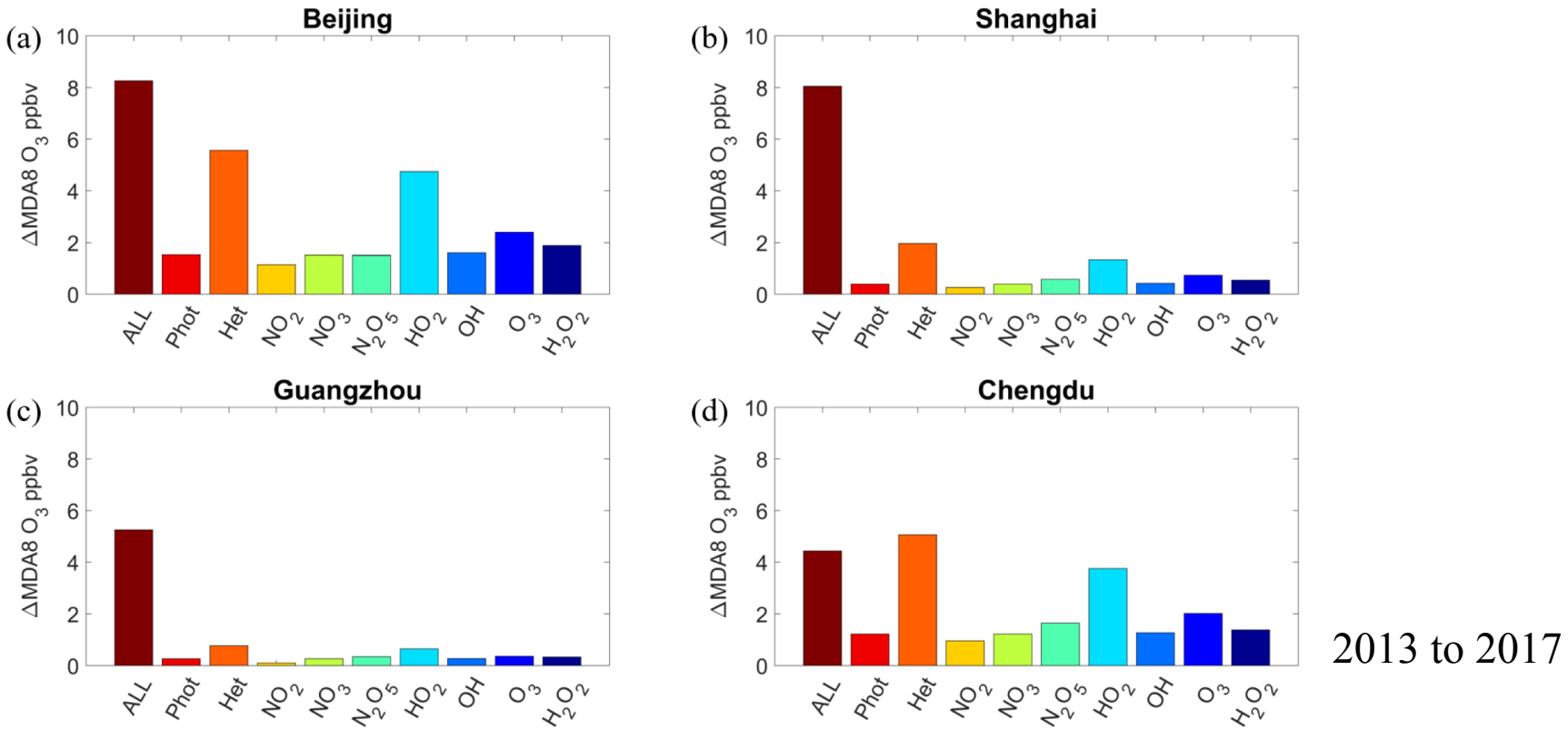
2013 to 2017

- Reduction of NO_x emission contributes the greatest to the increasing ozone among all the emitted species.

- Reduction of CO emission helps decrease ozone while reduction of SO_2 emission increase ozone through aerosol impact.

(Liu and Wang, 2020 @ ACPD)

Response of MDA8 O_3 to changes of aerosol effect



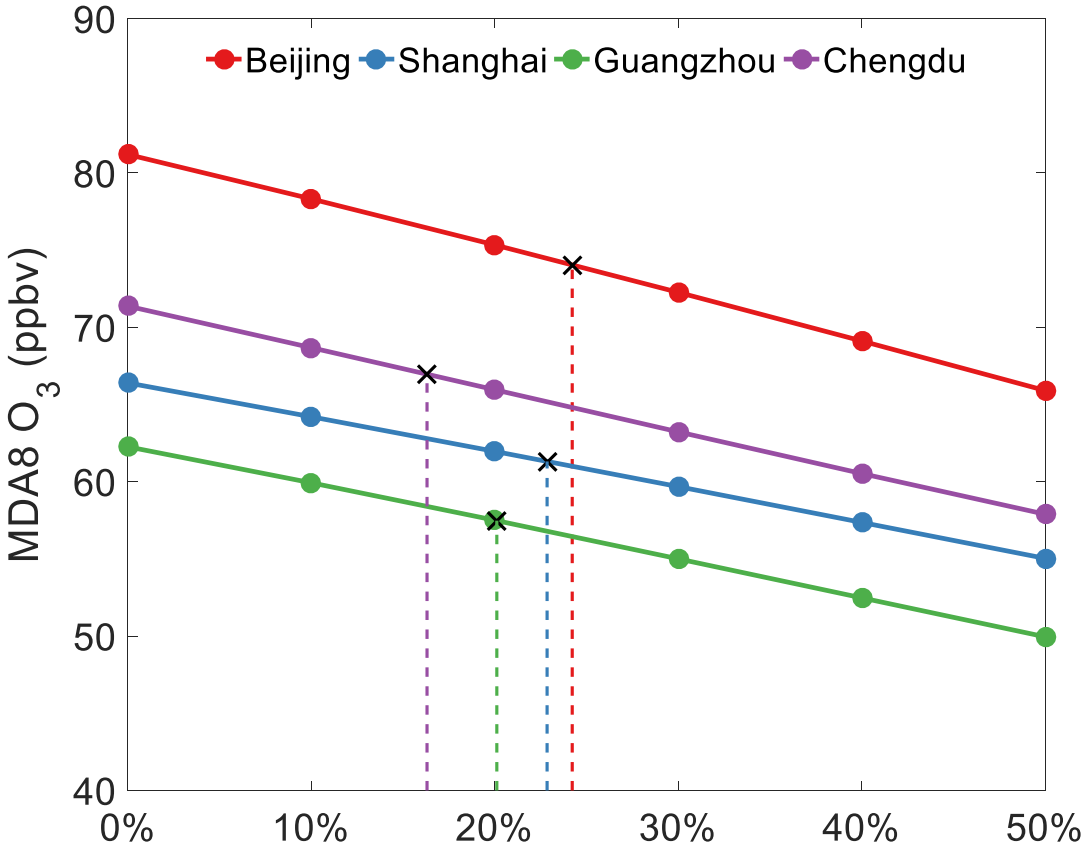
2013 to 2017

- HO_2 and O_3 are two of the most important species among all the gases untaken on aerosol surfaces.

(Liu and Wang, 2020 @ ACPD)

"All" is the change due to anthropogenic emission (all species). "Het" is the change due to all heterogeneous reactions.

Reduction of anthropogenic VOCs emissions

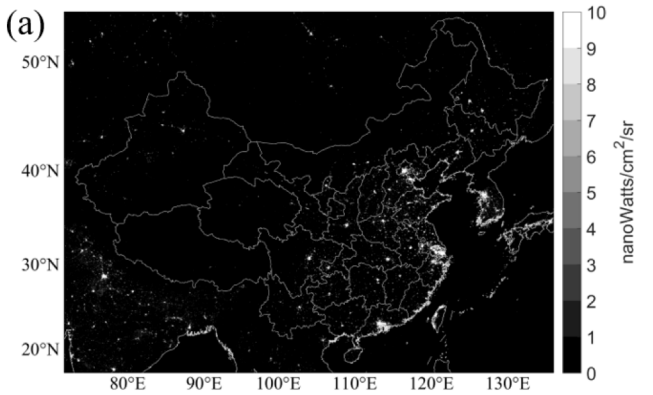


- To overcome the adverse effect of reduction in anthropogenic NO_x, SO_2 and PM on urban ozone, reduction of anthropogenic VOCs emission by ~20% from 2013 to 2017 is required.

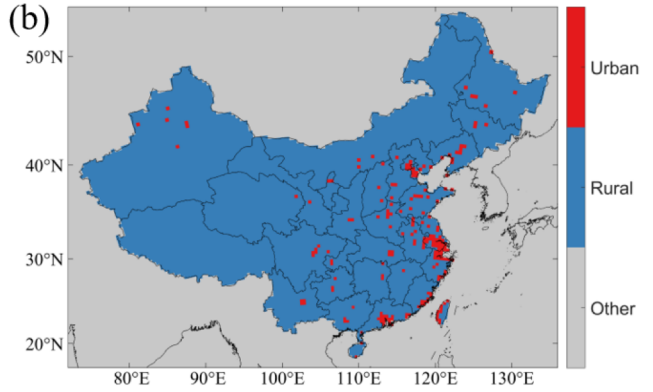
(Liu and Wang, 2020 @ ACPD)

But rural ozone has a different picture – decreasing

Nighttime light data

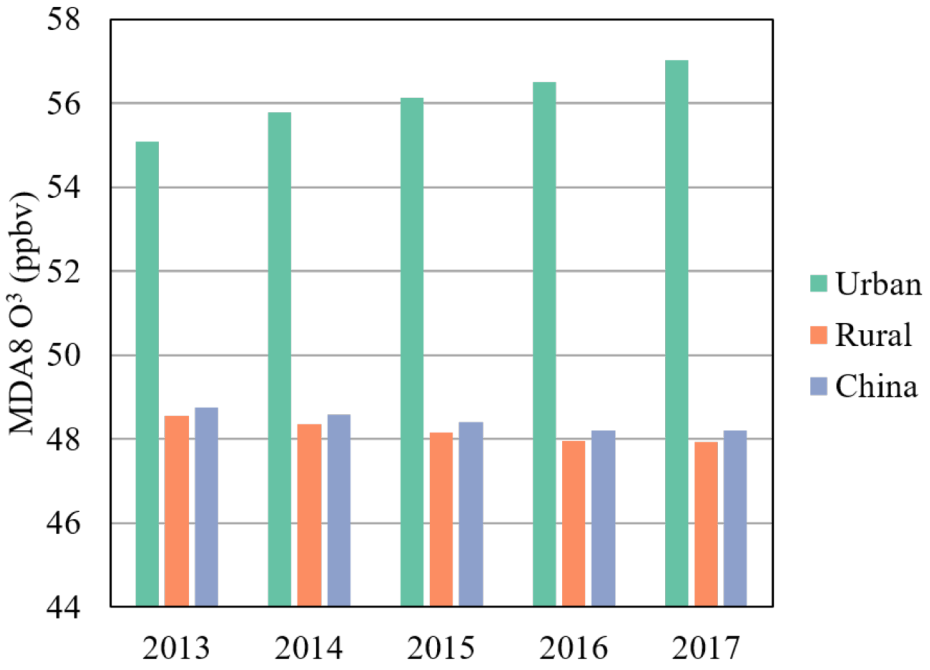


Urban & Rural



We average the gridded model results:

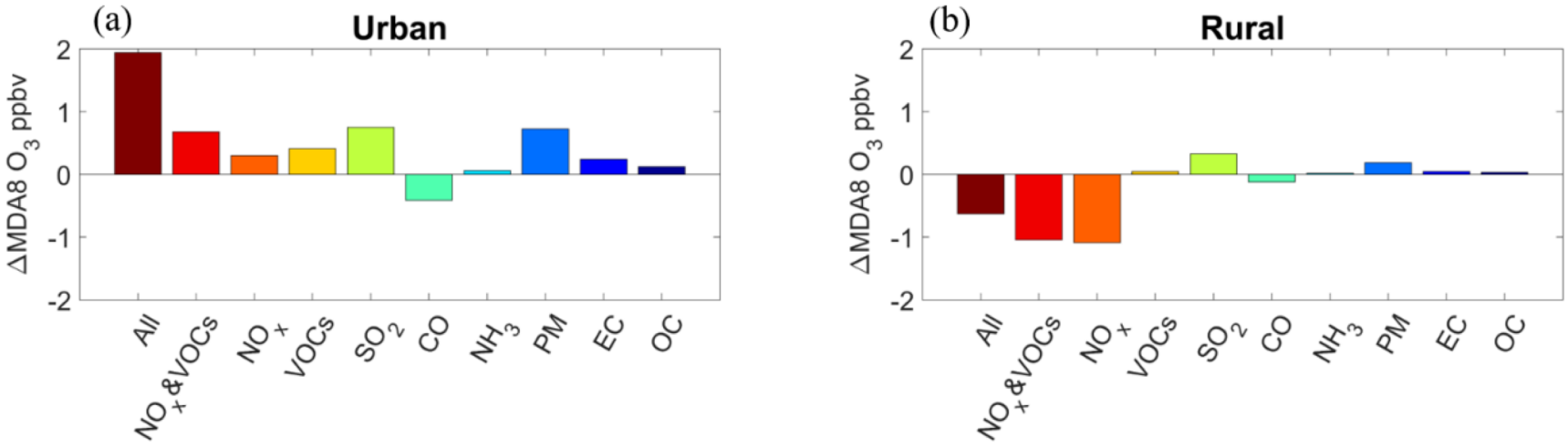
- An increase (~0.4 ppb a^{-1}) in urban areas
- A slight decrease (~-0.1 ppb a^{-1}) in rural areas.



Nighttime data from NOAA/NCEI (https://www.ngdc.noaa.gov/eog/viirs/download_dnb_composites.html) (Liu and Wang, 2020 @ ACPD)

Response of MDA8 O_3 to changes in emissions (Urban and rural)

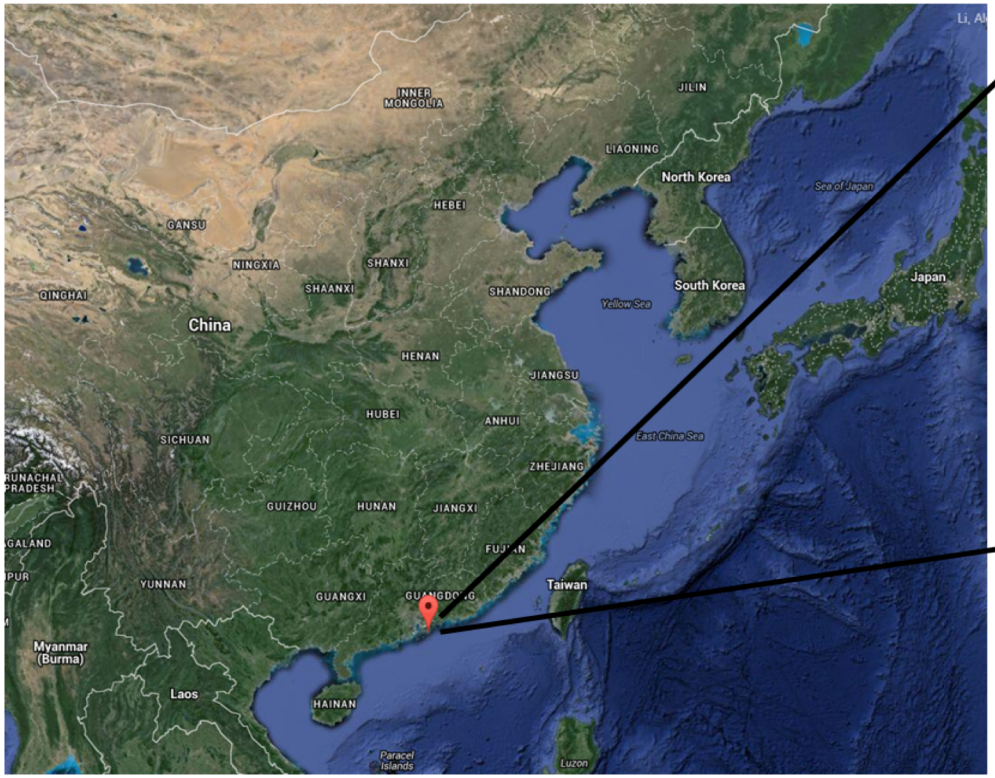
2013 to 2017



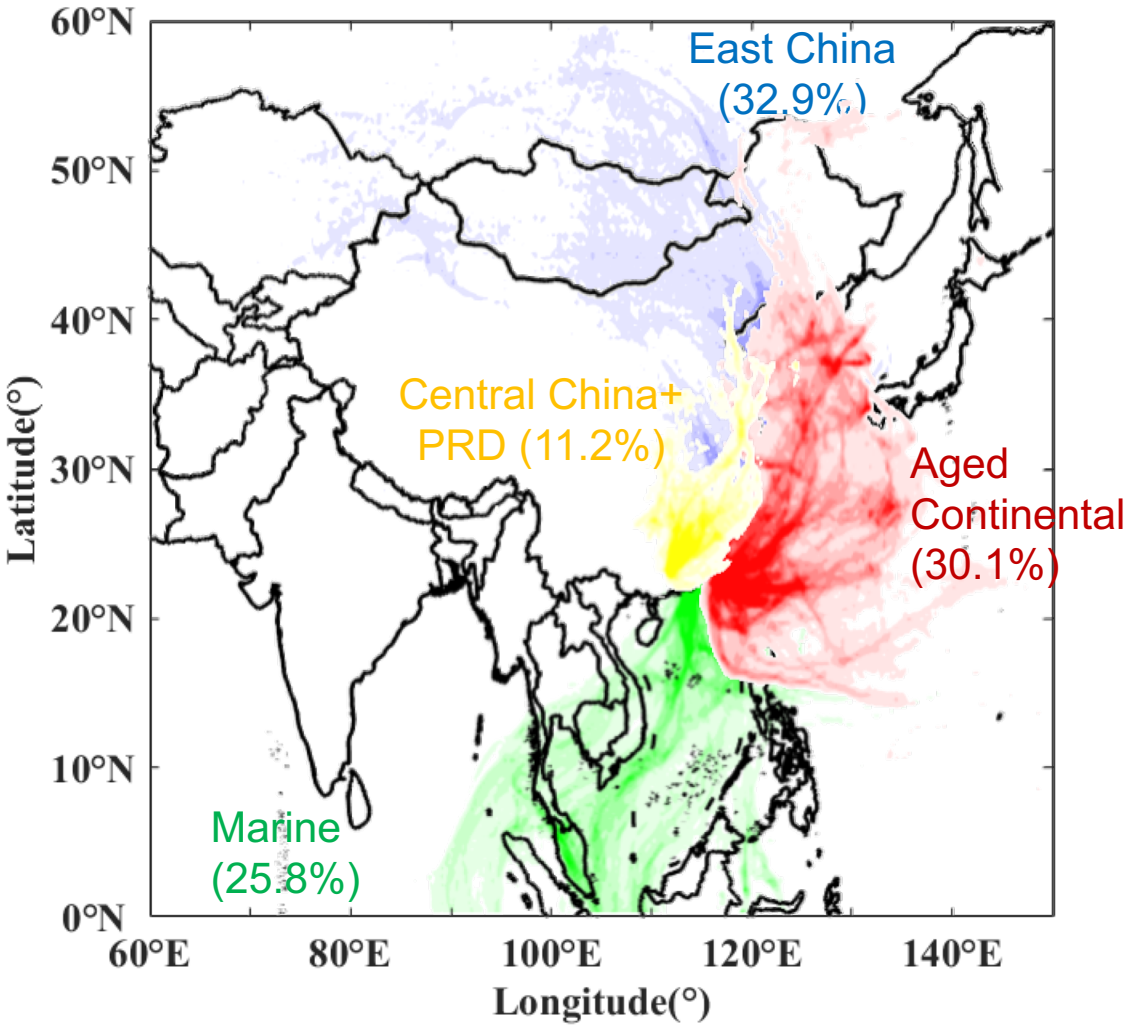
- NO_x emission reduction induced an increase of urban ozone but a decrease of rural ozone.

(Liu and Wang, 2020 @ ACPD)

HK PolyU measured surface ozone and CO since 1994 at coastal site in Hong Kong

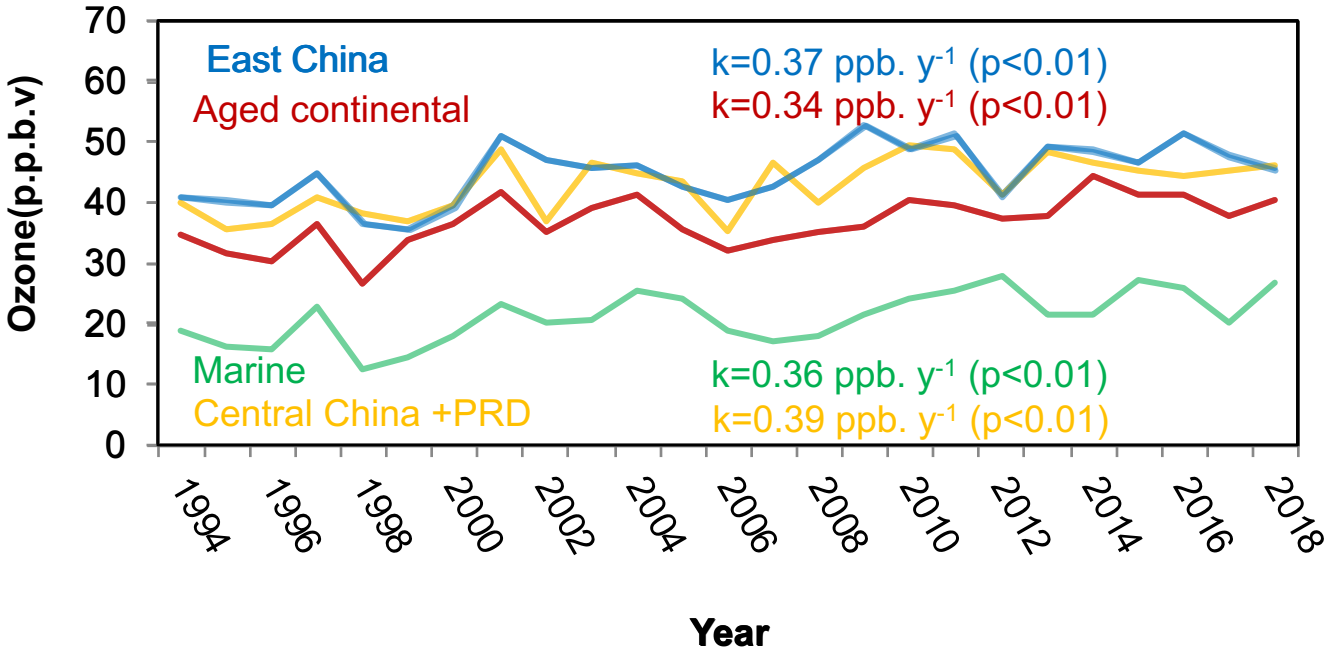


Four major types of air masses



(Wang et al., GRL, 2019)

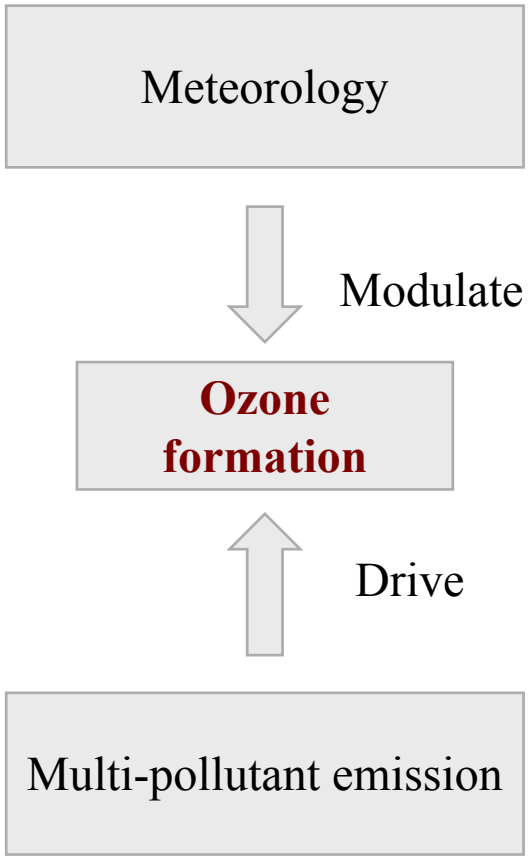
Surface ozone in the four air masses



- 0.64-0.67 ppbv y^{-1} in 'East China' and 'Central China + PRD' air masses in 1994-2007, but no significant change during the recent decade (p=0.83 to 0.85)
- Effect of NOx emission redcutions in China mainland?

(Wang et al., GRL, 2019)

Summary and implications



The meteorological influence on ozone depended on regions and years, and could be comparable with or even larger than the impact of anthropogenic emissions change.
——Meteorology variation should be considered when evaluating the reasons for the changes in ozone concentrations.

The PM targeting emission reductions led to O_3 decreases in rural areas but increases in urban areas. Long-term monitoring at a background site in Hong Kong reveals no obvious trend in surface ozone in outflow from mainland China in the recent decade, perhaps a result from NOx reduction.
——To reduce urban ozone, VOC control should be implemented with the existing policy.

Publication

1. Liu, Y.M., Wang, T.* Worsening urban ozone pollution in China during 2013-2017 — Part 1: The complex and varying roles of meteorology. Atmospheric Chemistry and Physics Discussion, 2020.

2. Liu, Y.M., Wang, T.* Worsening urban ozone pollution in China during 2013-2017 — Part 2: The effects of emission changes and implications for multi-pollutant control. Atmospheric Chemistry and Physics Discussion, 2020.

Acknowledgement

- Hong Kong Research Grant Council
  (Theme-based research T24-504/17-N)
- National Natural Science Foundation of China
  (91844301)

Thank you !

Update of heterogeneous reactions in the model

No.	Heterogeneous reactions	Uptake coefficient (γ) or reaction rate (k)	References
Original CMAQ			
OR1	$N_2O_5(g) + H_2O(cd) + \varphi^a Cl^-(cd) \rightarrow \varphi^a(HNO_3(g) + ClNO_2(g)) + 2(1-\varphi^a)HNO_3(g)$	$\gamma_{N_2O_5} = 3.2\times10^{-8}k'\left(1-\frac{1}{\left(\frac{0.06[H_2O(I)]}{[NO_3^-]}\right)+1+\left(\frac{29[Cl^-]}{[NO_3^-]}\right)}\right)$ [b] $k' = 1.15\times10^6 - 1.15\times10^6 e^{[-0.13\times[H_2O(I)]]}$ [b]	Bertram and Thornton (2009)
OR2	$NO_2(g) \rightarrow 0.5HONO(g) + 0.5HNO_3(g)$	$k_{NO_2} = 5\times10^{-5}\times(S/V)$ S/V = surface to volume ratio	Kurtenbach et al. (2001)
OR3	$NO_3(g) \rightarrow HNO_3(g)$	1.0×10^{-4}	Mao et al. (2013)
Newly updated CMAQ			
NR1	$N_2O_5(g) + H_2O(cd) + \varphi^a Cl^-(cd) \rightarrow \varphi^a(HNO_3(g) + ClNO_2(g)) + 2(1-\varphi^a)HNO_3(g)$	$\gamma_{N_2O_5} = 3.2\times10^{-8}k\left(1-\frac{1}{\left(\frac{0.06[H_2O(I)]}{[NO_3^-]}\right)+1+\left(\frac{29[Cl^-]}{[NO_3^-]}\right)}\right)$ [b] $k = 1.15\times10^6 - 1.15\times10^6 e^{[-0.13\times[H_2O(I)]]}$ [b]	Bertram and Thornton (2009)
NR2	$NO_2(g) \rightarrow 0.5HONO(g) + 0.5HNO_3(g)$	$k_{NO_2} = 5\times10^{-5}\times f_{RH}\times(S/V)$ $f_{RH} = \begin{cases} RH/50 & (RH<50) \\ RH/10-4 & (50\le RH<80) \\ 4 & (RH\ge80) \end{cases}$ $k_{NO_2} = 1\times10^{-3}\times\frac{Light\ intensity}{400}\times(S/V)$ RH = relative humidity S/V = surface to volume ratio	Fu et al. (2019)
NR3	$NO_3(g) \rightarrow HNO_3(g)$	1.0×10^{-3}	Jacob (2000)
NR4	$HO_2(g) \rightarrow 0.5H_2O_2(g)$	2.0×10^{-1}	Jacob (2000)
NR5	$OH(g) \rightarrow$ Products	1.0×10^{-1}	Zhang and Carmichael (1999)
NR6	$O_3(g) \rightarrow$ Products	1.0×10^{-5}	Liao et al. (2004)
NR7	$H_2O_2(g) \rightarrow$ Products	2.0×10^{-3}	Zhu et al. (2010)

Before

Update

[a] The yield of $ClNO_2$. [b] $[H_2O(I)]$, $[NO_3^-]$, $[Cl^-]$ are the concentrations of particle liquid water, particulate nitrate, and particulate chloride, respectively.