Air Pollution in Developing Mega-cities – Something Old, Something New – Lessons from Los Angeles

David Parrish

Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado

NOAA/ESRL Chemical Sciences Division

Boulder, Colorado USA

7 August 2014

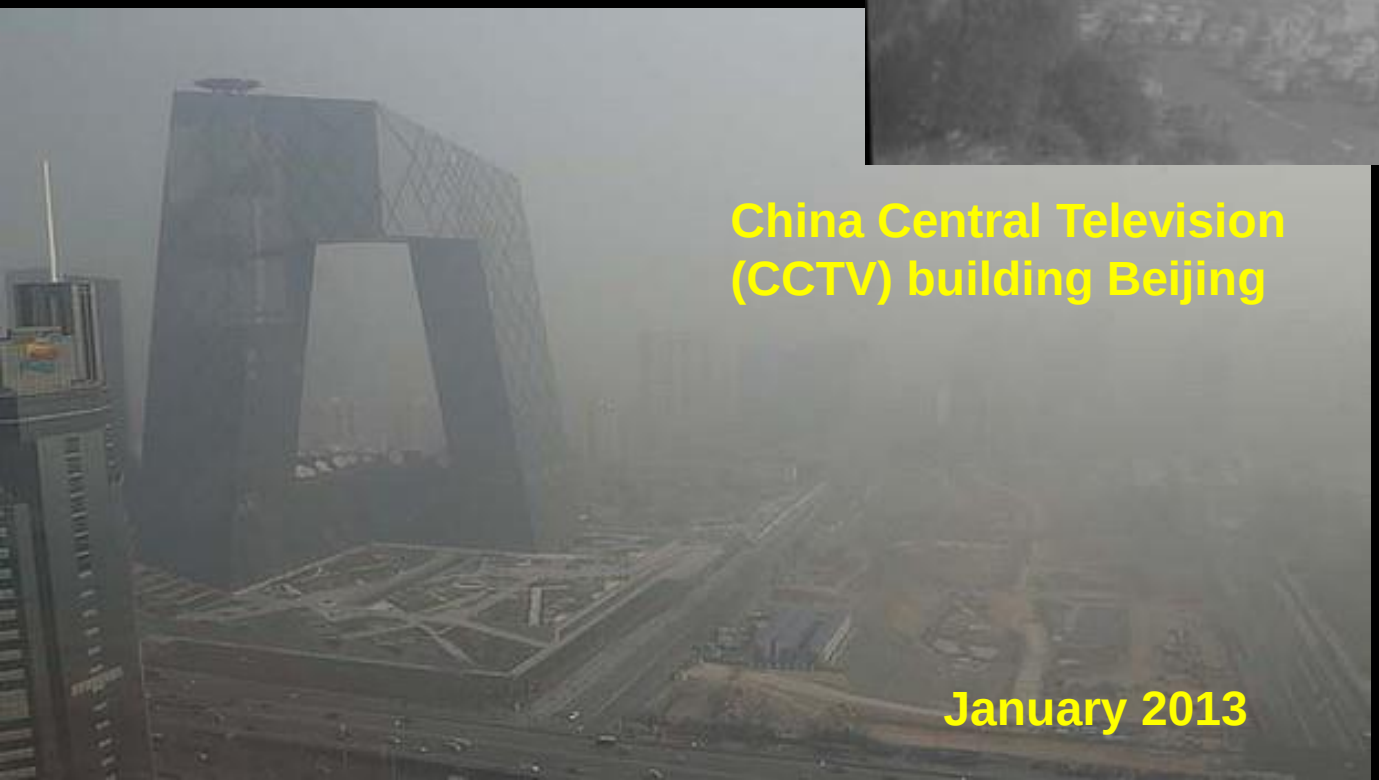
Air Pollution in Developing Mega-cities – Something Old, Something New – Lessons from Los Angeles

Today:

1. Severe air pollution in urban areas is an old problem
2. Review how air quality was improved in Los Angeles (Can this experience be useful guide for Asia?)
3. Are larger cities better for urban air quality and global climate?
4. Extremely important regional transport: A new challenge faced by East Asia

1. Severe air pollution in urban areas is an old problem

(Haze is caused by particulate matter, PM)



Air pollution in Los Angeles in mid-20th century was second to none

1. Severe air pollution in urban areas is an old problem

Los Angeles Civic Center

24-hour average PM_{10} concentrations exceeded 600 µg/m^3 in Los Angeles (*National Academy of Engineering Report*, 2007)

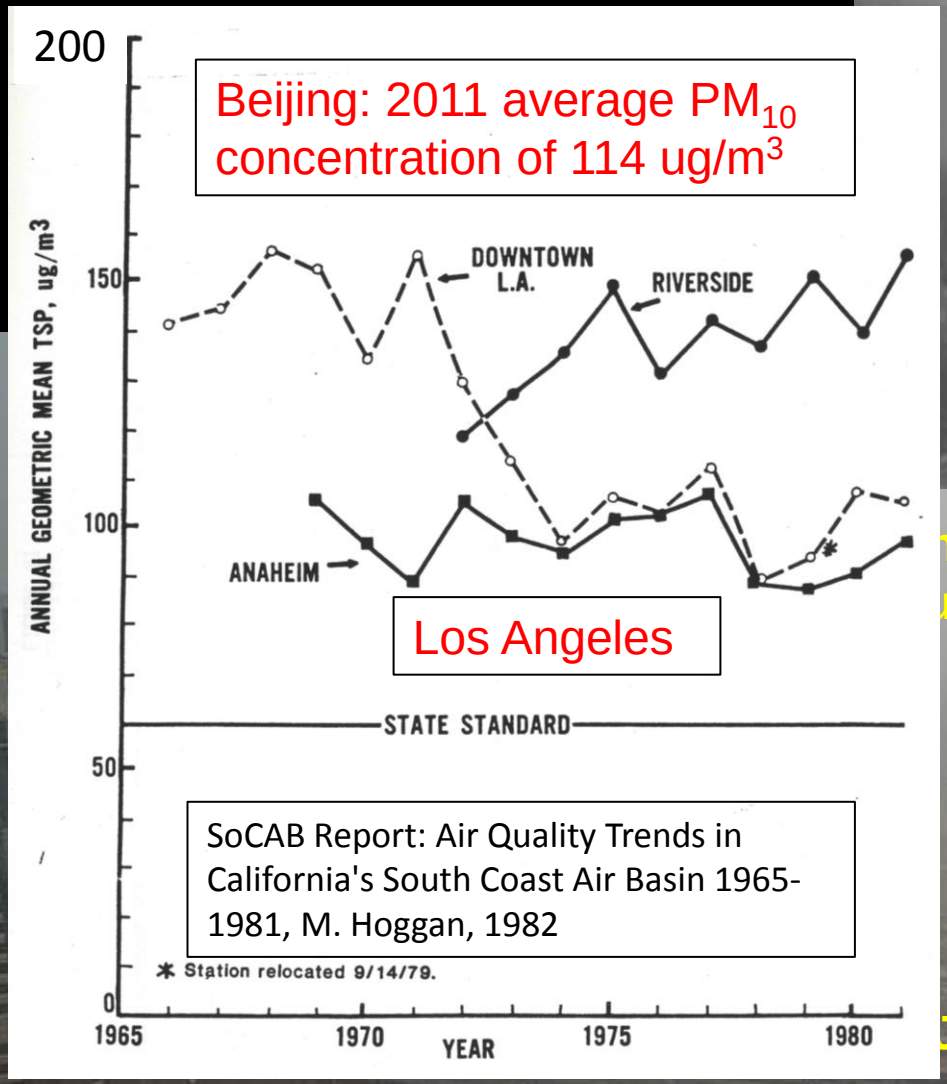
January 1948

China Central Television (CCTV) building Beijing

Peak PM_{10} concentrations exceeded 1150 µg/m^3 in Beijing (Zheng et al., *Atmos. Chem. Phys. Disc.*, 2014)

January 2013

1. Severe air pollution in urban areas is an old problem



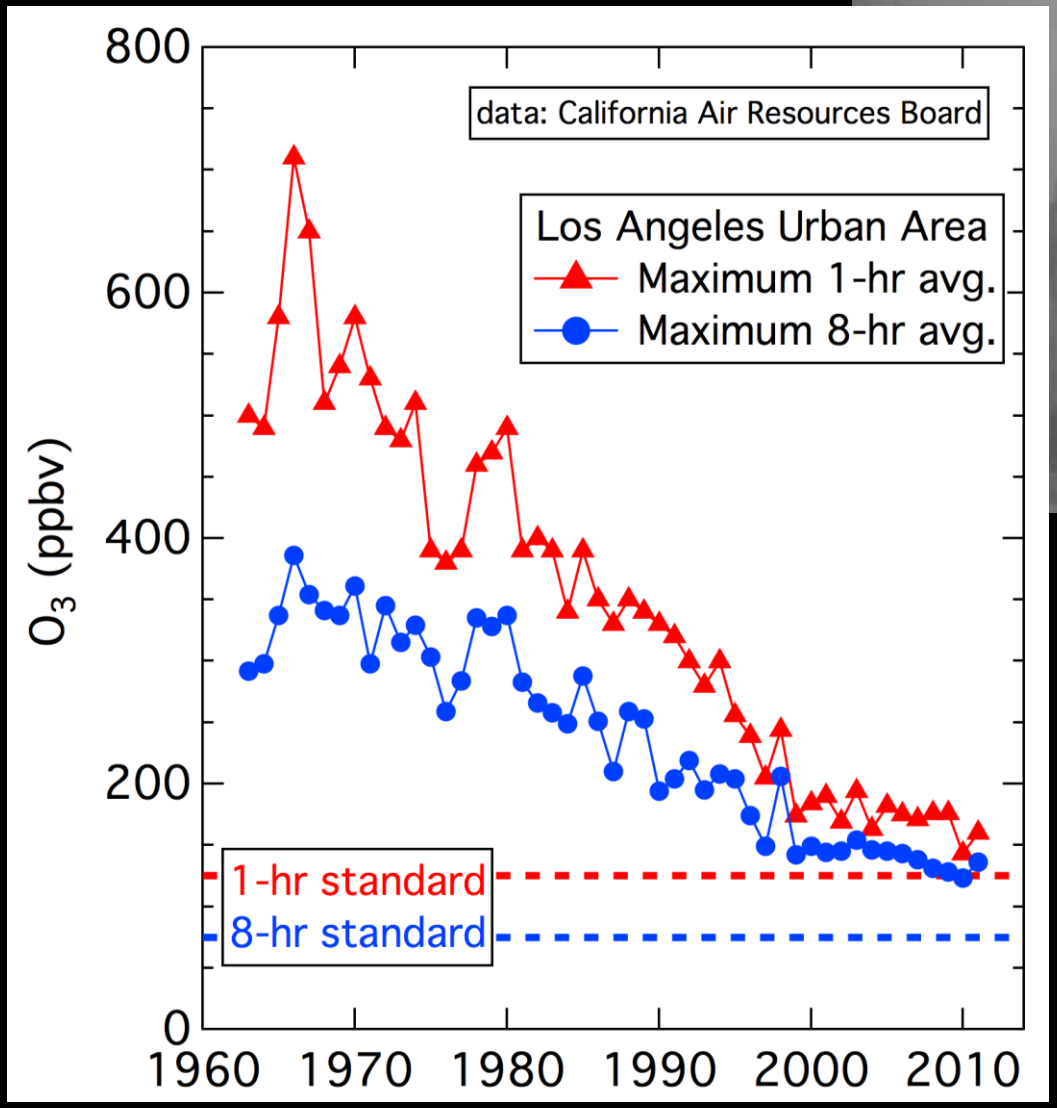
Los Angeles Civic Center

January 1948

ntral Television
uilding Beijing

January 2013

1. Severe air pollution in urban areas is an old problem



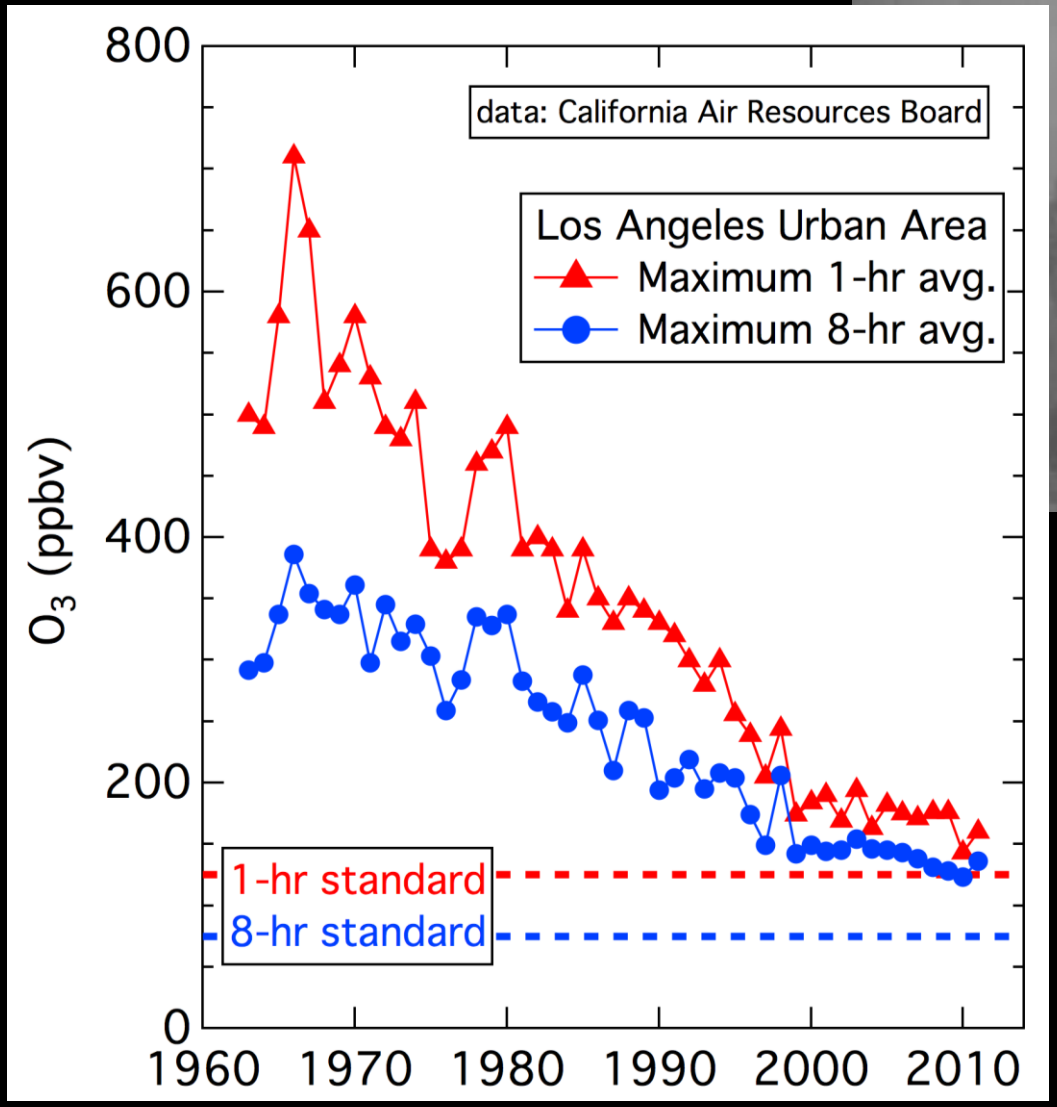
Tremendous progress has been made, but it required > 5 decades!

Ozone (O_3) exceeded 600 ppbv in Los Angeles

(> 350 ppbv 8-hour average)

O_3 seldom if ever has exceeded 200 ppbv in Beijing – higher in downwind plumes

1. Severe air pollution in urban areas is an old problem



2. What control efforts led to air quality improvement in Los Angeles?

What control efforts led to air quality improvement in Los Angeles?

Emissions from all sources addressed!

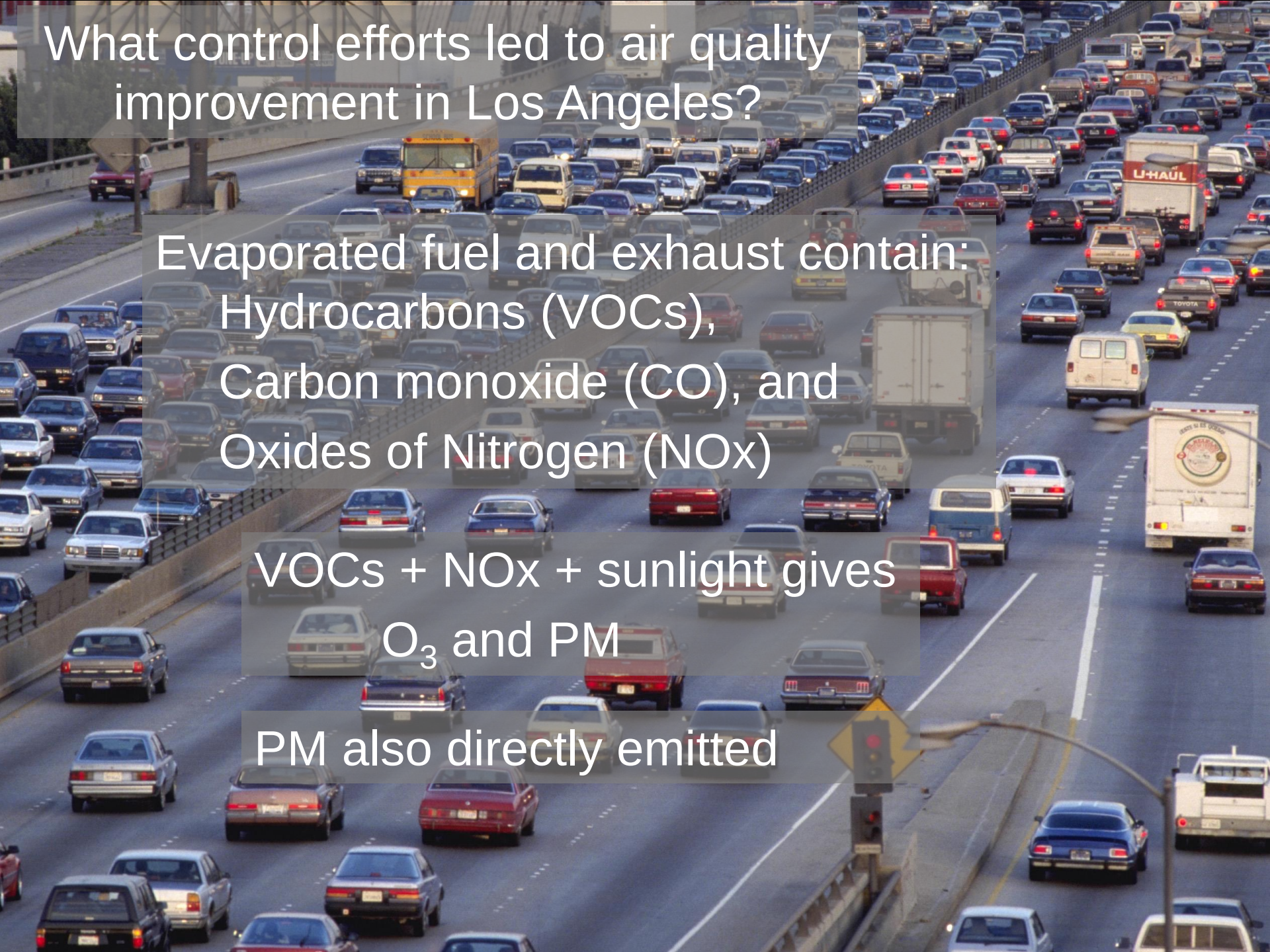
- Open burning banned
- Industrial emissions controlled
- Power plant emissions controlled, or moved elsewhere.

What control efforts led to air quality improvement in Los Angeles?

Emissions from all sources addressed!

- Open burning banned
- Industrial emissions controlled
- Power plant emissions controlled, or moved elsewhere.
- U.S. Urban Areas: Motor Vehicles dominate emissions.

What control efforts led to air quality improvement in Los Angeles?



Evaporated fuel and exhaust contain:

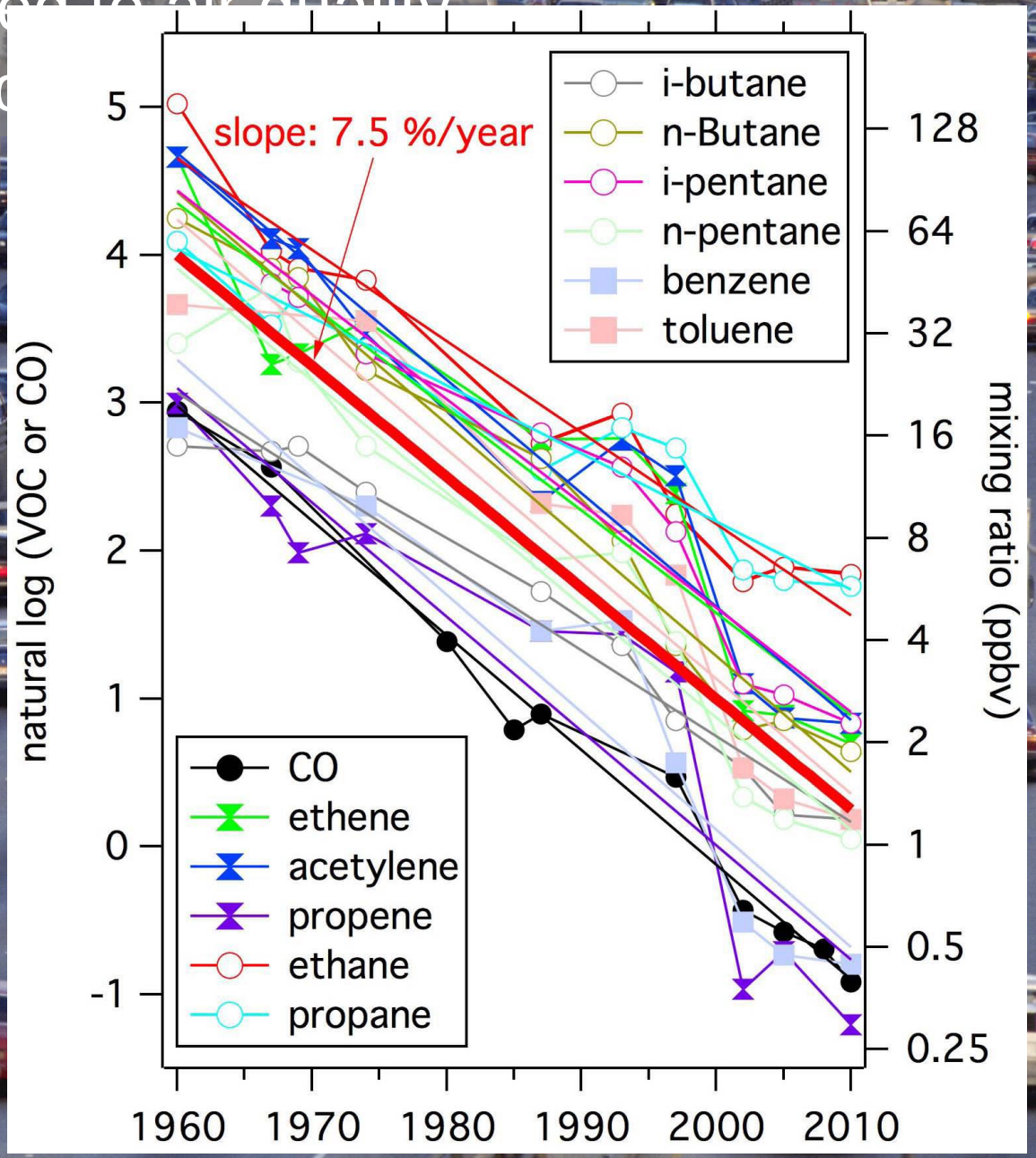
- Hydrocarbons (VOCs),
- Carbon monoxide (CO), and
- Oxides of Nitrogen (NOx)

VOCs + NOx + sunlight gives O_3 and PM

PM also directly emitted

What control efforts led to air quality improvement in Lo

Ambient VOC and CO concentrations decreased by factor of ~50 in 5 decades



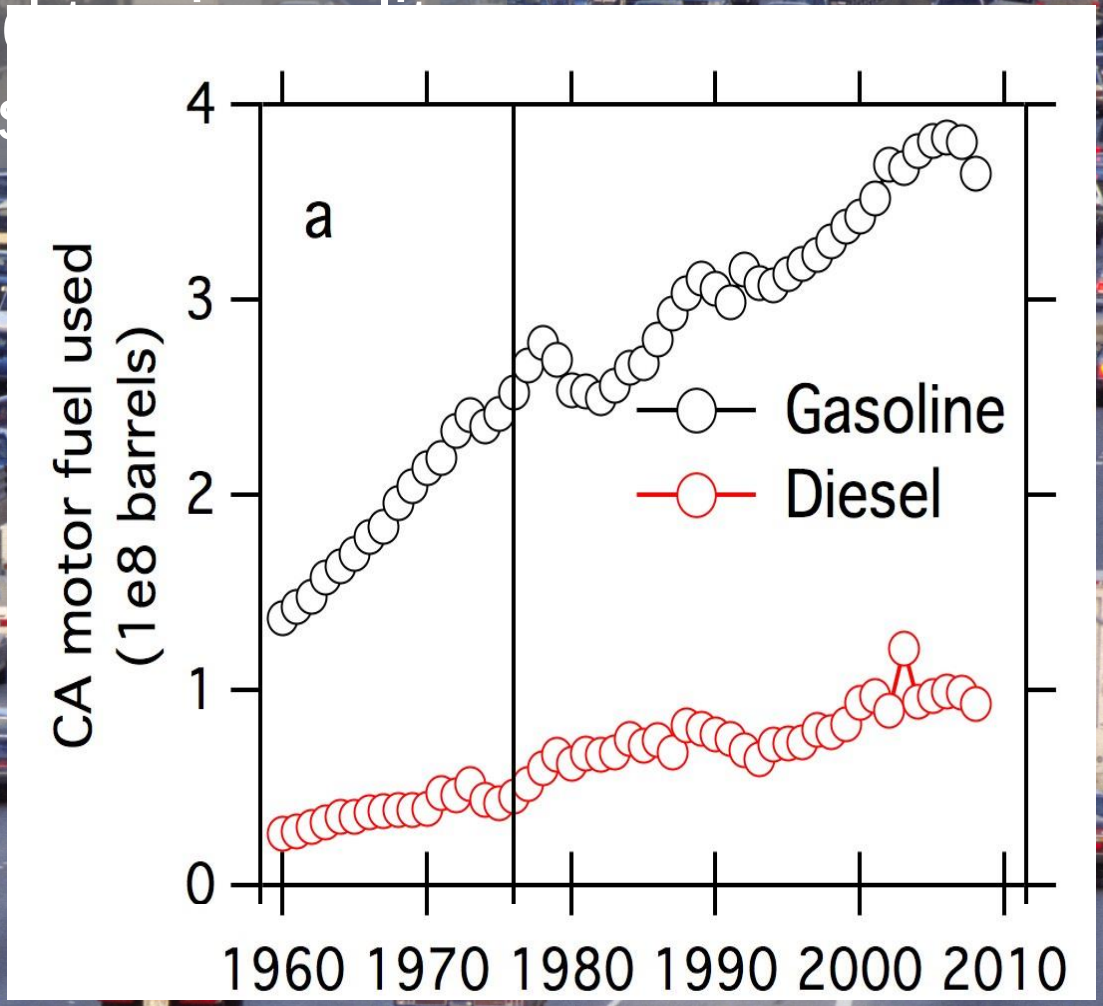
Warneke et al., *J. Geophys. Res.*, 2012

This and following slides summarize data collected from a variety of sources at a variety of sites

What control efforts le… improvement in Los…

Ambient VOC and CO concentrations decreased by factor of ~50 in 5 decades

…even while fuel use increased by factor of ~3.



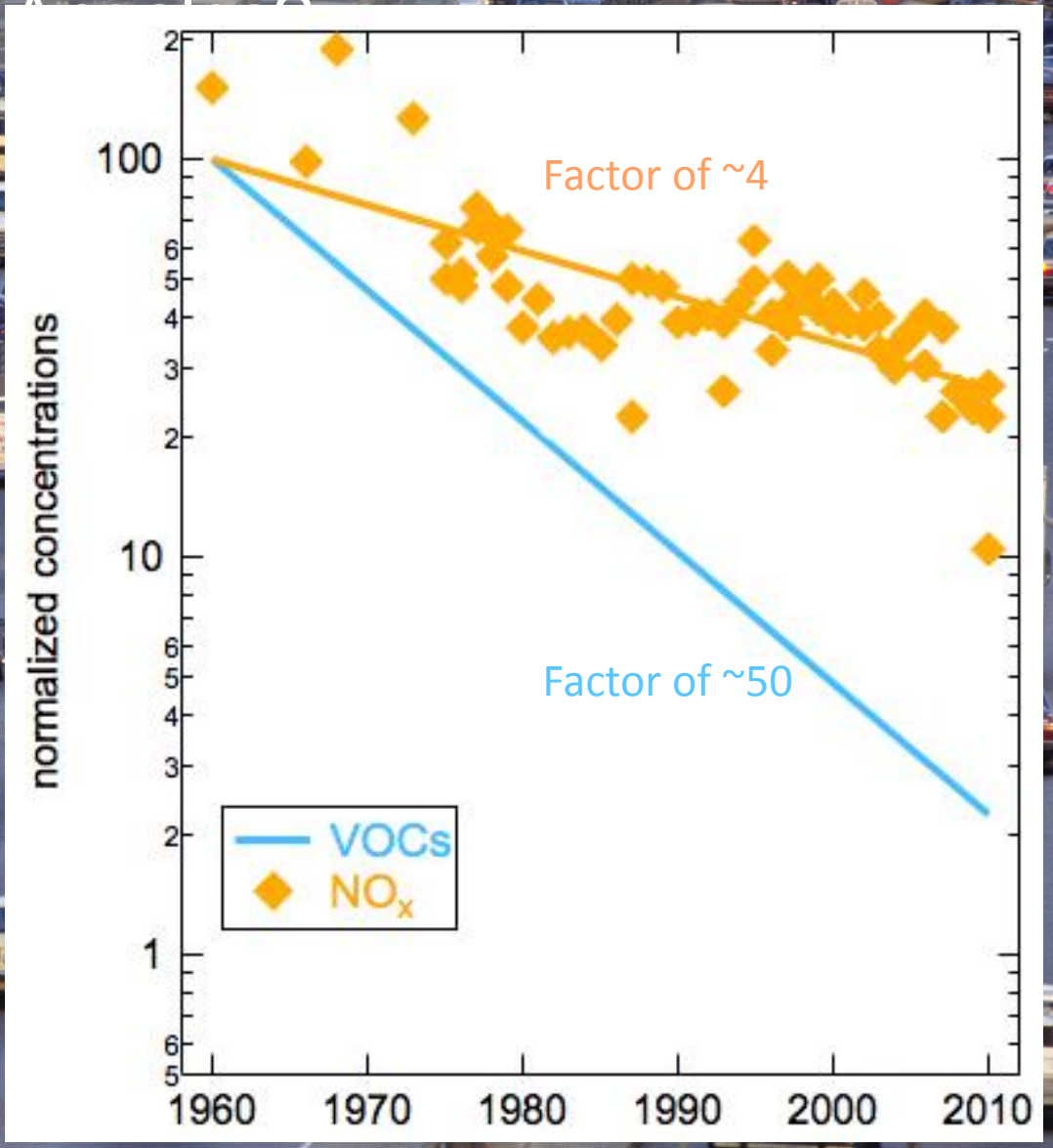
Per km traveled, modern U.S. vehicles emit ~1% of VOCs and CO compared to 1960 vehicles

Warneke et al., *J. Geophys. Res.*, 2012

What control efforts led to air quality improvement in Los Angeles?

Response of pollutants to emission controls:

NO_X reductions much slower than VOC reductions.



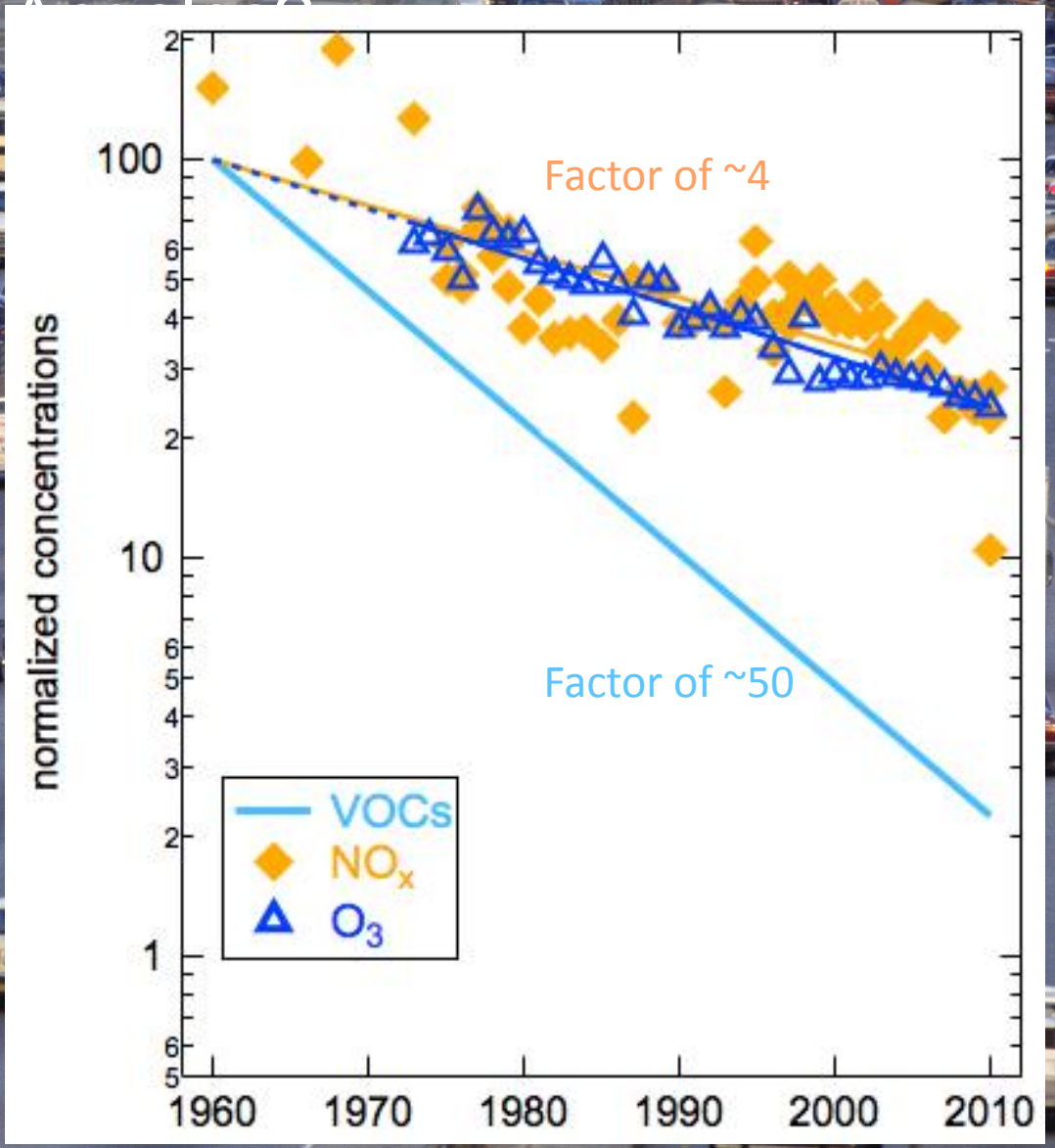
Pollack et al., *J. Geophys. Res.*, 2013

What control efforts led to air quality improvement in Los Angeles?

Response of pollutants to emission controls:

NO_X reductions much slower than VOC reductions.

Response of O_3 is not proportional to VOC reductions.



Pollack et al., *J. Geophys. Res.*, 2013

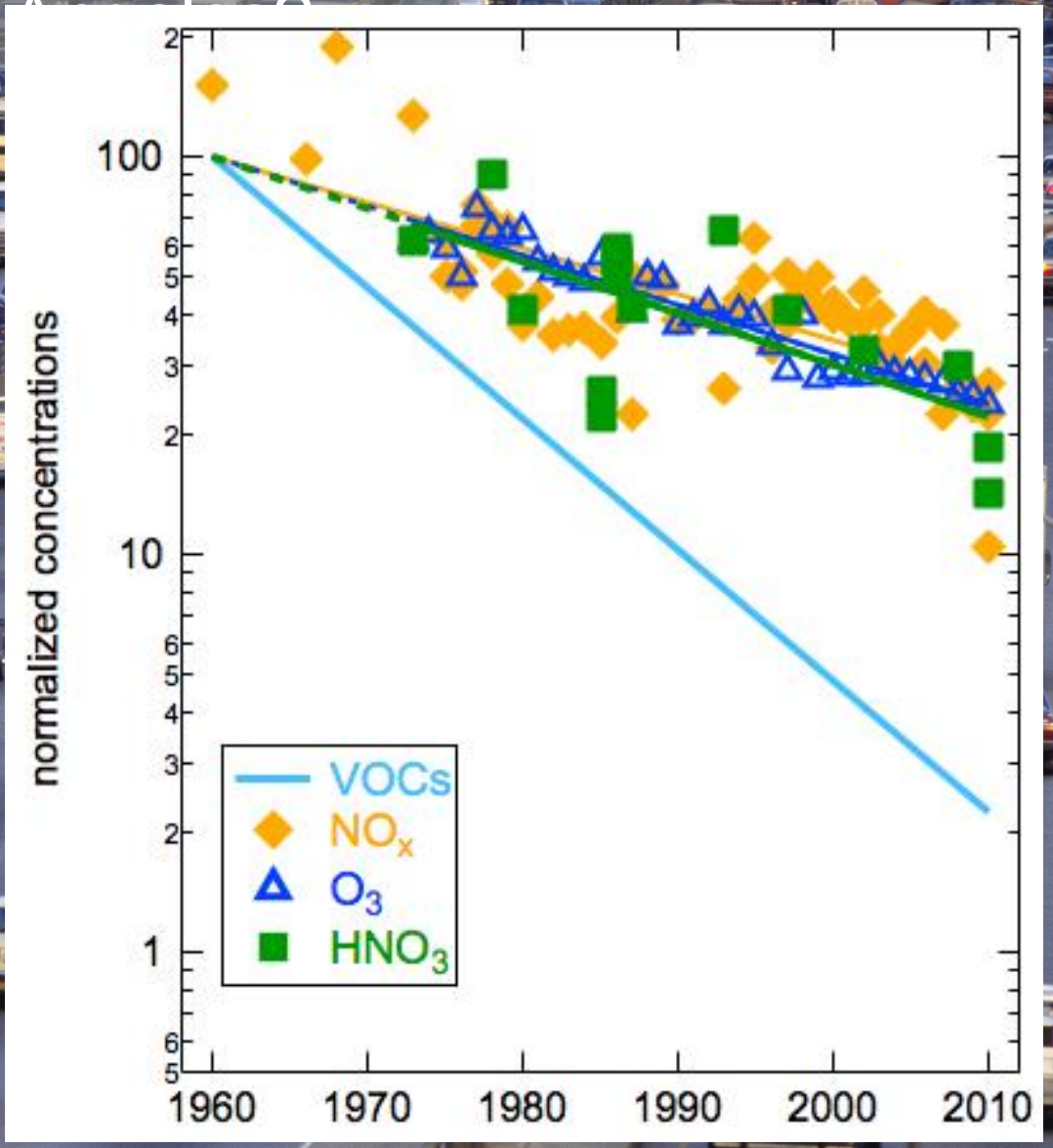
What control efforts led to air quality improvement in Los Angeles?

Response of pollutants to emission controls:

NO_X reductions much slower than VOC reductions.

Response of O_3 is not proportional to VOC reductions.

Reduction in HNO_3 has followed NOx reduction.



Pollack et al., *J. Geophys. Res.*, 2013

What control efforts led to air q… improvement in Los A…

Response of pollutants to emission controls:

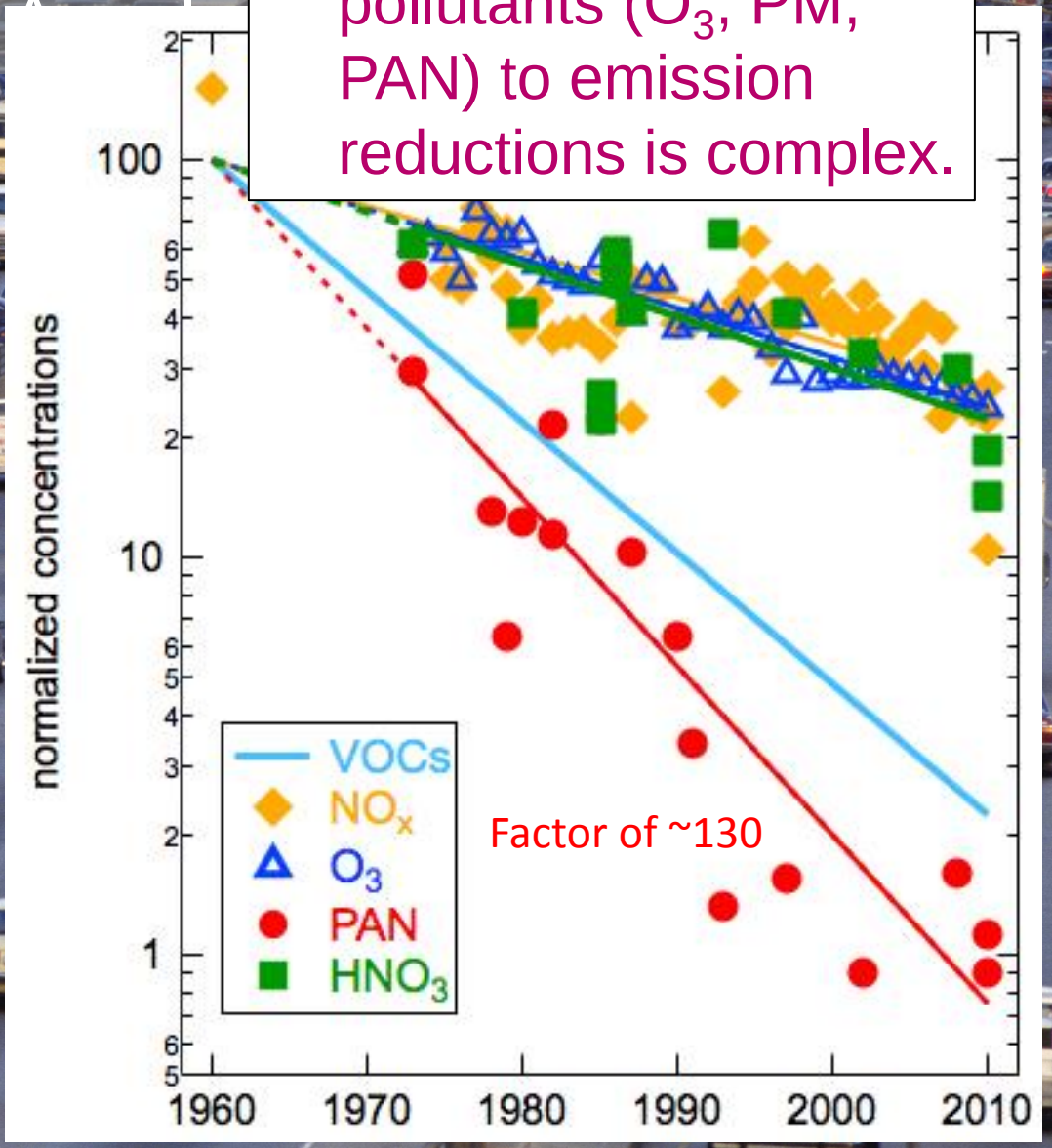
NO_X reductions much slower than VOC reductions.

Response of O_3 is not proportional to VOC reductions.

Reduction in PAN has been very different.

PAN (peroxyacetyl nitrate) was responsible for severe eye irritation in Los Angeles.

Response of secondary pollutants (O_3, PM, PAN) to emission reductions is complex.



Pollack et al., *J. Geophys. Res.*, 2013

What control efforts led to air quality improvement in Los A

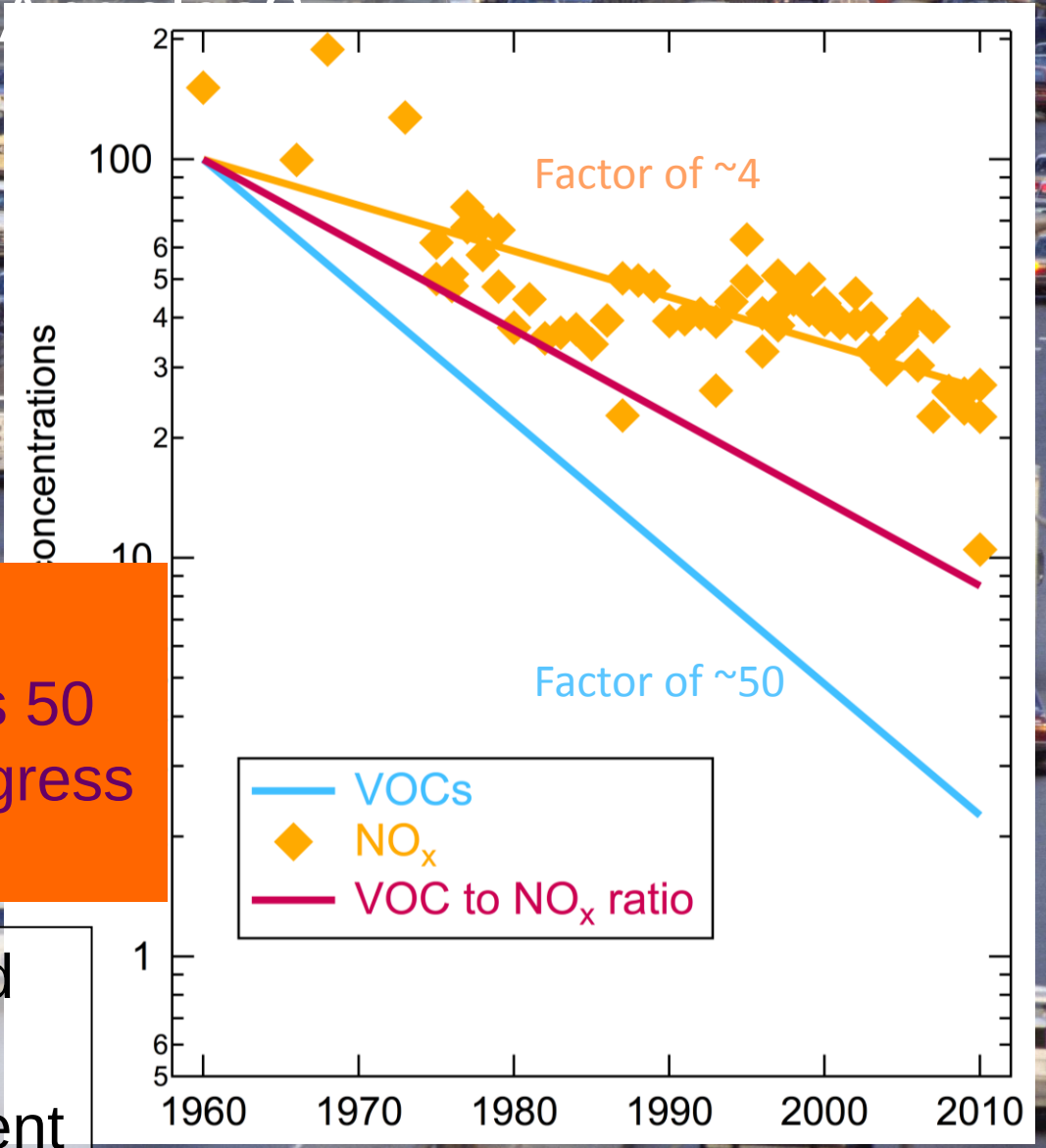
Response of pollutants to emission controls:

NO_X reductions much slower than VOC reductions.

Challenge for modelers:

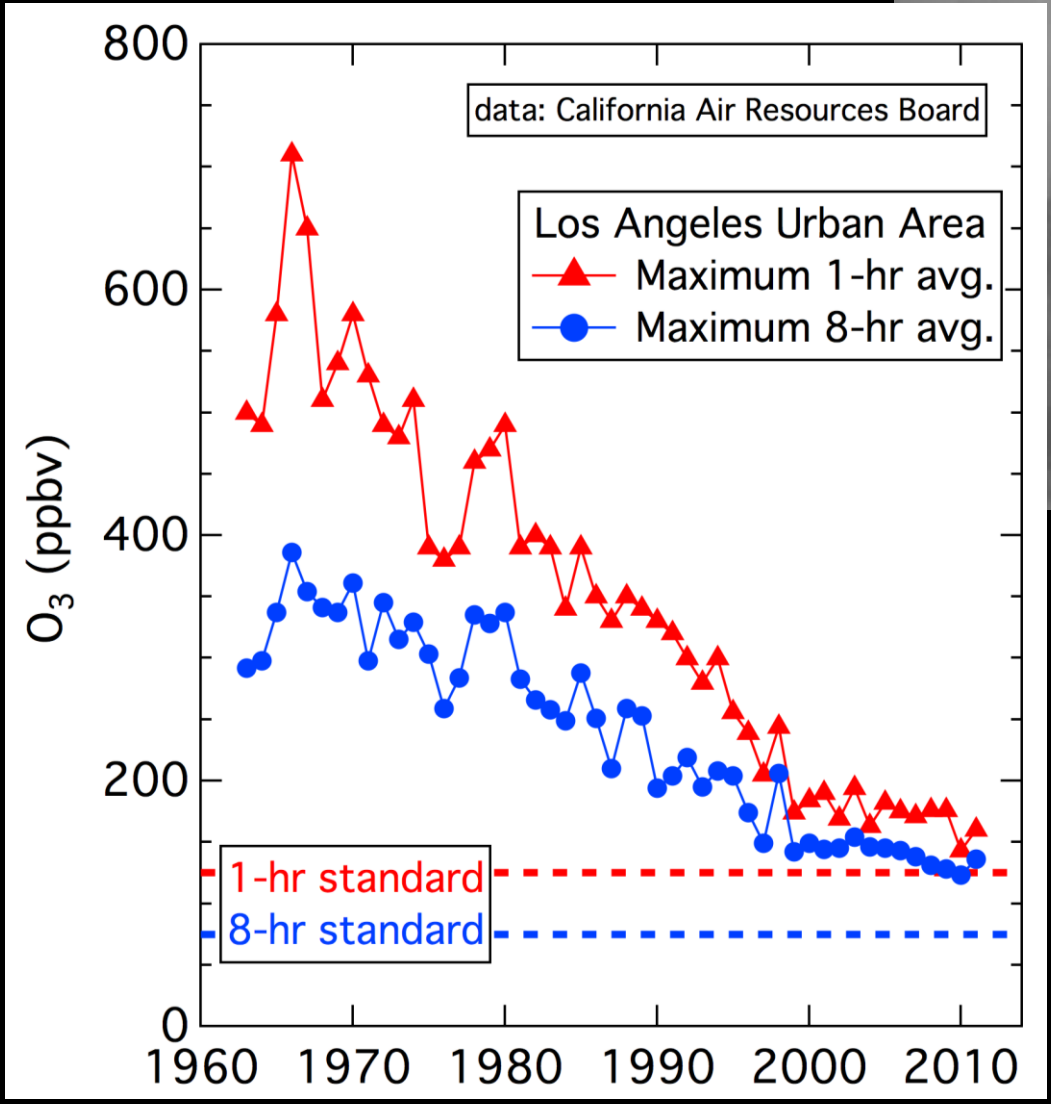
Can all major aspects of this 50 years of Los Angeles progress be accurately modeled?

VOC to NO_X ratio decreased by factor of 12 in L.A. - Photochemical environment has changed.



Pollack et al., *J. Geophys. Res.*, 2013

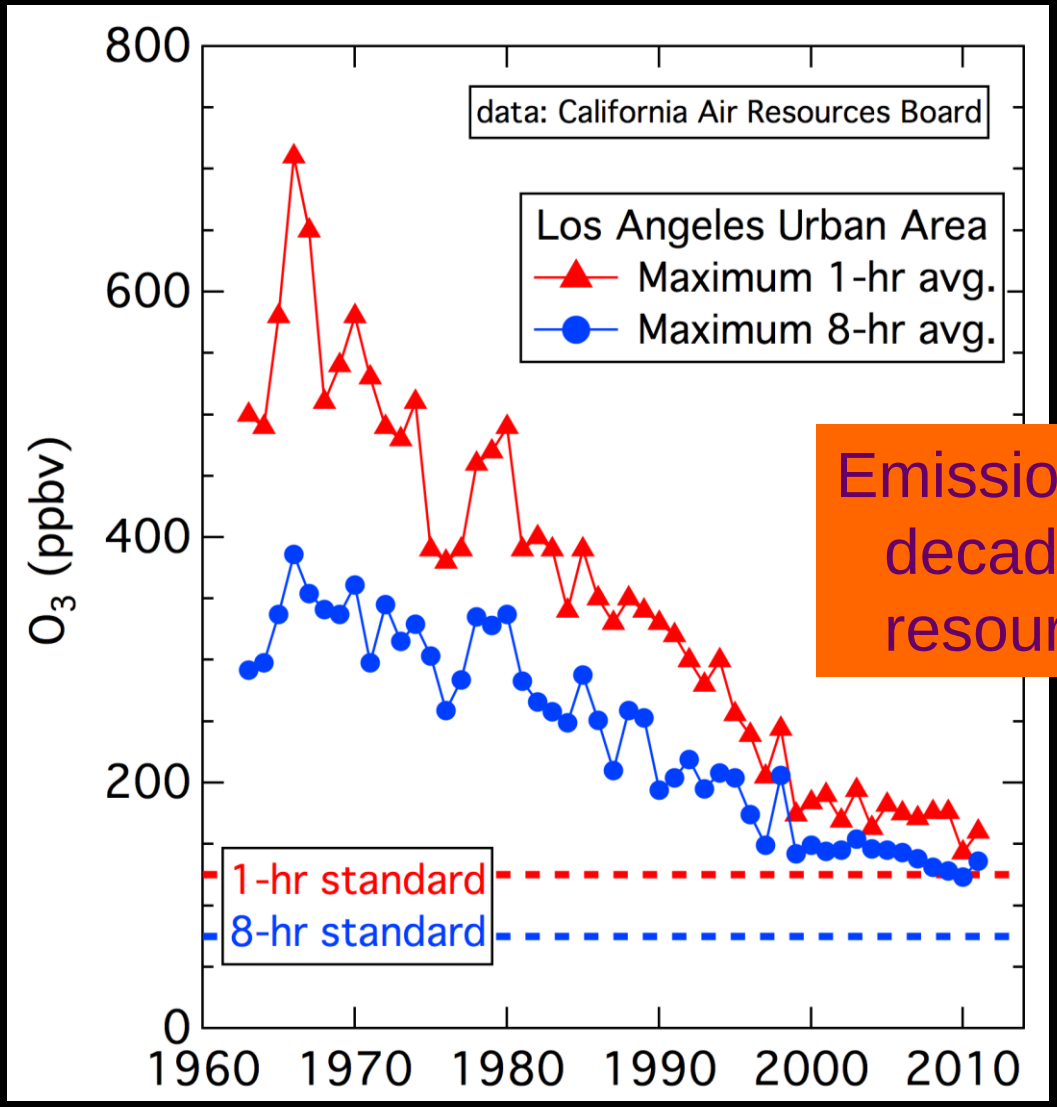
2. What control efforts led to air quality improvement in Los Angeles?



Tremendous progress has been made, but it required > 5 decades!

Why did it take so long?

2. What control efforts led to air quality improvement in Los Angeles?



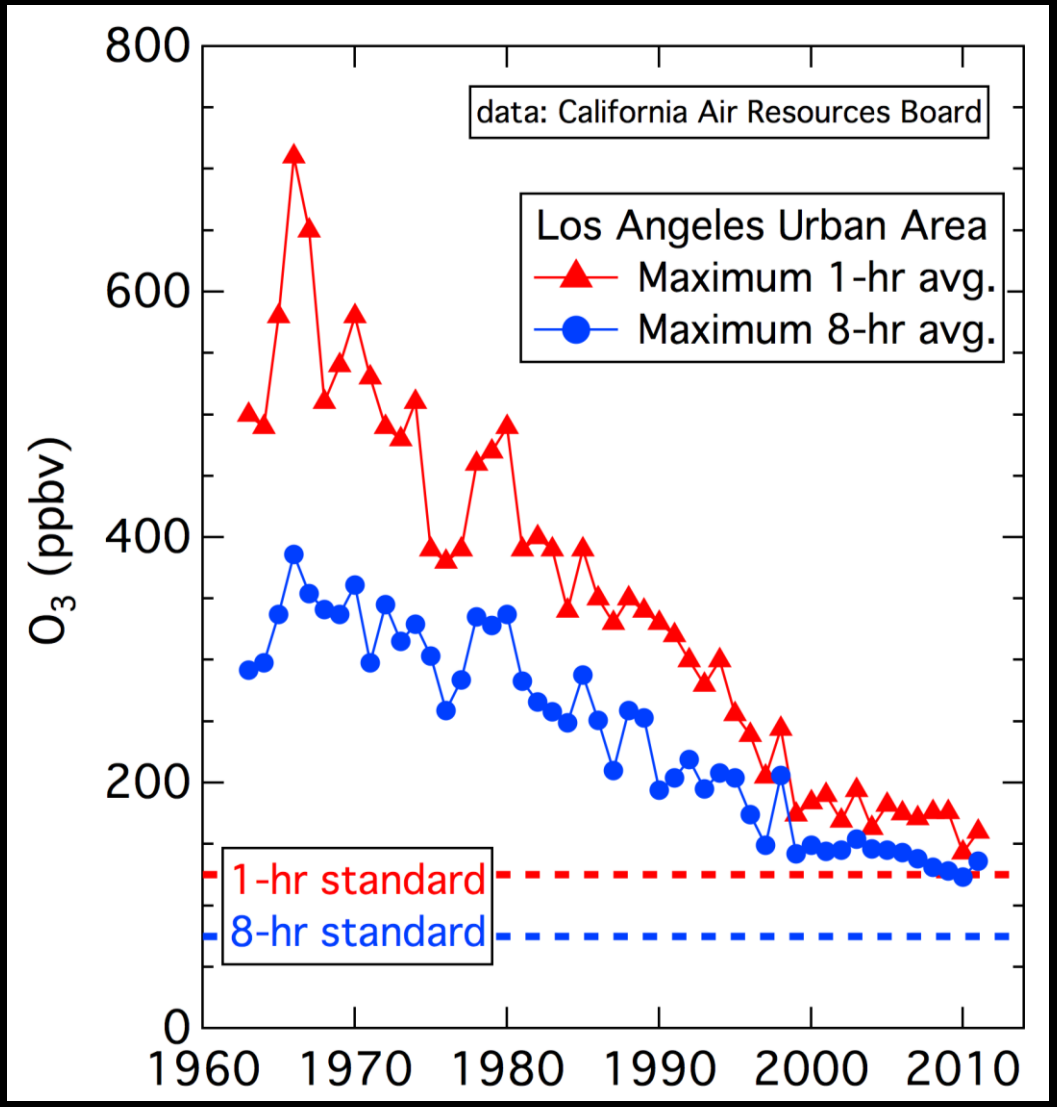
- Substantial Science and Engineering Challenges
  - What are the important emission sources?
  - How can we control those emissions?

Amazing technical success

Emission controls developed over decades are now a tremendous resource for others!

Why did it take so long?

2. What control efforts led to air quality improvement in Los Angeles?

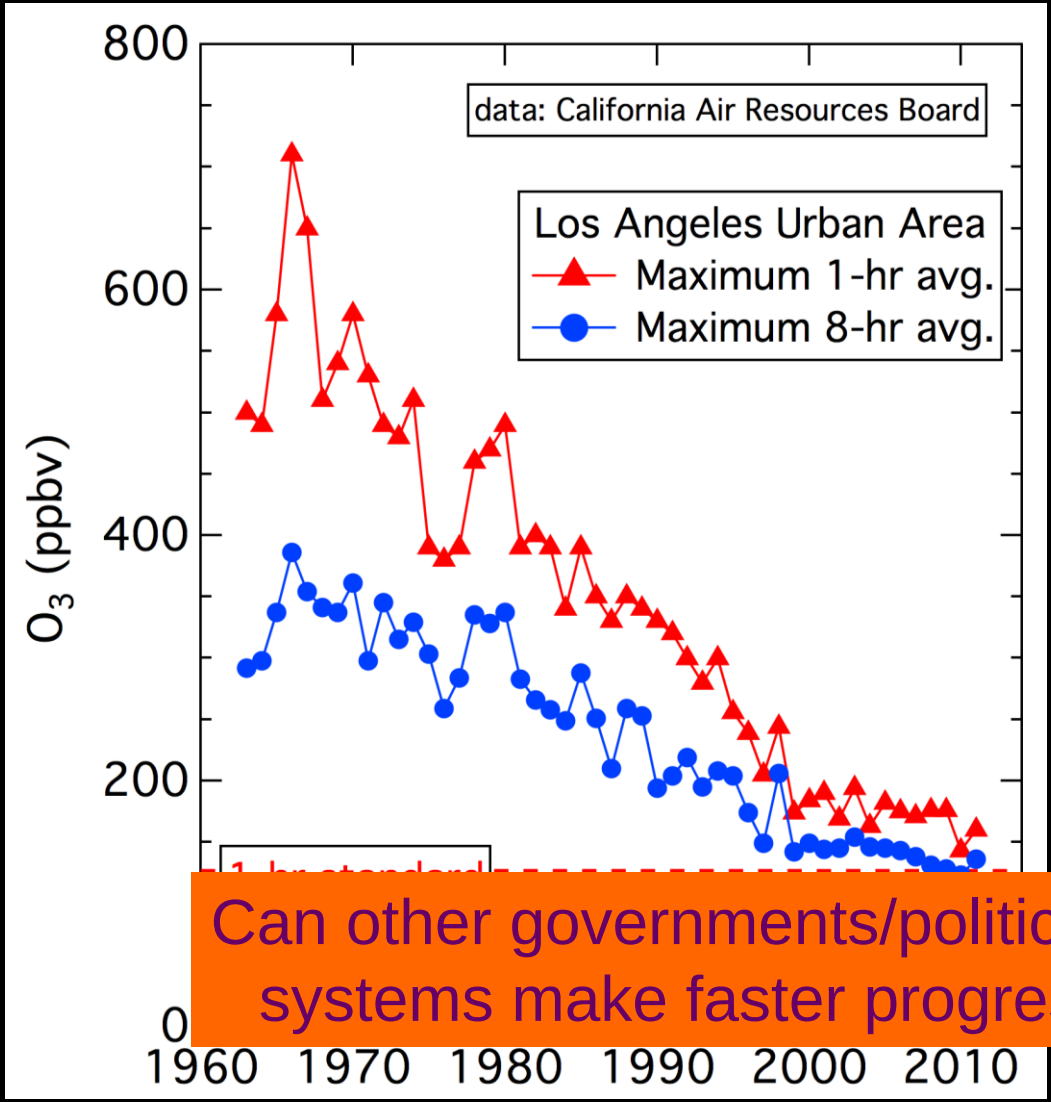


- Substantial Social Challenges – Every proposed emission control effort was met by strident protests from those controlled.

A long, exhausting political and legal process has been required.

Why did it take so long?

2. What control efforts led to air quality improvement in Los Angeles?



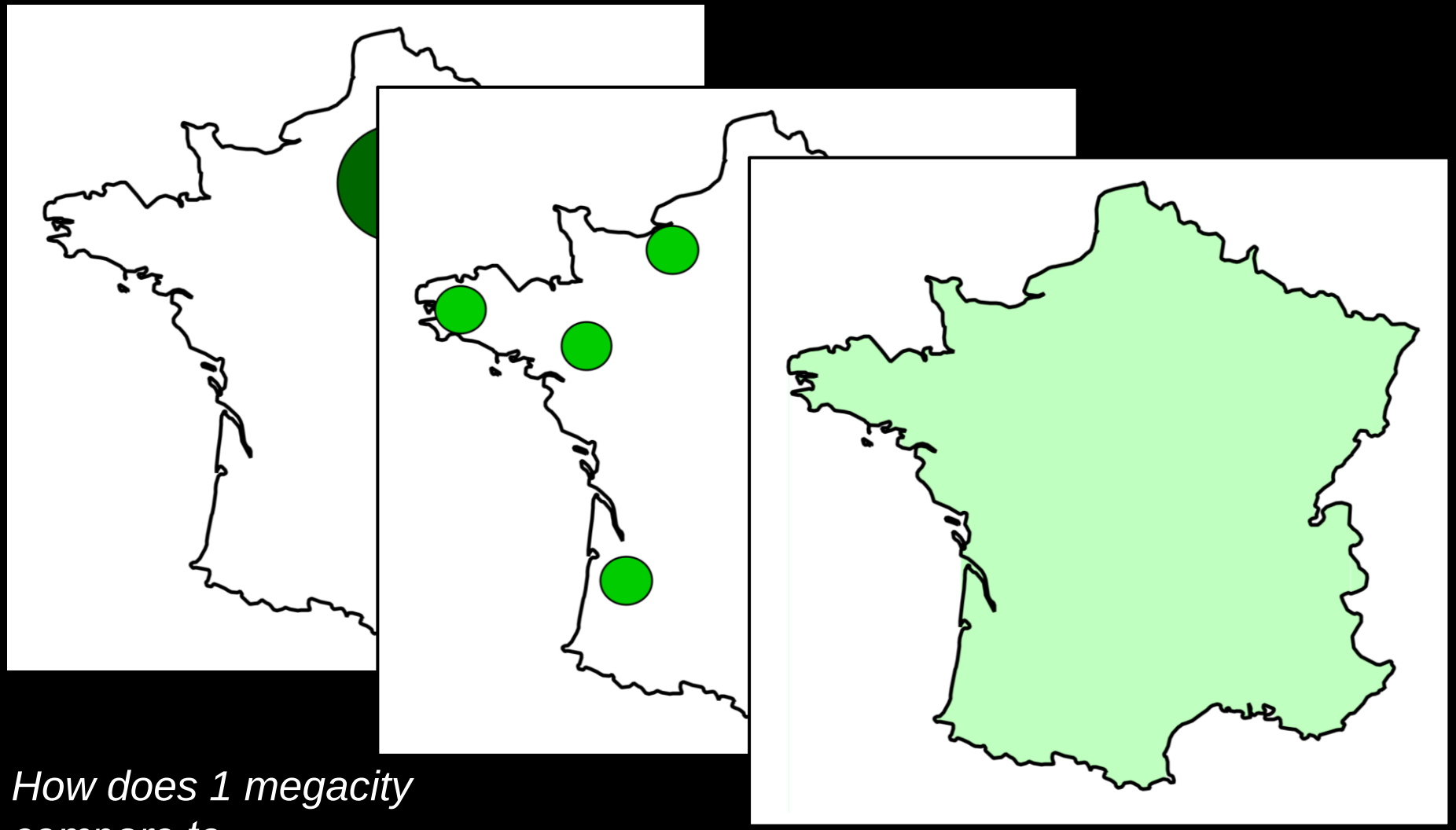
Can other governments/political systems make faster progress?

- Substantial Political Challenges
  - The Los Angeles Basin contains 3 counties, and more than 50 separate cities
  - Progress was slow until South Coast Air Quality Management District was formed in 1977.

Concerted action over the entire air shed is critical

Why did it take so long?

3. Are larger cities better for urban air quality and global climate?

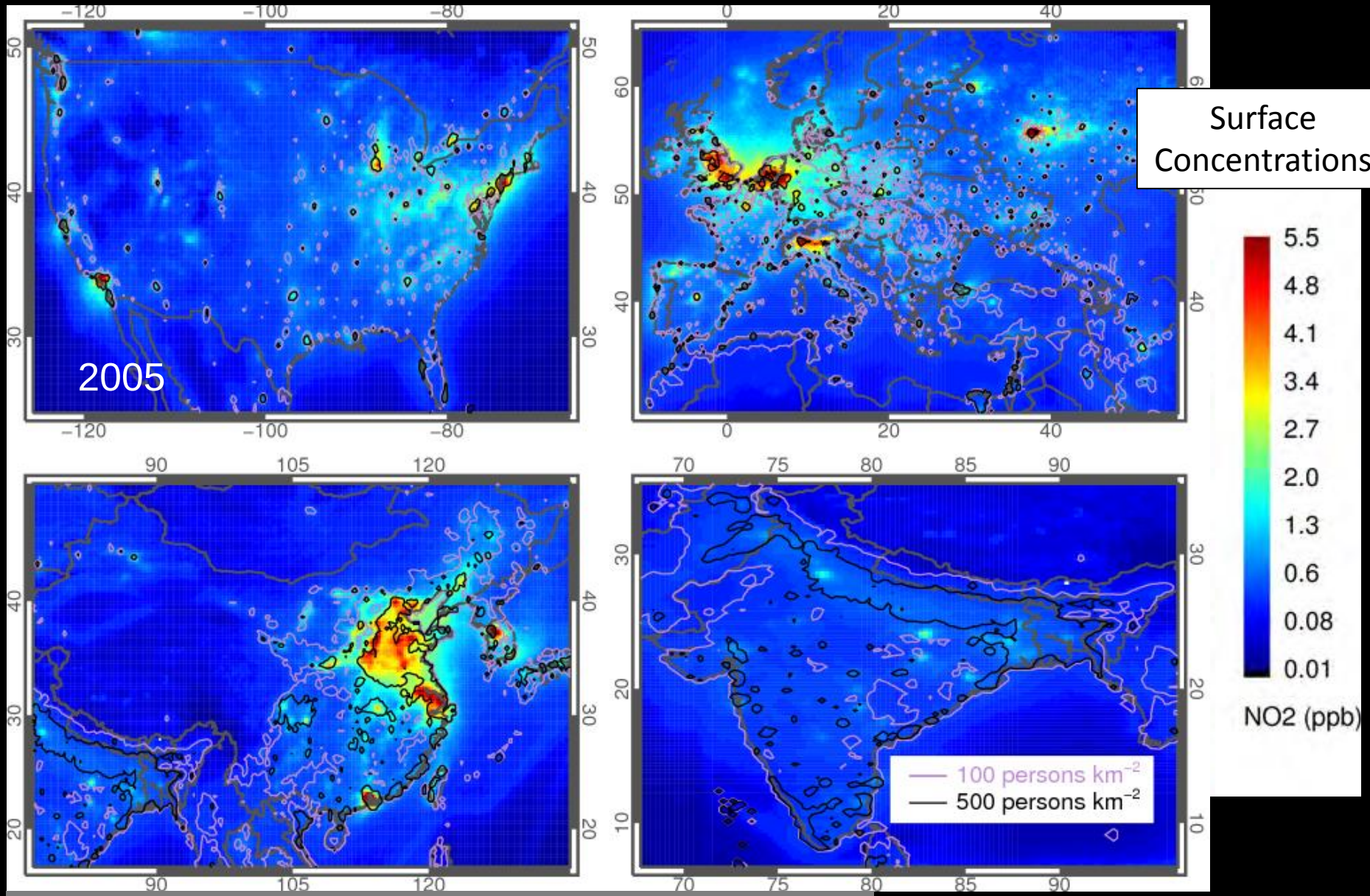


How does 1 megacity compare to …

10 smaller cities with the same total population …

or the same total rural population?

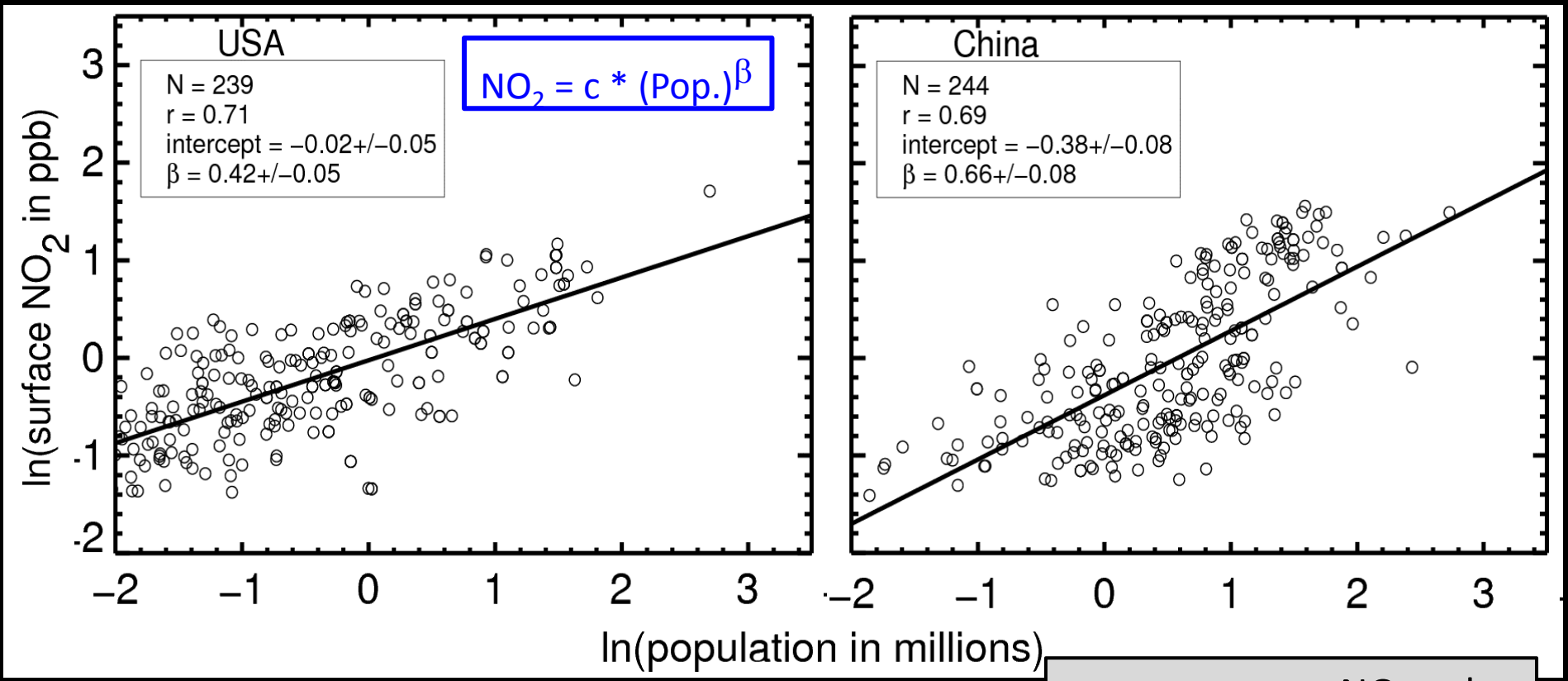
3. Are larger cities better for urban air quality and global climate?



Satellite data can provide an indication

Lamsal et al., *ES&T*, 2013

3. Are larger cities better for urban air quality and global climate?



Air pollutant concentrations increase with urban population

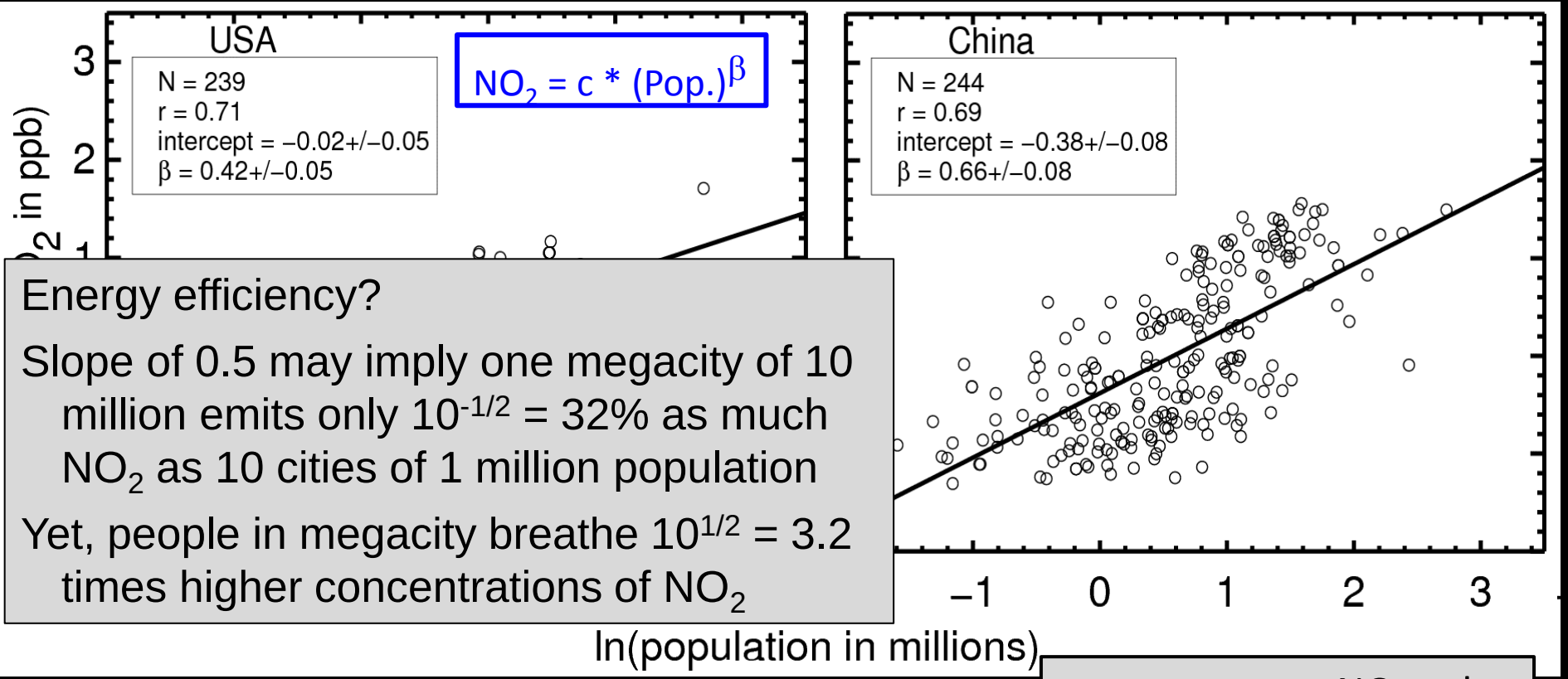
Larger cities worsen urban air quality health effects.

Area	slope	NO_2 ppbv (intercept)
U.S.	0.42	0.98
China	0.66	0.68
Europe	0.48	1.33
India	0.36	0.23

Satellite data can provide an indication

Lamsal et al., *ES&T*, 2013

3. Are larger cities better for urban air quality and global climate?



Energy efficiency?

Slope of 0.5 may imply one megacity of 10 million emits only $10^{-1/2}$ = 32% as much NO_2 as 10 cities of 1 million population

Yet, people in megacity breathe $10^{1/2}$ = 3.2 times higher concentrations of NO_2

Air pollutant concentrations increase with urban population

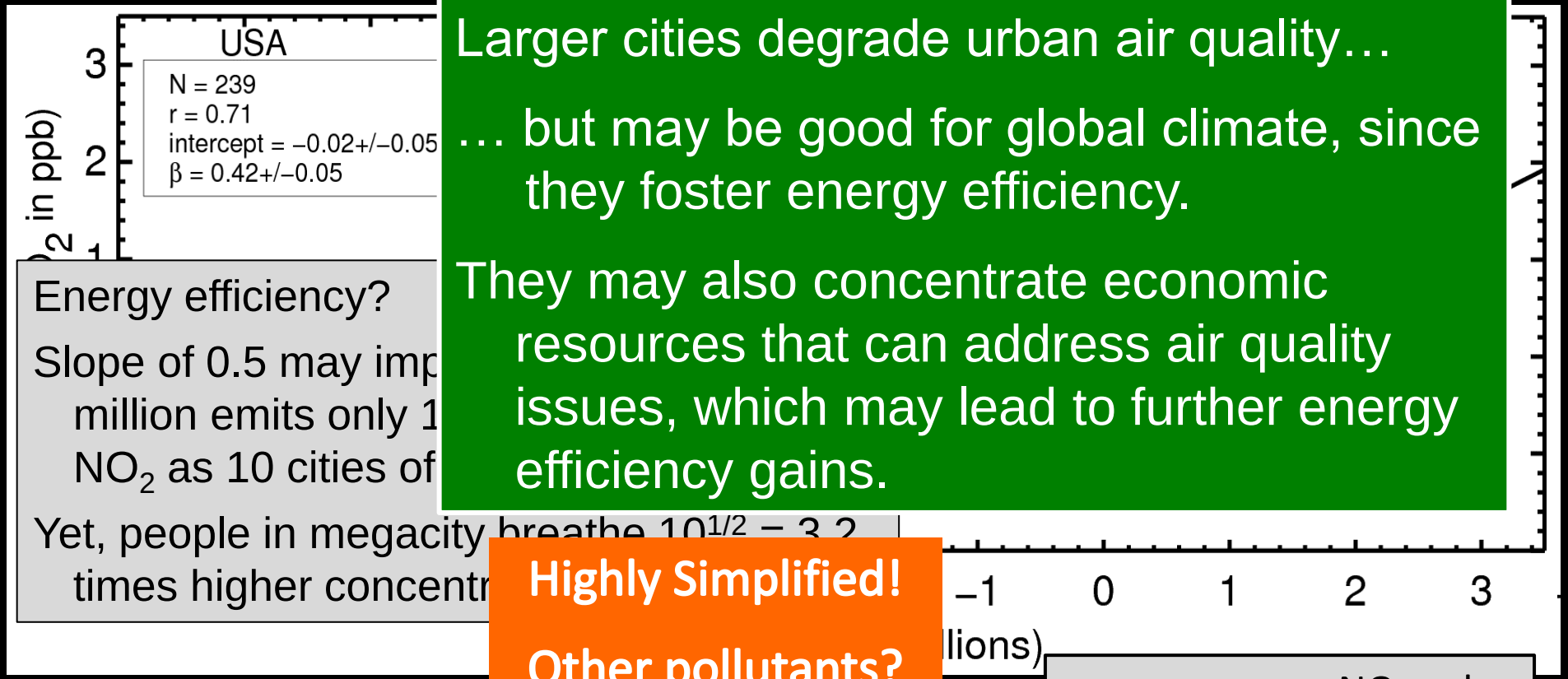
How can slopes be so small?

Area	slope	NO_2 ppbv (intercept)
U.S.	0.42	0.98
China	0.66	0.68
Europe	0.48	1.33
India	0.36	0.23

Satellite data can provide an indication

Lamsal et al., *ES&T*, 2013

3. Are larger cities better for urban air quality and global climate?



Larger cities degrade urban air quality…

… but may be good for global climate, since they foster energy efficiency.

They may also concentrate economic resources that can address air quality issues, which may lead to further energy efficiency gains.

Energy efficiency?

Slope of 0.5 may imp
million emits only 1
NO_2 as 10 cities of

Yet, people in megacity breathe $10^{1/2} = 3.2$
times higher concentr

Highly Simplified!

Other pollutants?

Air pollutant concentrations increase with urban population

How can slopes be so small?

Area	slope	NO_2 ppbv (intercept)
U.S.	0.42	0.98
China	0.66	0.68
Europe	0.48	1.33
India	0.36	0.23

Satellite data can provide an indication

Lamsal et al., *ES&T*, 2013

4. Regional transport: A unique challenge faced by East Asia

Houston:

> 6 million people

≈ 40% U.S. petrochemical industry

Second worst O_3 pollution in the U.S.

Oklahoma

Texas

Mexico

Gulf of Mexico

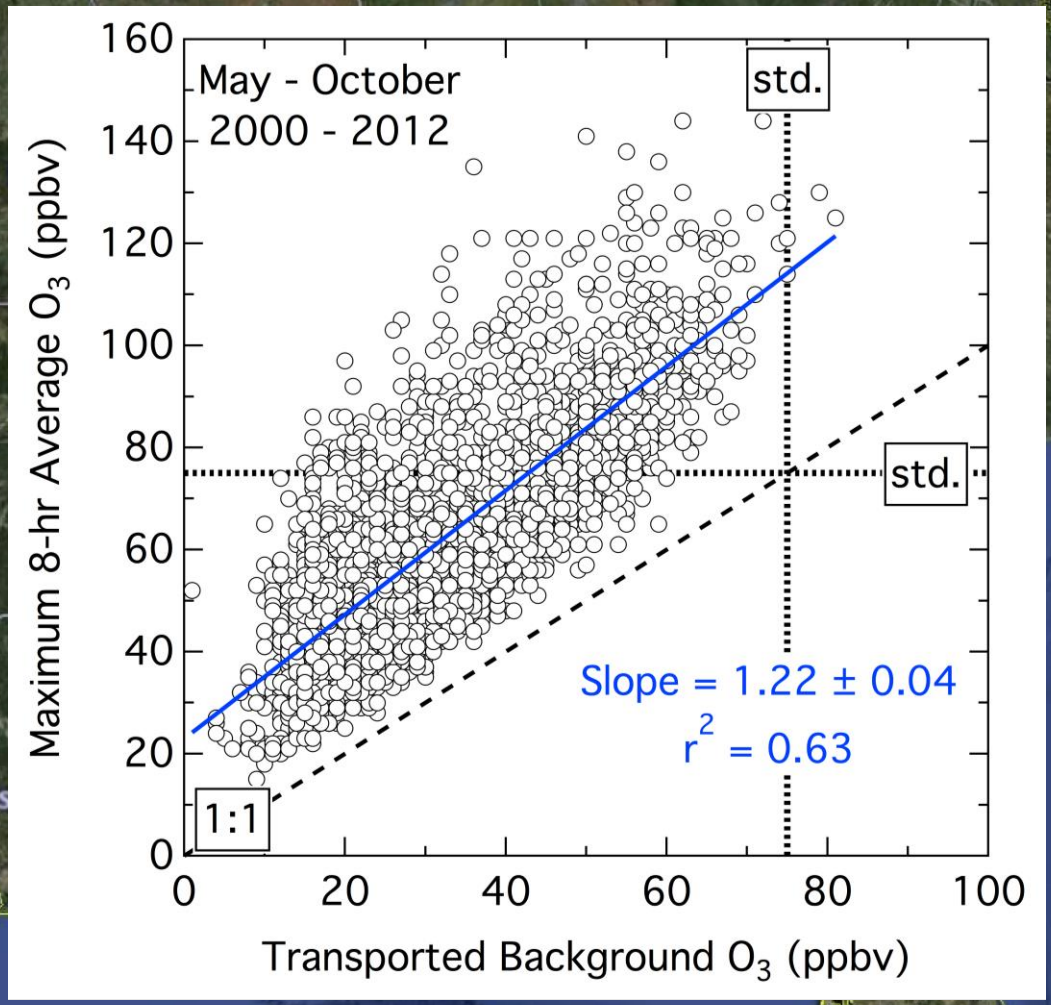
Havana

4. Regional transport: A unique challenge faced by East Asia

Much of Houston's O_3 is transported into the city

Transported O_3:
10 to 75 ppbv.
Can exceed standard.

Houston adds ≈ 35 ppbv
(<10 to 100 ppbv)

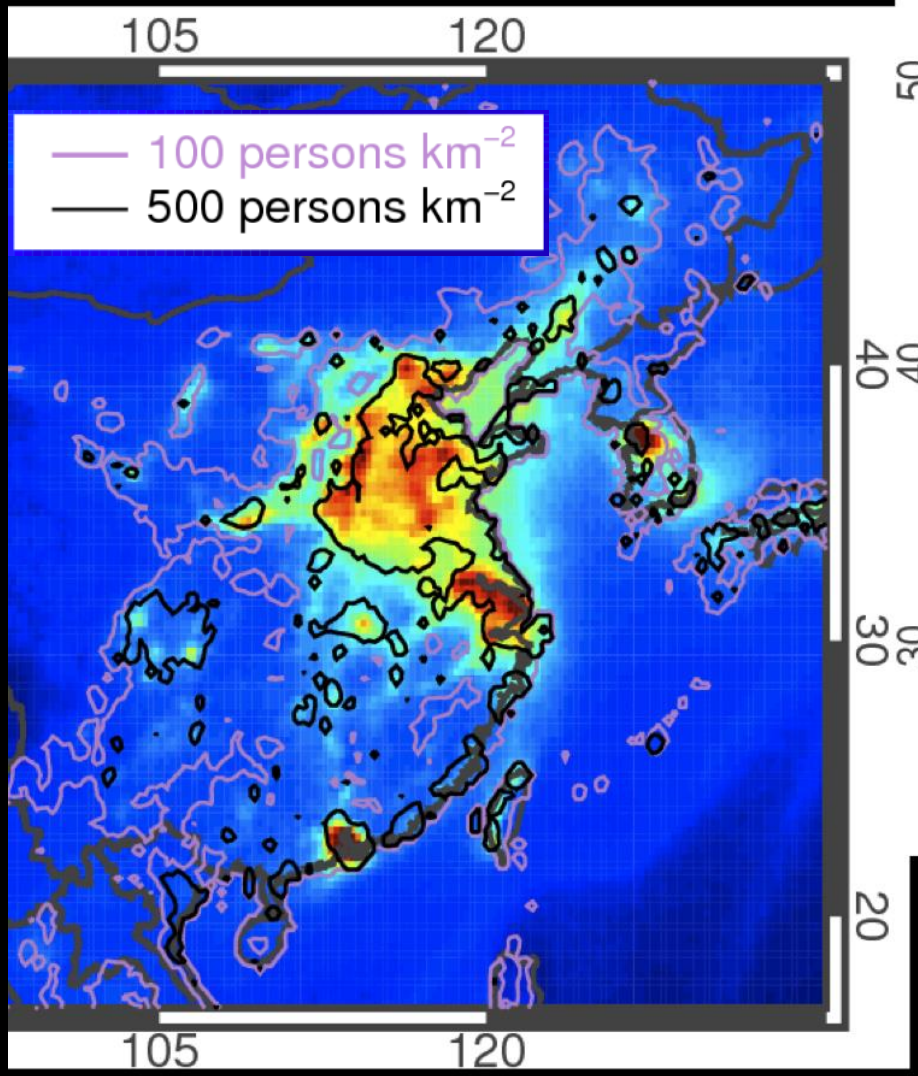


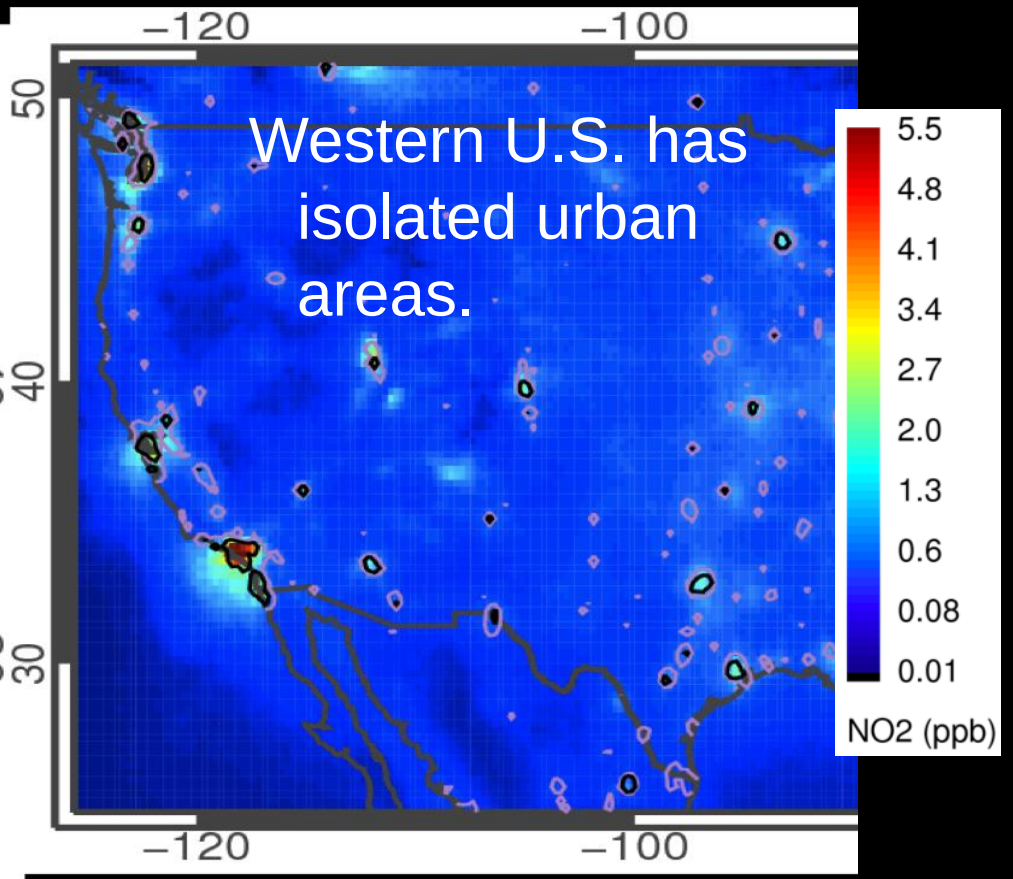
Houston:
> 6 million people
≈ 40% U.S. petrochemical industry
Second worst O_3 pollution in the U.S.

More O_3 is transported into Houston than produced locally!

Berlin et al., *ES&T*., 2013

4. Regional transport: A unique challenge faced by East Asia





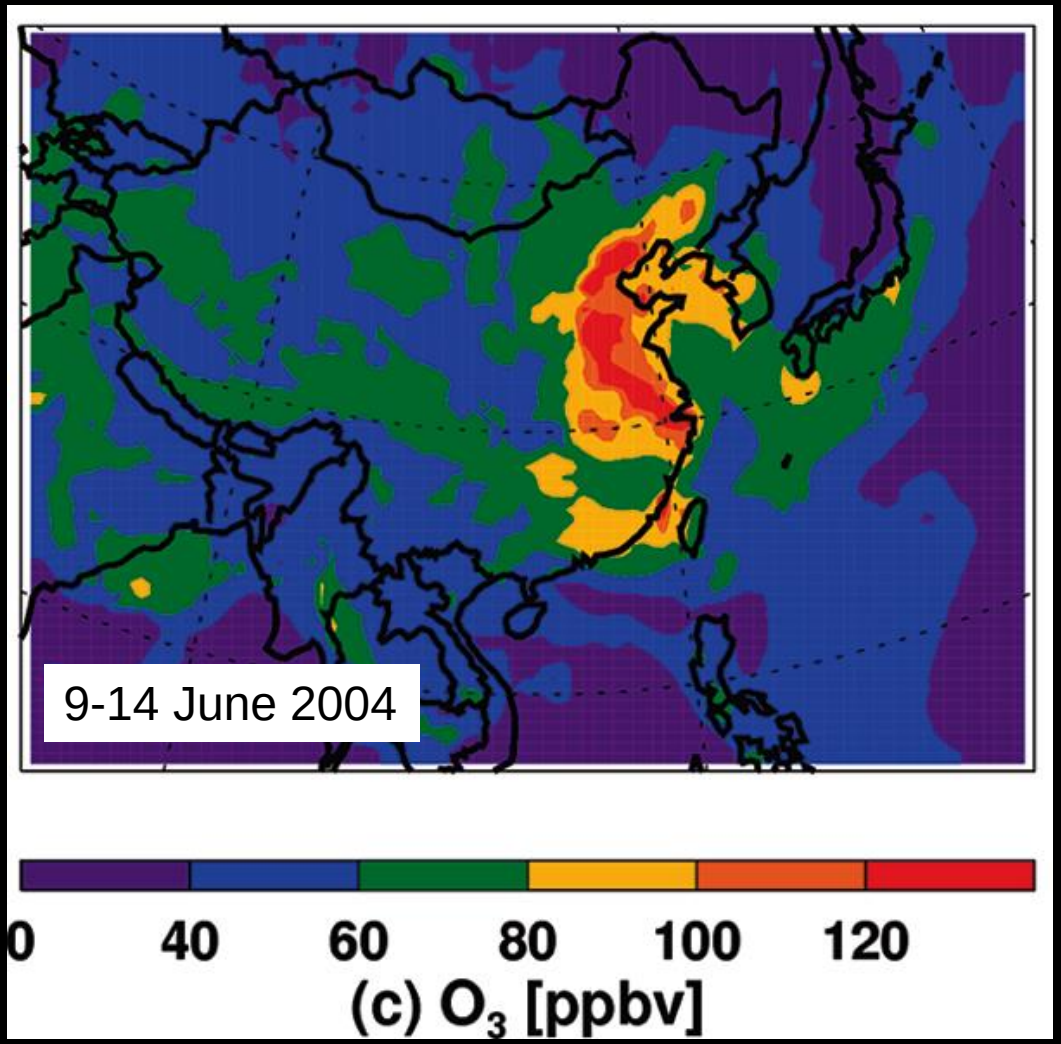
Regional Transport will be particularly important in East Asia

Colors: Surface NO_2 concentration from satellite

Contours: Population density

Lamsal et al., *ES&T*, 2013

4. Regional transport: A unique challenge faced by East Asia



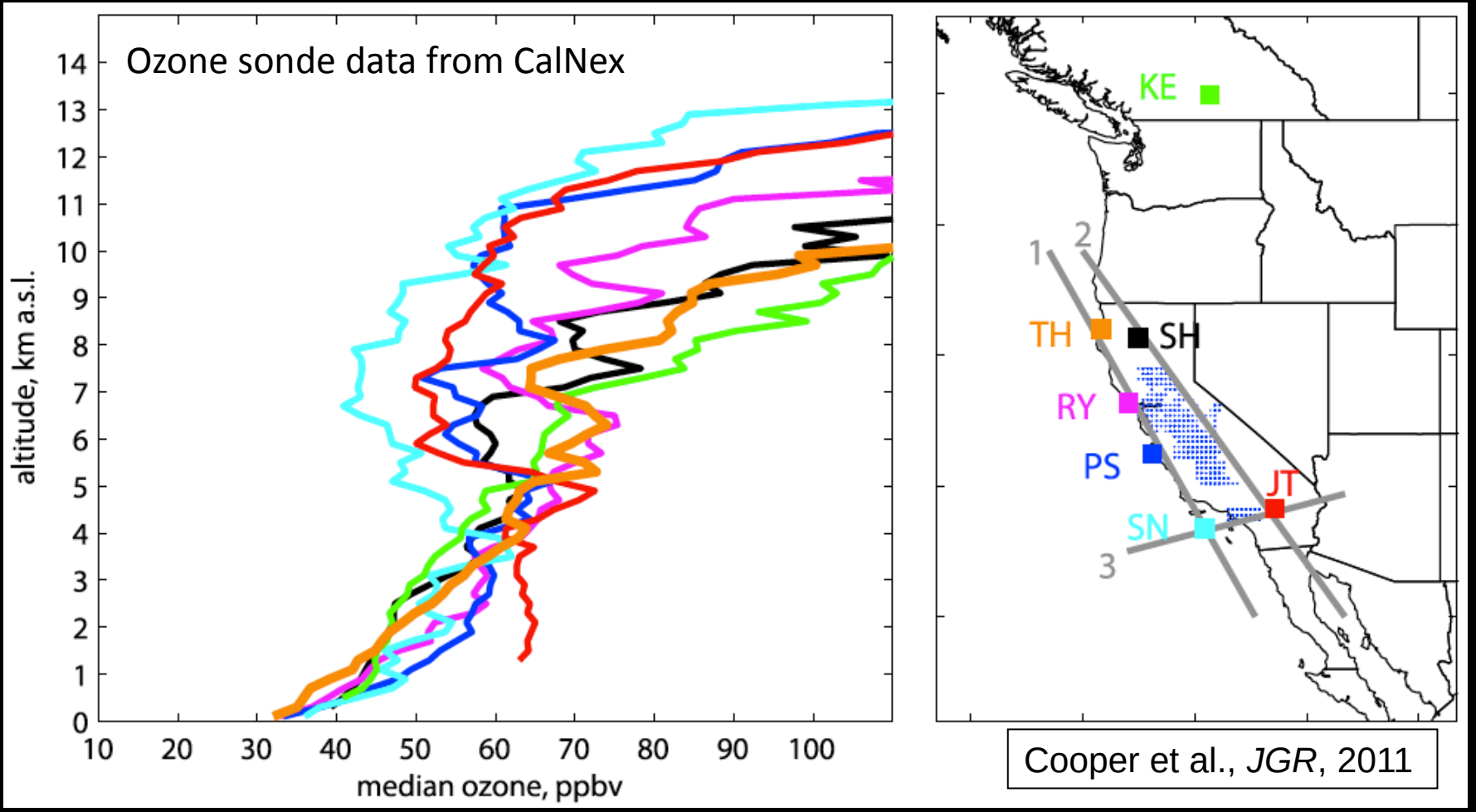
Modeling suggests that pollution episodes may encompass a large fraction of East China plains

In essence the East China plains constitute one mega-city with >800 million people

Regional Transport will be particularly important in East Asia

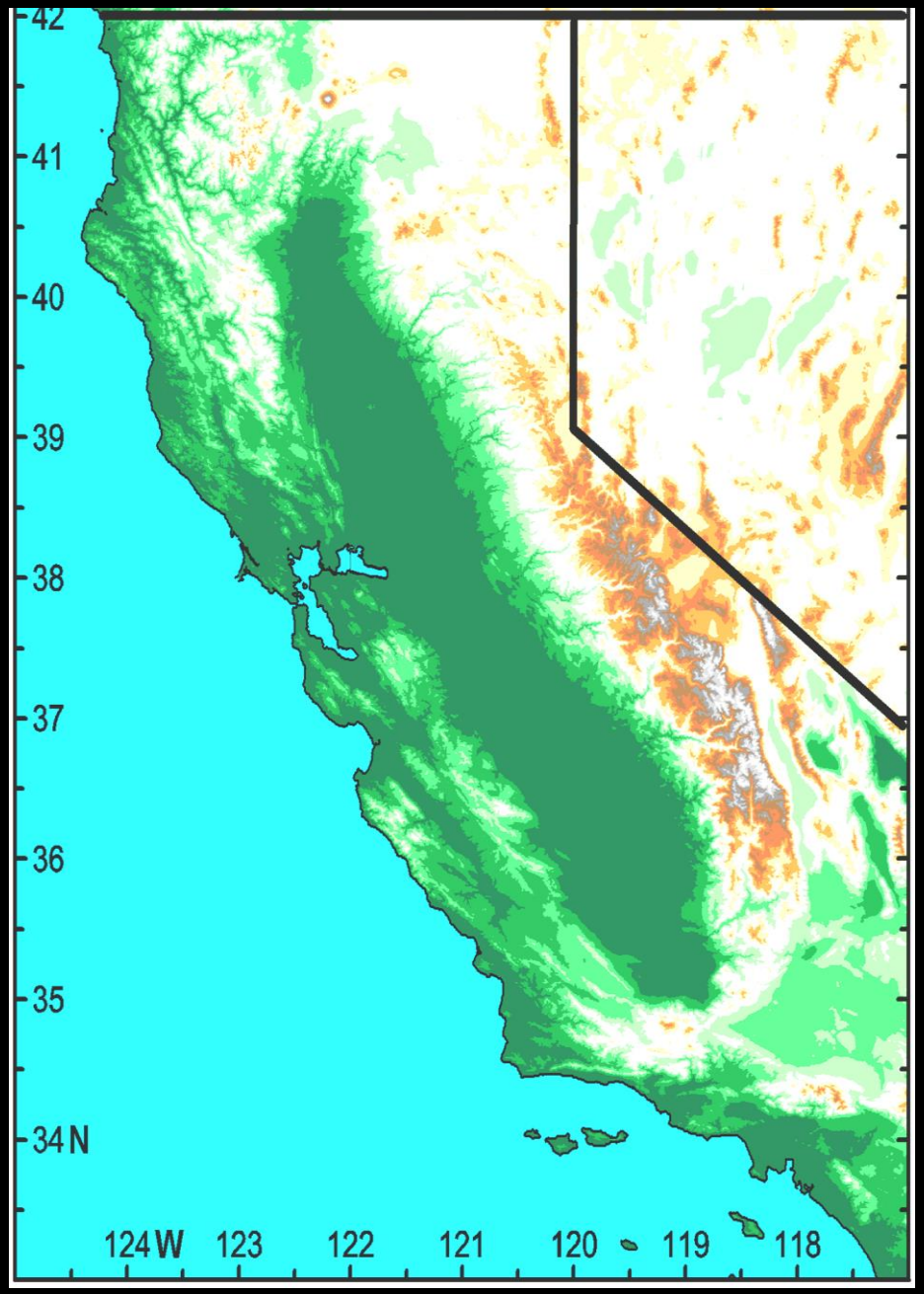
Zhao et al., *ES&T*, 2009

4. Regional transport: What about California?



O_3 concentrations coming ashore to California increase with altitude in lower few kilometers.

4. Regional transport: What about California?

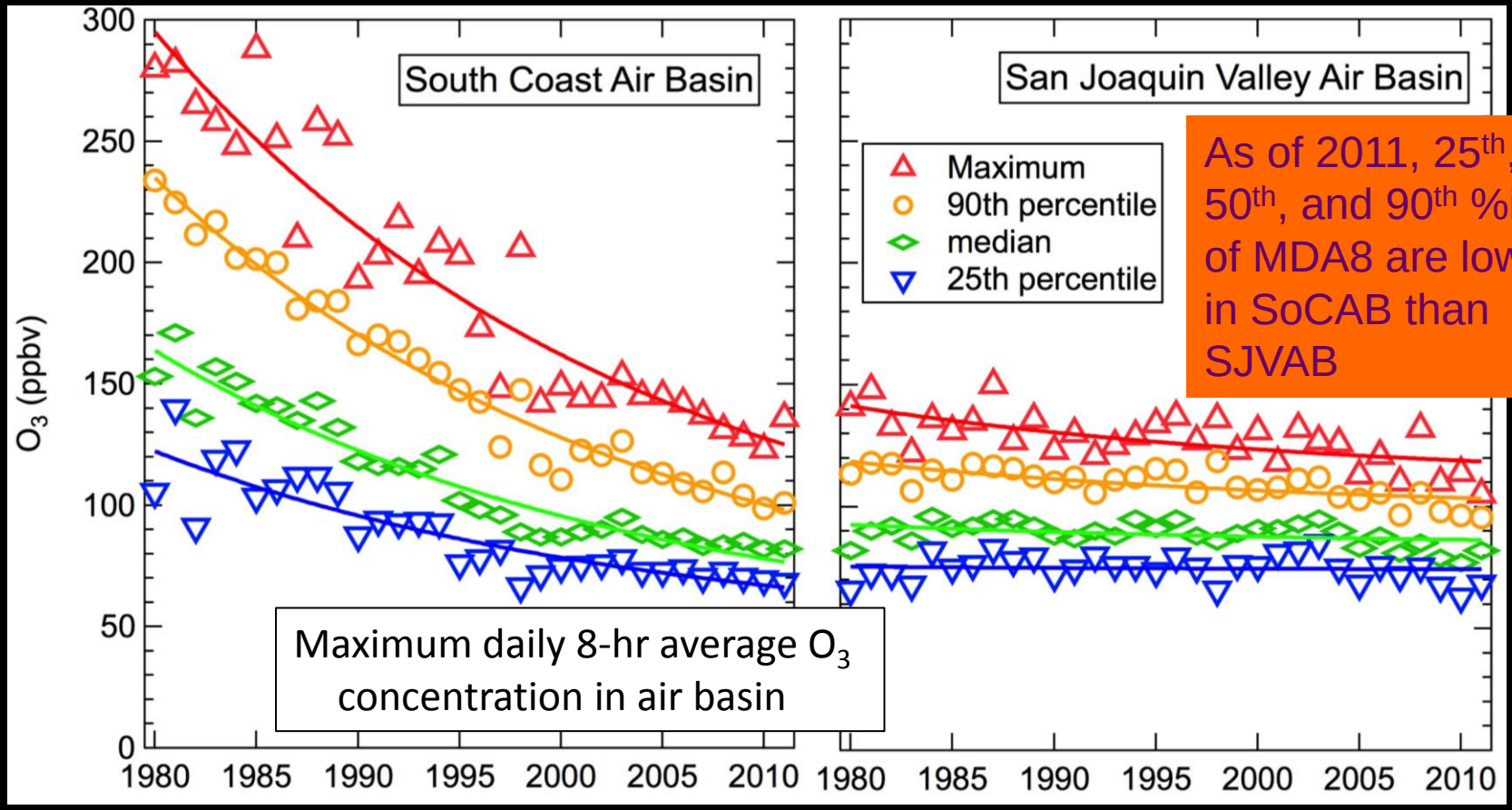


Coastal air basins receive inflow from the Pacific marine boundary layer: ~ 30 ppbv in summer

Central Valley air basins are partially isolated from the Pacific marine boundary layer – may receive higher O_3 concentrations

Is this difference partially responsible for difference in response to control efforts between SoCAB and SJVAB?

4. Regional transport: What about California?



As of 2011, 25th, 50th, and 90th %iles of MDA8 are lower in SoCAB than SJVAB

Other differences (emissions, transport, meteorology, etc.) likely contribute as well

Is this difference partially responsible for difference in response to control efforts between SoCAB and SJVAB?

Today:

May currently developing mega-cities learn from earlier experience, and improve air quality more quickly than was possible in Los Angeles!

1. Air Pollution in today's developing mega-cities is no worse than in earlier developing mega-cities
2. Improving urban air quality is possible, … but requires very substantial emission reductions: The Los Angeles experience – Scientific, social, and political dimensions.
3. Larger cities degrade urban air quality,…
   … but may be good for global climate, since they foster energy efficiency.
4. Extremely important regional transport is a unique challenge faced by East Asia – Exacerbate political dimension?