

Linking in situ radical observations to pollution production in megacities

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Workshop on a Pilot Design for Air Quality in Africa

June 8, 2021

Sources of air pollution – Engines of economies ...



Need smart regulatory policy based on sound science to improve standards of living while reducing air pollution.

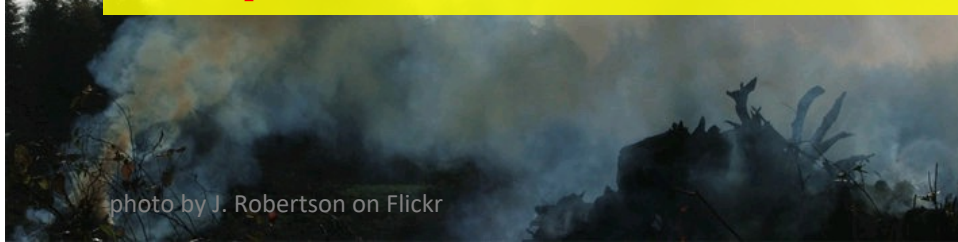
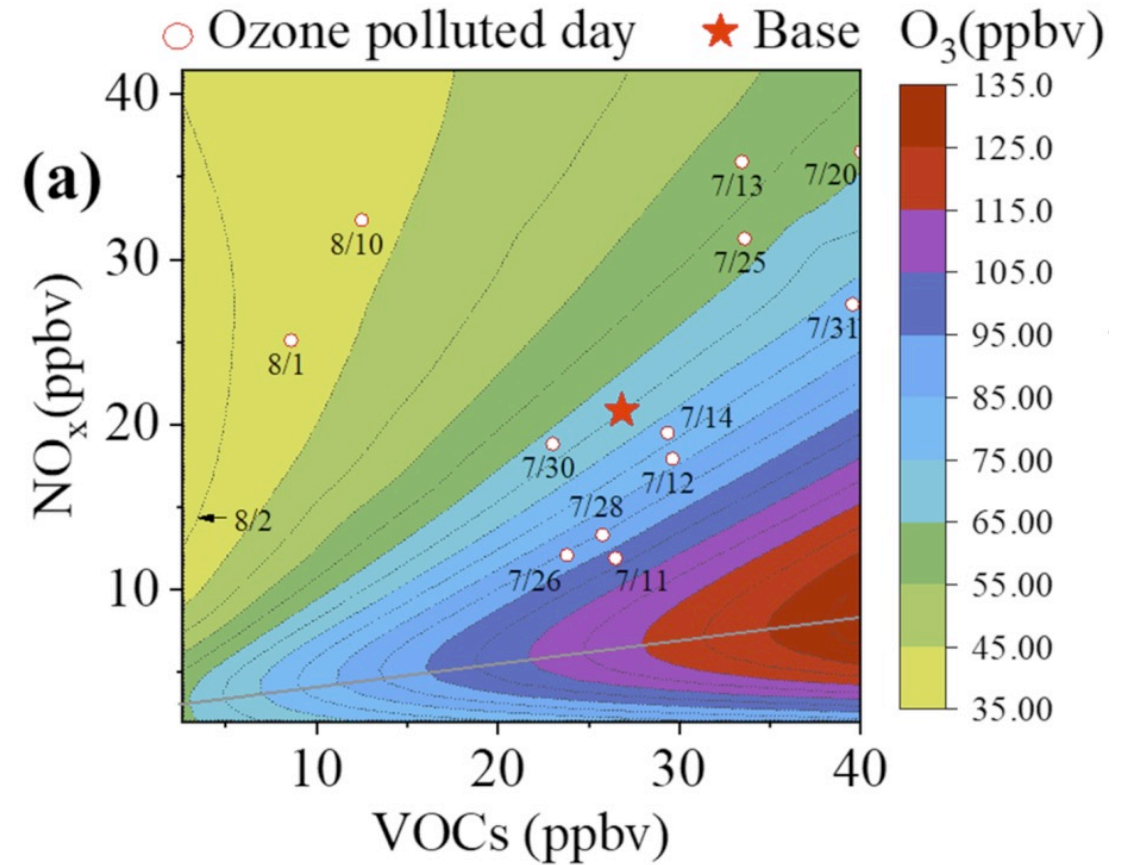
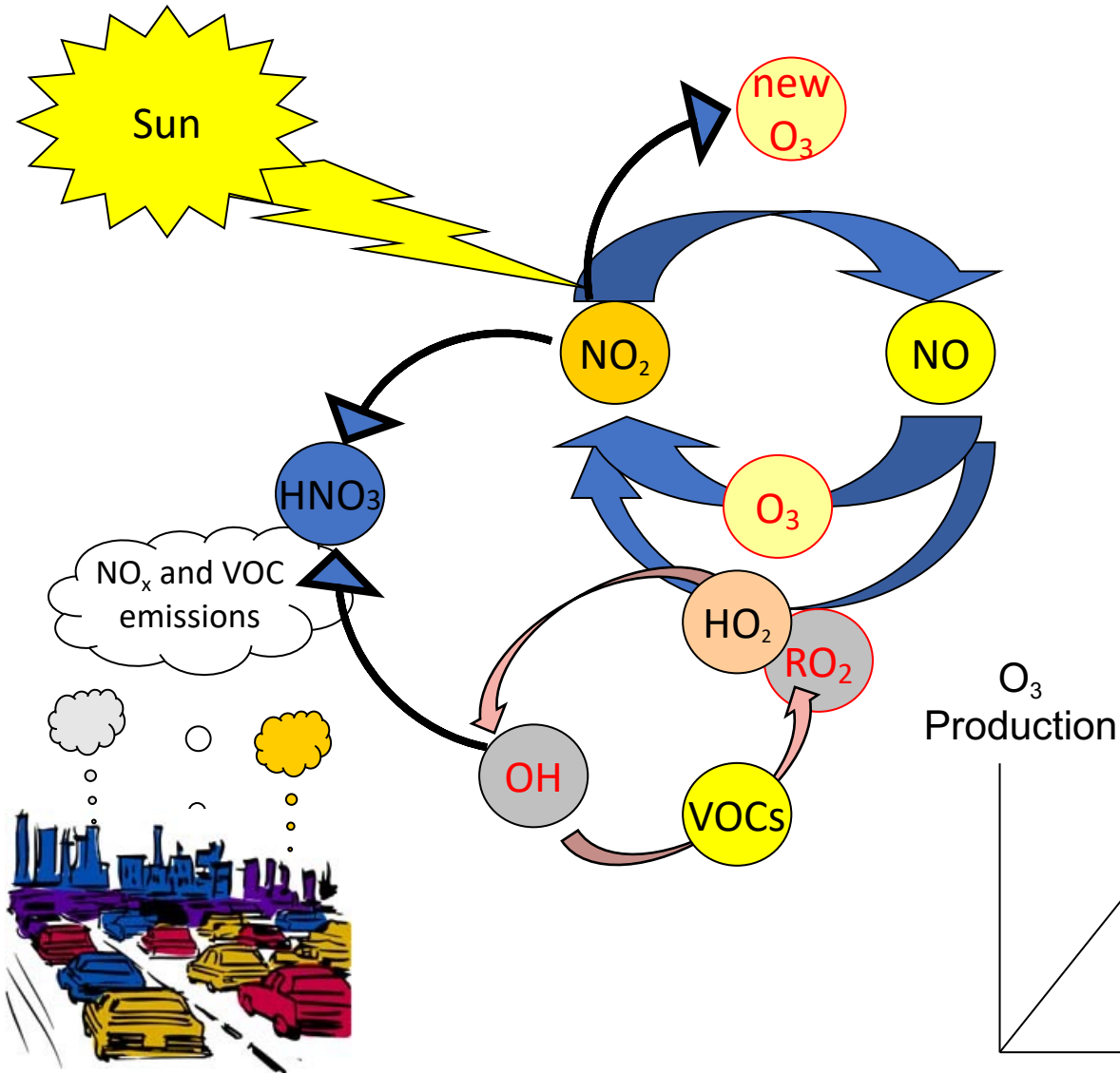


photo by J. Robertson on Flickr

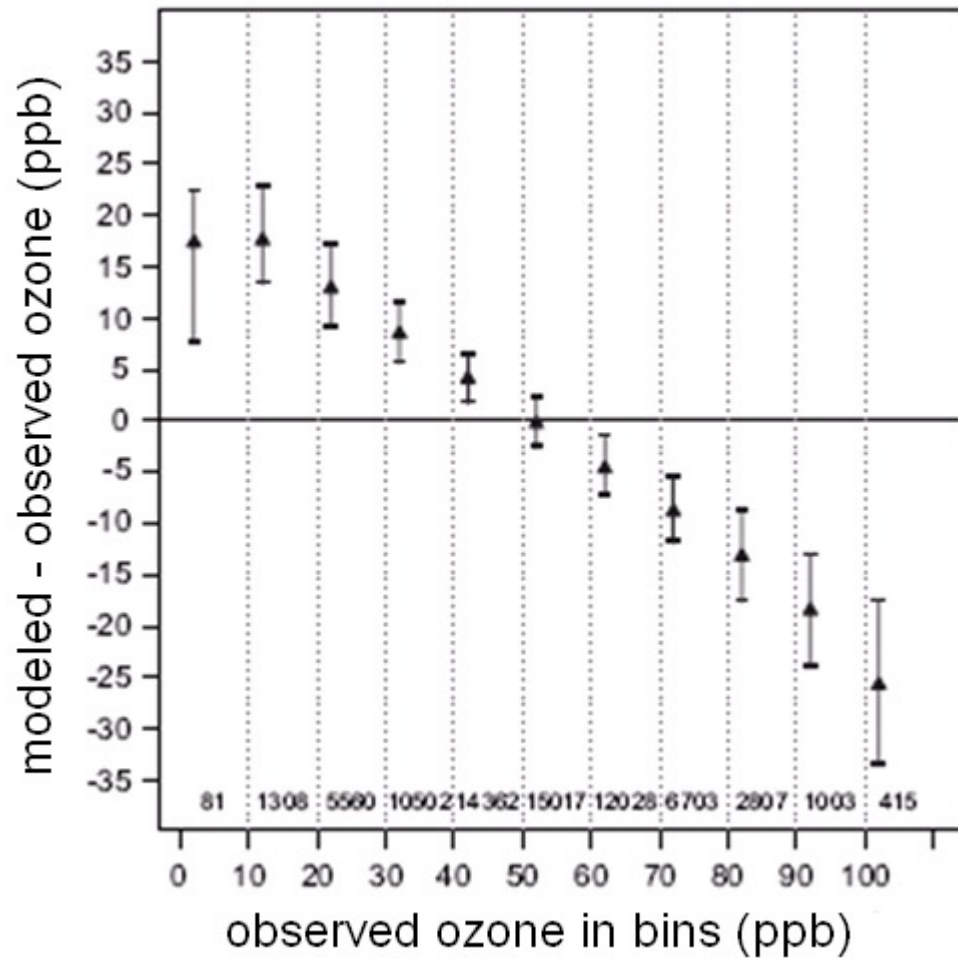


Ozone (O_3) pollution – focus on net production

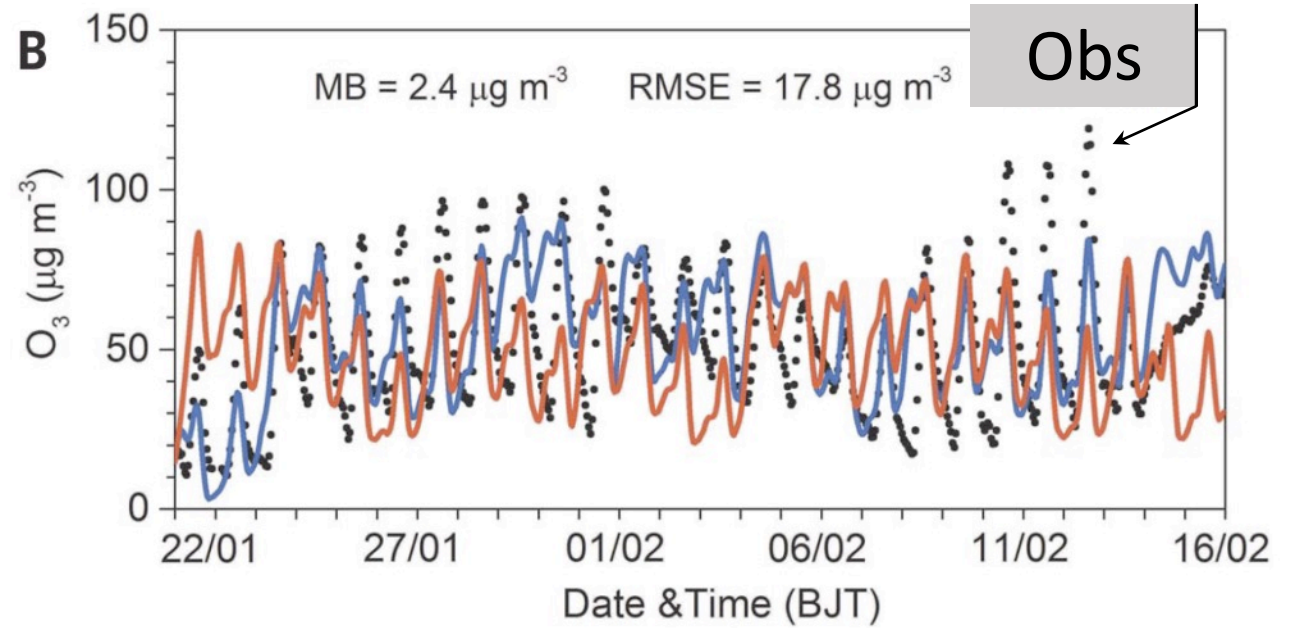


Yin et al., O_3 in Yulin, China, Peerj, 2021

A problem: Most models underpredict unhealthy O₃ levels



Aggregated EPA CMAQ model O₃.
K.W. Appel (NOAA), et al., Atmospheric Environment, 41, 9603–9615, 2007.



WRF-Chem model for Beijing O₃ during the COVID lockdown.
T. Le et al., Science, 369, 702-706, 2020.

What does this underprediction say about model guidance for O₃ mitigation strategies involving NO_x and VOC reduction?

For mitigation, considering O_x ($=O_3+NO_2$) is better than considering O_3 alone.

- O_3 and NO_2 readily adjust to move toward photostationary state equilibrium during the day.

$$[NO_2] = (k_1[NO] + k_2[HO_2 \text{ and } RO_2])[O_3]/J_{NO_2}$$

- Diesel vehicles emit $\sim(20-70)\%$ of their NO_x as NO_2 , and thus are another O_3 source.
- O_3 and NO_2 have similar air quality standards.

US EPA NAAQS Nitrogen Dioxide (NO_2)	primary	1 hour	100 ppb	98th percentile of 1-hour daily maximum concentrations, averaged over 3 years
	primary and secondary	1 year	53 ppb ⁽²⁾	Annual Mean
Ozone (O_3)	primary and secondary	8 hours	0.070 ppm ⁽³⁾	Annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years

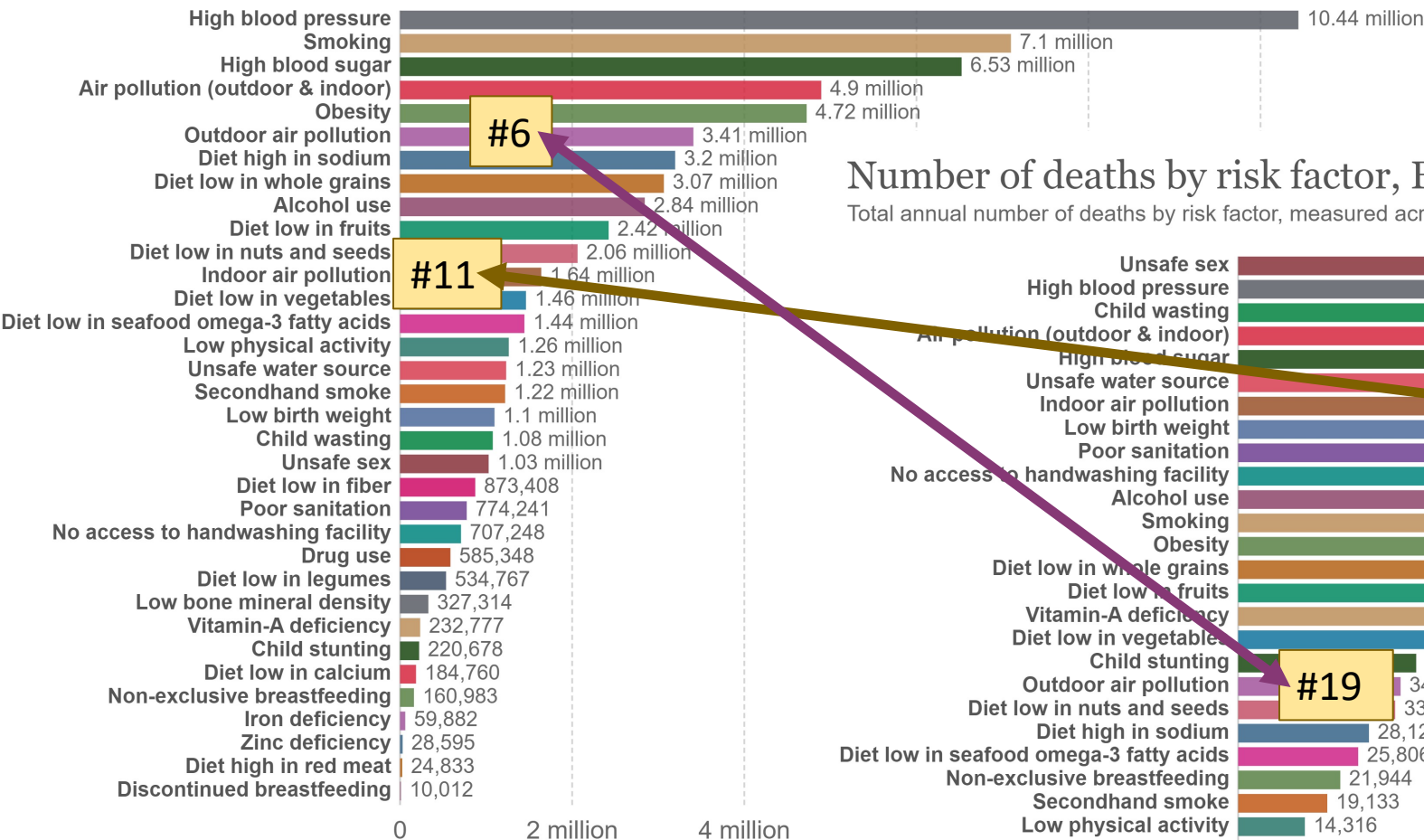
NO_2 also increases $PM_{2.5}$. Need to weigh O_3 and $PM_{2.5}$ risks together.

Number of deaths by risk factor, World, 2017

Total annual number of deaths by risk factor, measured across all age groups and both sexes.



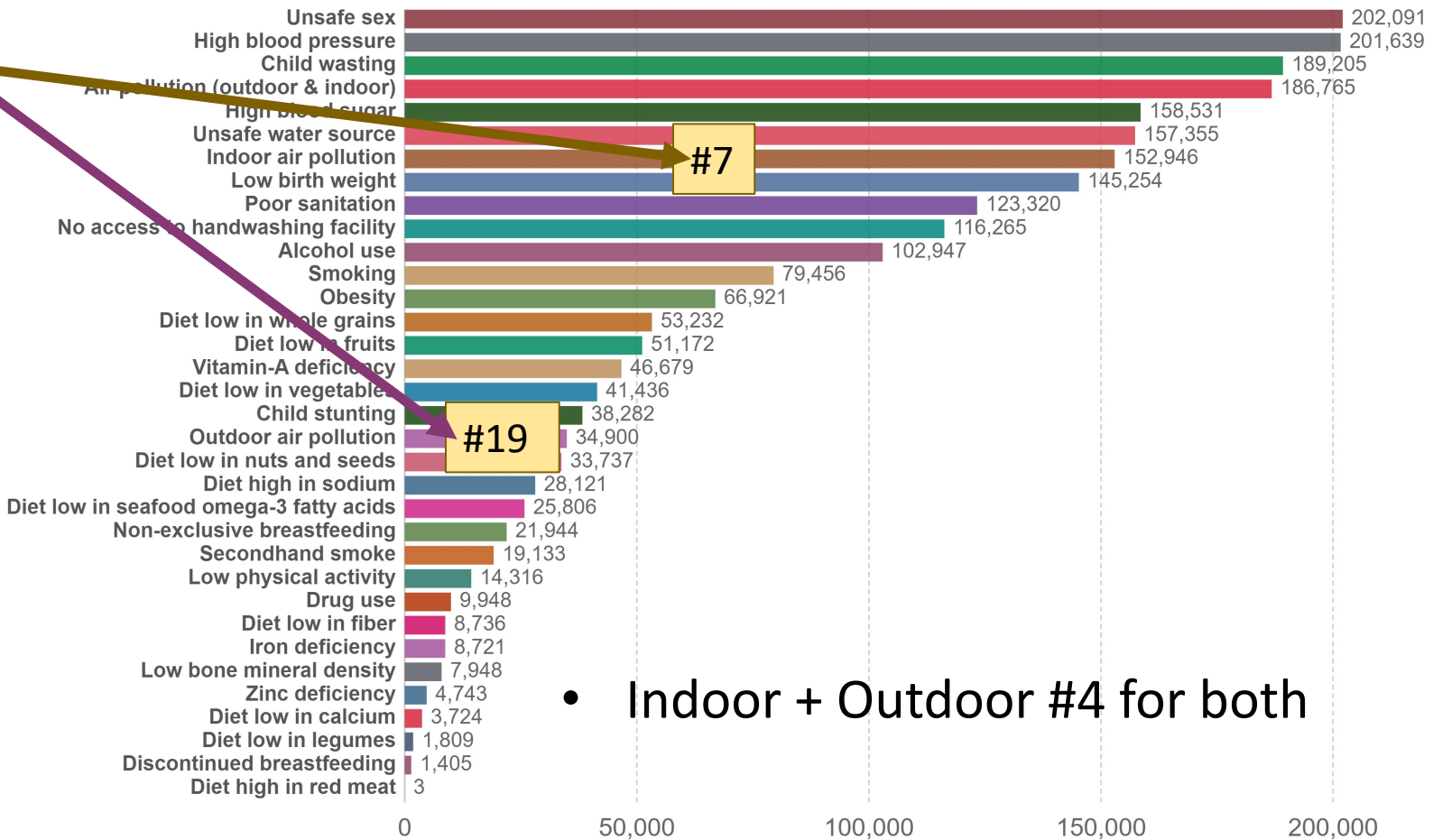
Some perspective on air pollution in Eastern Sub-Saharan Africa



Source: IHME, Global Burden of Disease (GBD)

Number of deaths by risk factor, Eastern Sub-Saharan Africa, 2017

Total annual number of deaths by risk factor, measured across all age groups and both sexes.



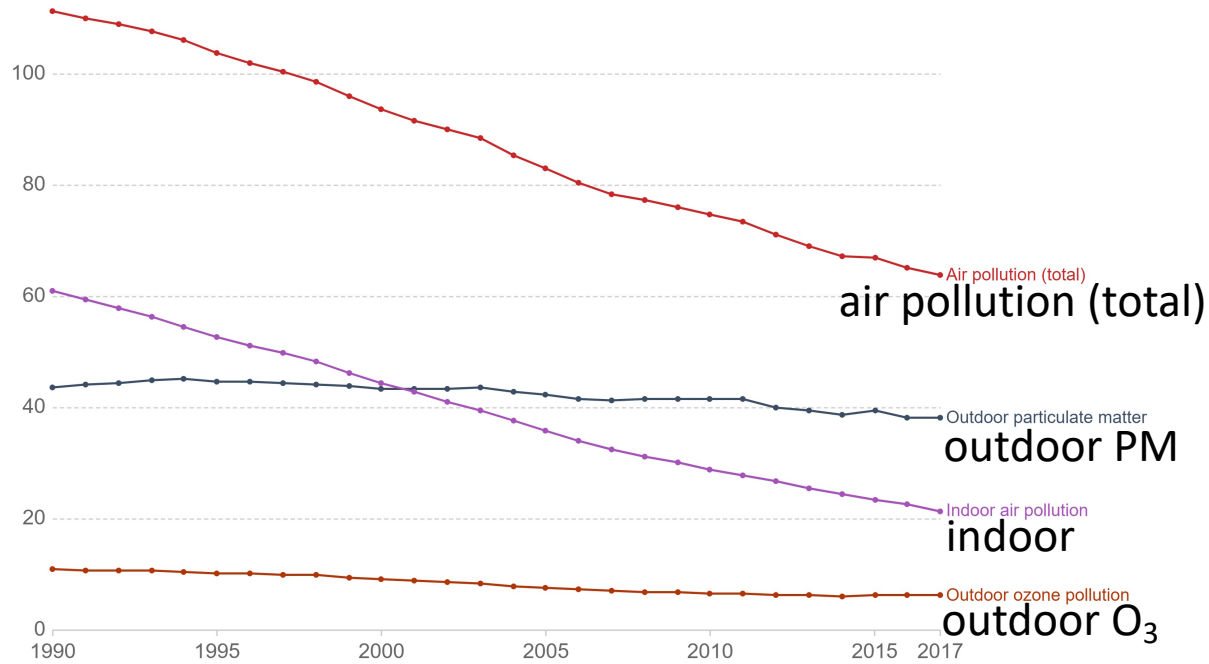
Source: IHME, Global Burden of Disease (GBD)

• Indoor + Outdoor #4 for both

Death rates from air pollution, World, 1990 to 2017

Death rates are given as the number of attributed deaths from pollution per 100,000 population. These rates are age-standardized, meaning they assume a constant age structure of the population: this allows for comparison between countries and over time.

Our World
in Data



Source: IHME, Global Burden of Disease

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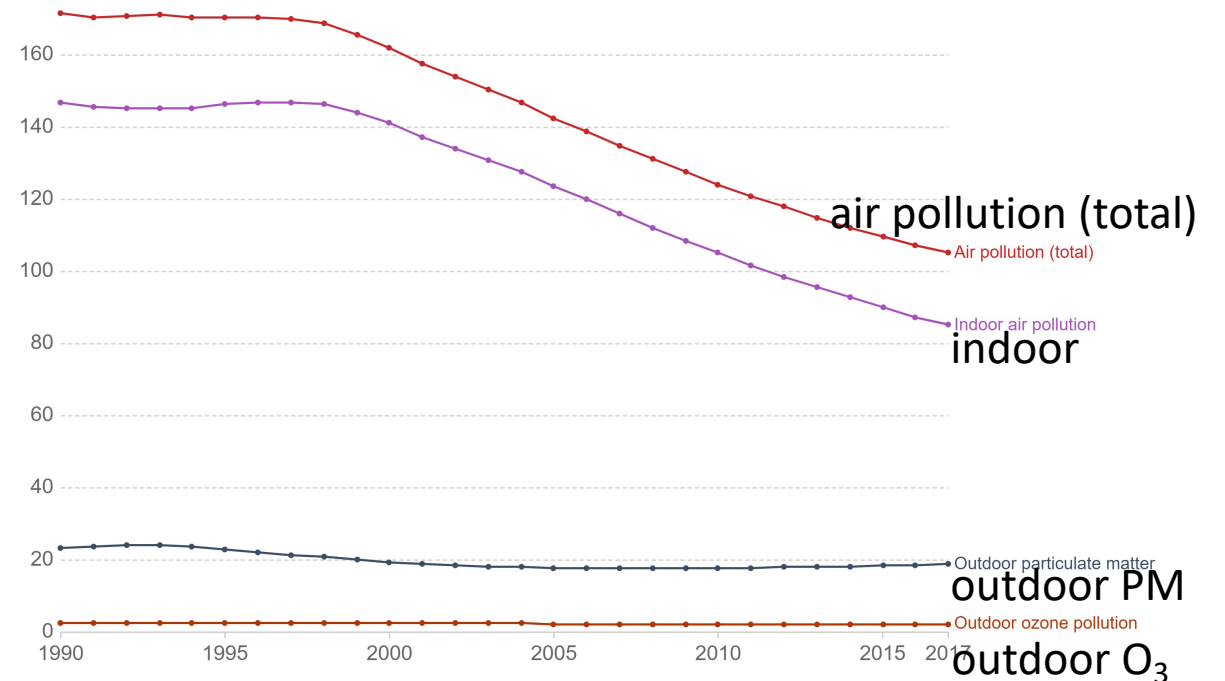
If indoor air pollution deaths decrease, will outdoor air pollution deaths rise?

Take care of indoor air pollution first, then outdoor PM, and then outdoor O₃?

Death rates from air pollution, Eastern Sub-Saharan Africa, 1990 to 2017

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Our World
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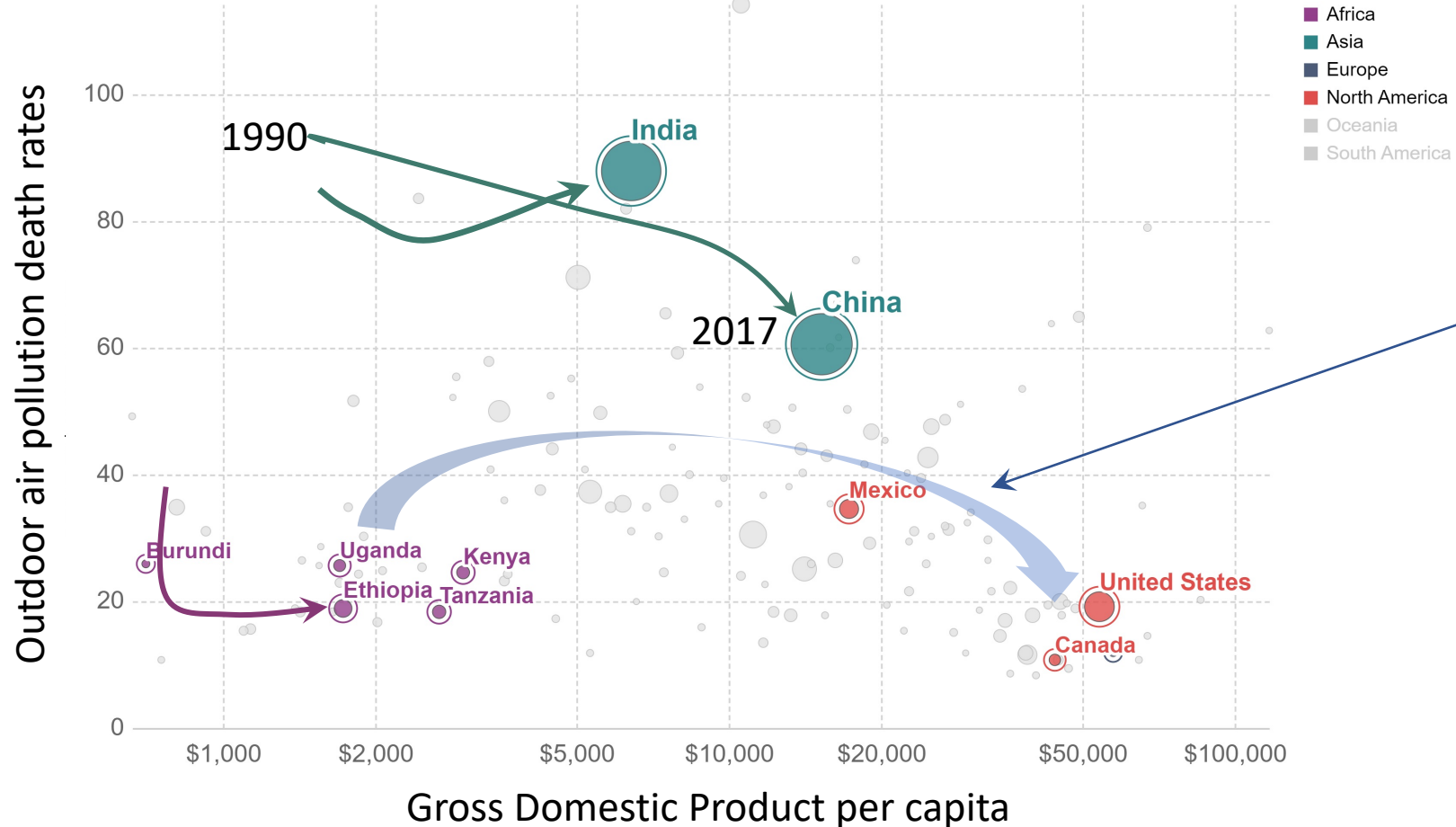
Source: IHME, Global Burden of Disease

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How to achieve a higher standard of living?

Death rate from particulate pollution vs GDP per capita, 2017

Death rates from outdoor air pollution are measured as the number of premature deaths attributed to outdoor air pollution per 100,000 individuals. Gross domestic product (GDP) per capita is measured in constant 2011 international-\$.
Our World in Data



Typical Path

Can Sub-Saharan East Africa follow a different path?

Source: IHME, Global Burden of Disease; World Bank

OurWorldInData.org/outdoor-air-pollution • CC BY

In Sub-Saharan East Africa, O₃ levels are not high, even though NO_x and VOCs are fairly high. Why?

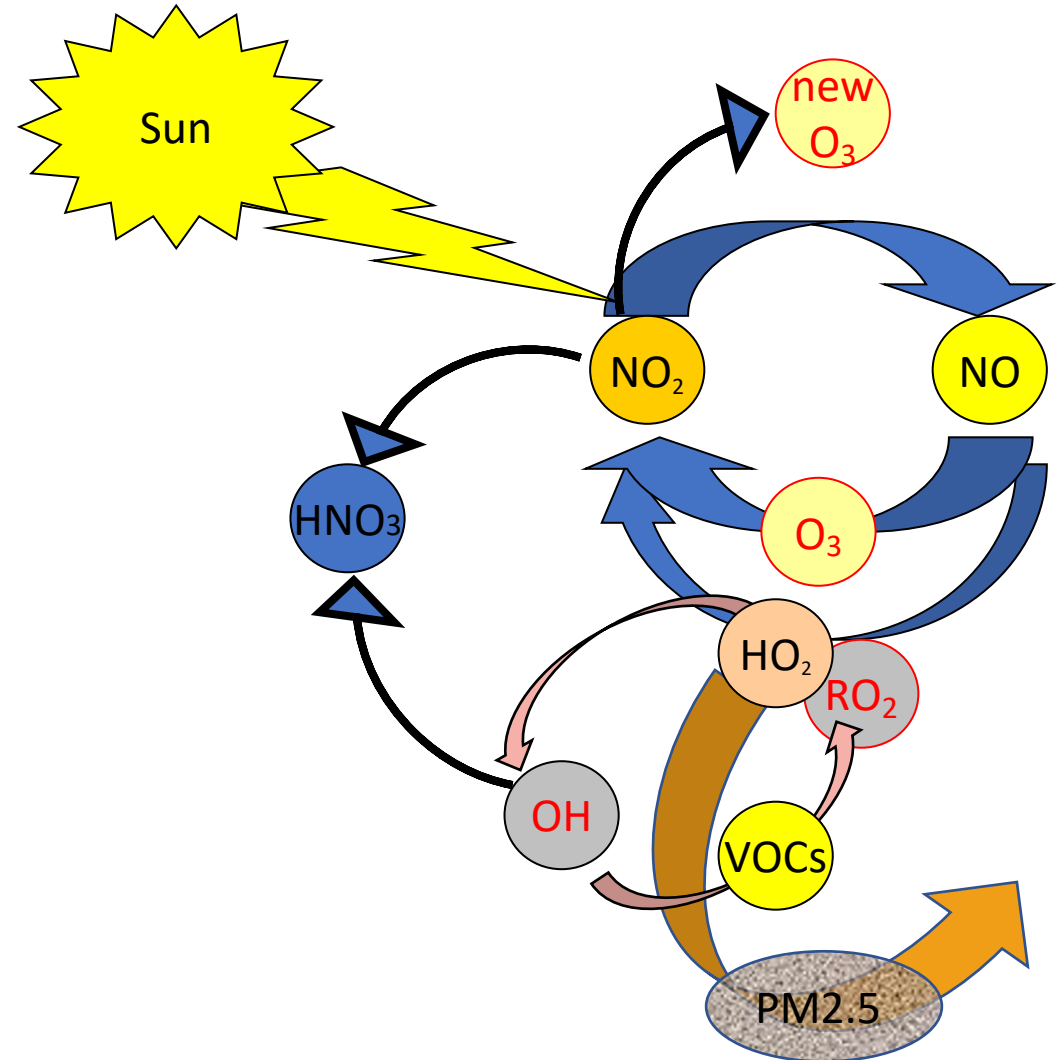
24-hr Averages for Select Cities						
Location	Year	O ₃ (ppbv)	NO (ppbv)	NO ₂ (ppbv)	O _x (ppbv)	CO (ppmv)
Nairobi, Kenya*	2015	4-14	6-18	1-55	5-69	0.5-1.7
Seoul, S. Korea	2016	36	7.9	32	68	0.46
Mexico City, Mex.	2003	28	2.4	28	56	0.72
Bakersfield, CA	2010	42	0.65	6.4	48	0.16
Houston, TX	2006	30	1.2	6.4	36	0.21
Houston, TX	2009	37	0.32	5.1	42	0.18
New York City	2004	23	4.2	28	51	0.38

* From 6 different sites in and around Nairobi. deSouza, Air Quality, Atmosphere & Health (2020) 13:1487–1495

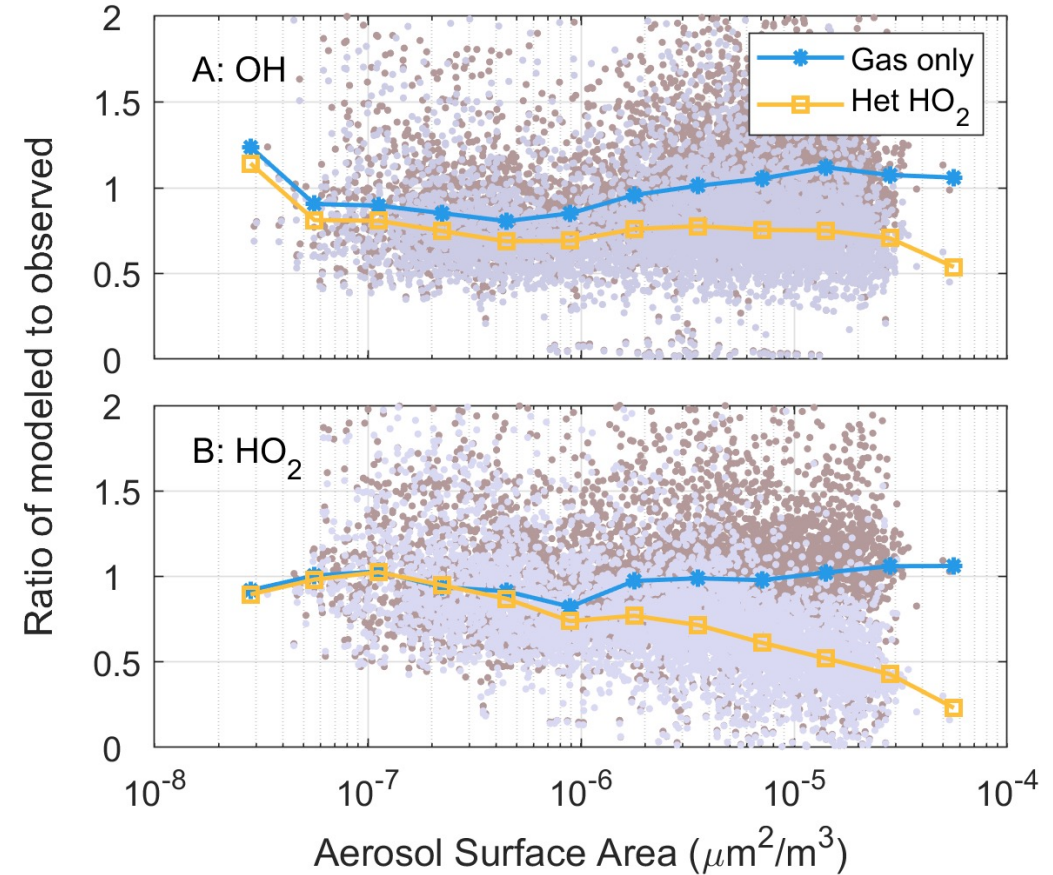
In China, why is O₃ going up when PM_{2.5} is going down?

Li et al., Anthropogenic drivers of 2013-2017 trends in summer surface ozone in China, PNAS, doi/10.1073/pnas.1812168116, 2018

- GEOS-Chem global model study of China O₃ from 2013-2017
- PM_{2.5} goes down, but O₃ goes up over standard in eastern China (8-hr 82 ppbv)
- Reductions in a combination of NO_x and VOCs required to bring O₃ down as PM_{2.5} levels decline
- Claim: PM_{2.5} a sink for HO₂ ... Add HO₂ aerosol uptake (lost in 20% of collisions)
- PM_{2.5} down means HO₂ up and thus O₃ up



Airborne observations from South Korea: KORUS-AQ (2016)



Observed HO₂ inconsistent with HO₂ uptake on PM_{2.5}

Conclusions for Sub-Saharan East Africa

- There appears to be enough NO_x and VOCs to make much O_3 .
- Reducing $\text{PM}_{2.5}$ could increase in O_3 to unhealthy levels, although the chemical mechanism is not clear. However, it may be worth it.
- Simultaneously reducing NO_2 sources and VOCs that form O_3 and $\text{PM}_{2.5}$ should reduce $\text{PM}_{2.5}$ while keeping O_3 low.
- Model guidance for O_3 mitigation should be trusted only if it can demonstrate the ability to consistently simulate: (1) unhealthy O_3 values and (2) an O_3 increase with decreasing $\text{PM}_{2.5}$ in megacities.
- Hourly measurement of O_3 , NO_x , CO, and VOC/OH reactivity needed
- My recommendation: start restricting trash fires and diesel use.