# CHANGES IN EMISSIONS AND AMBIENT CONCENTRATIONS OF NITROGEN DIOXIDE: THE U.S. AND CALIFORNIA EXPERIENCE

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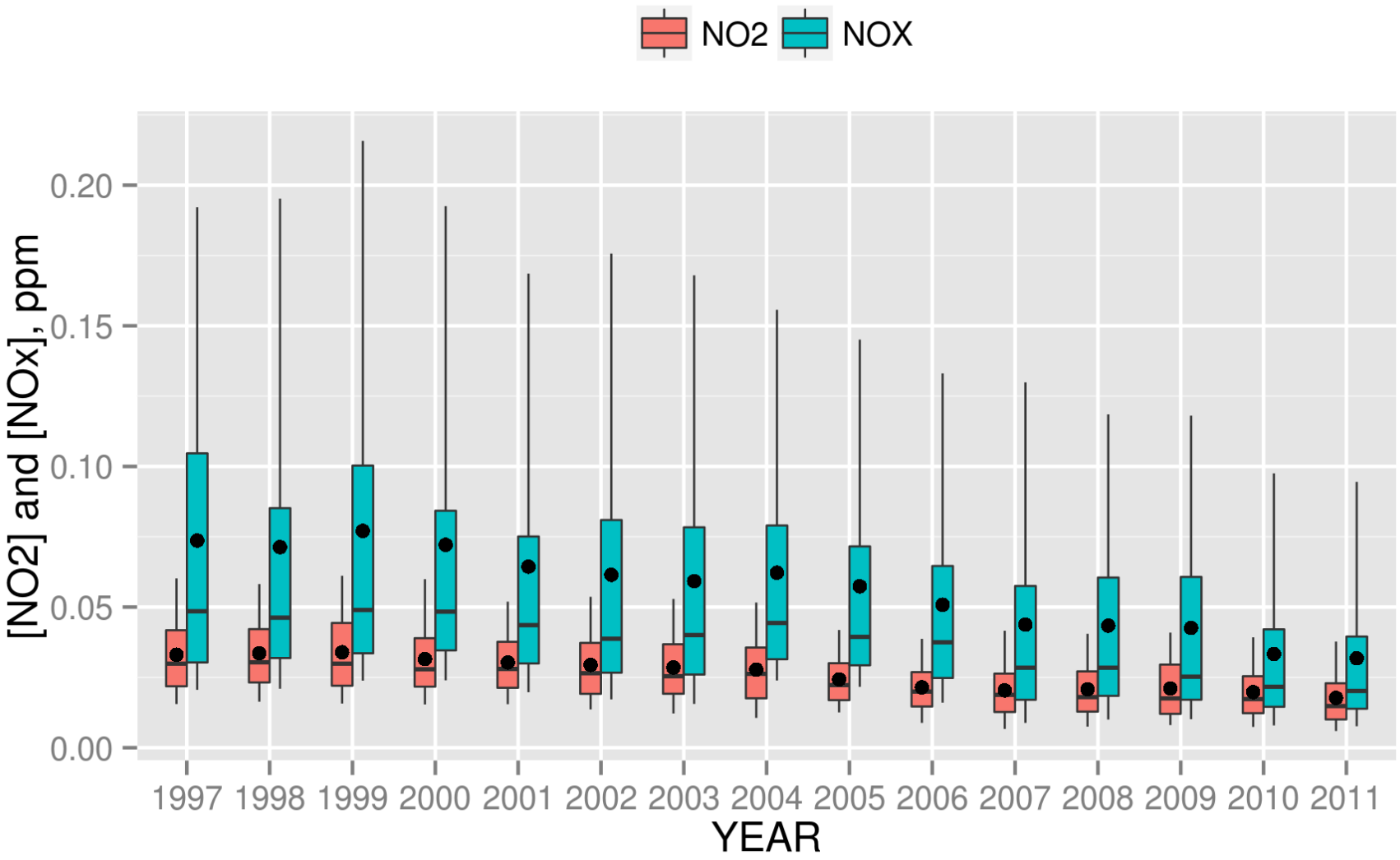
# Introduction

- $NO_2$ typically thought of as a secondary pollutant
  - Forms via atmospheric oxidation of primary $NO_x$ emissions which are mostly NO (nitric oxide)
- Emissions and ambient concentrations of $NO_x$ have been decreasing in the U.S. since the late 1990s
- Ambient $NO_2$ is not decreasing as rapidly as $NO_x$
  - due in part to increased primary $NO_2$ emissions?

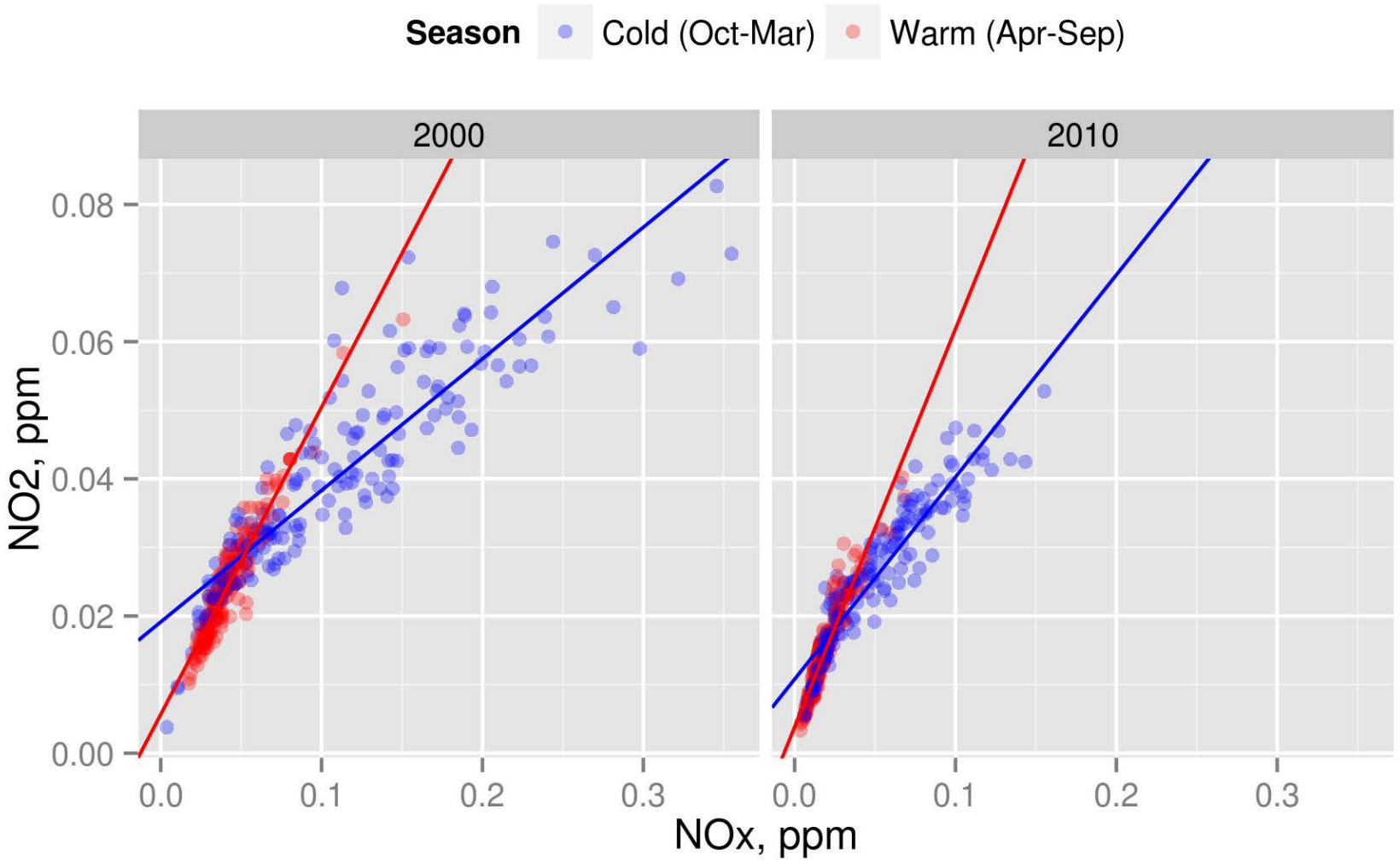
# Trends in Ambient $NO_2$ and $NO_x$

(Daily Averages from Long Beach, CA)



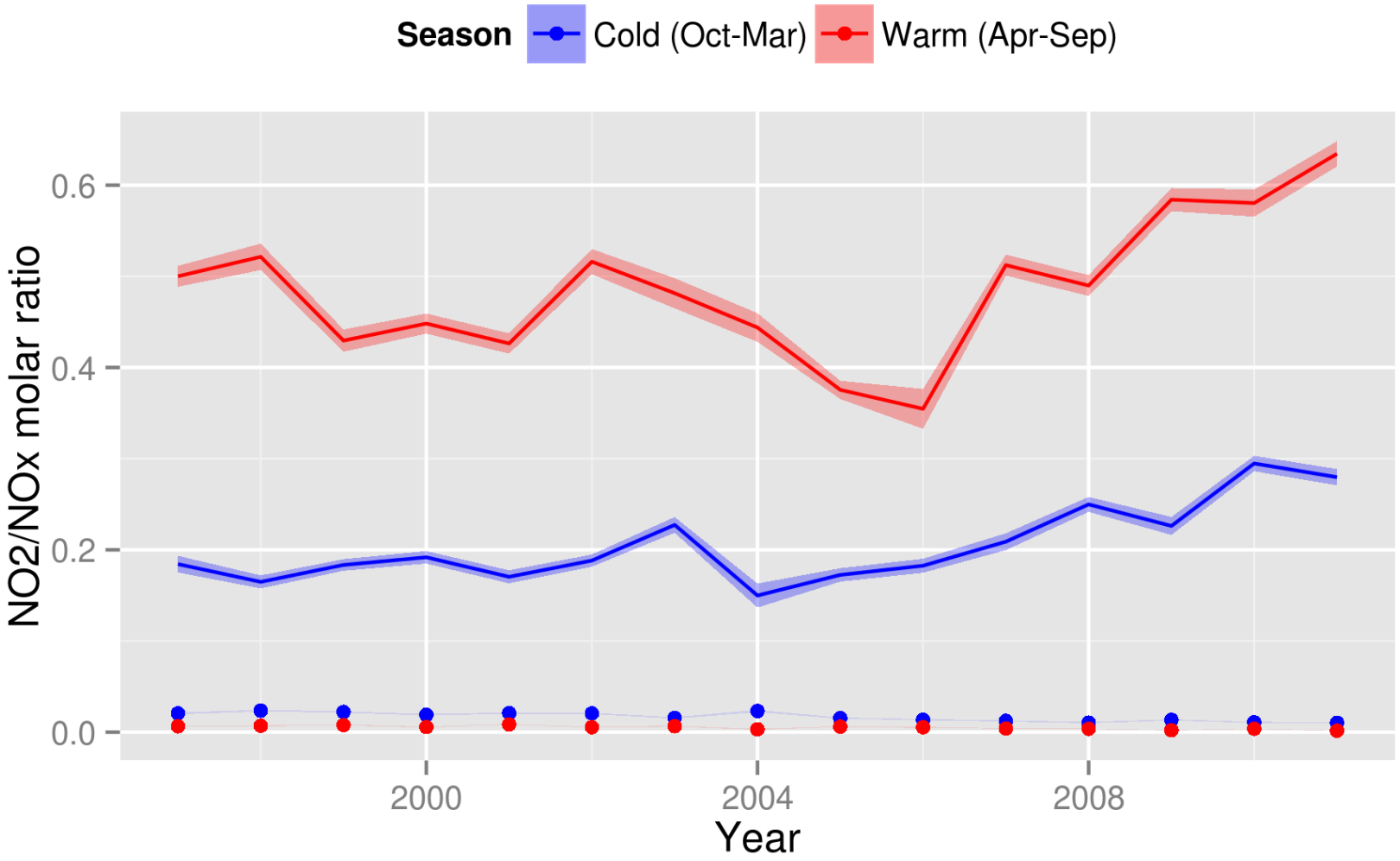
# Correlation Between Ambient $NO_2$ & $NO_x$

(Daily Averages from Long Beach, CA)



# Trends in Ambient $NO_2/NO_x$ Ratio

(Separate Results for Winter and Summer)

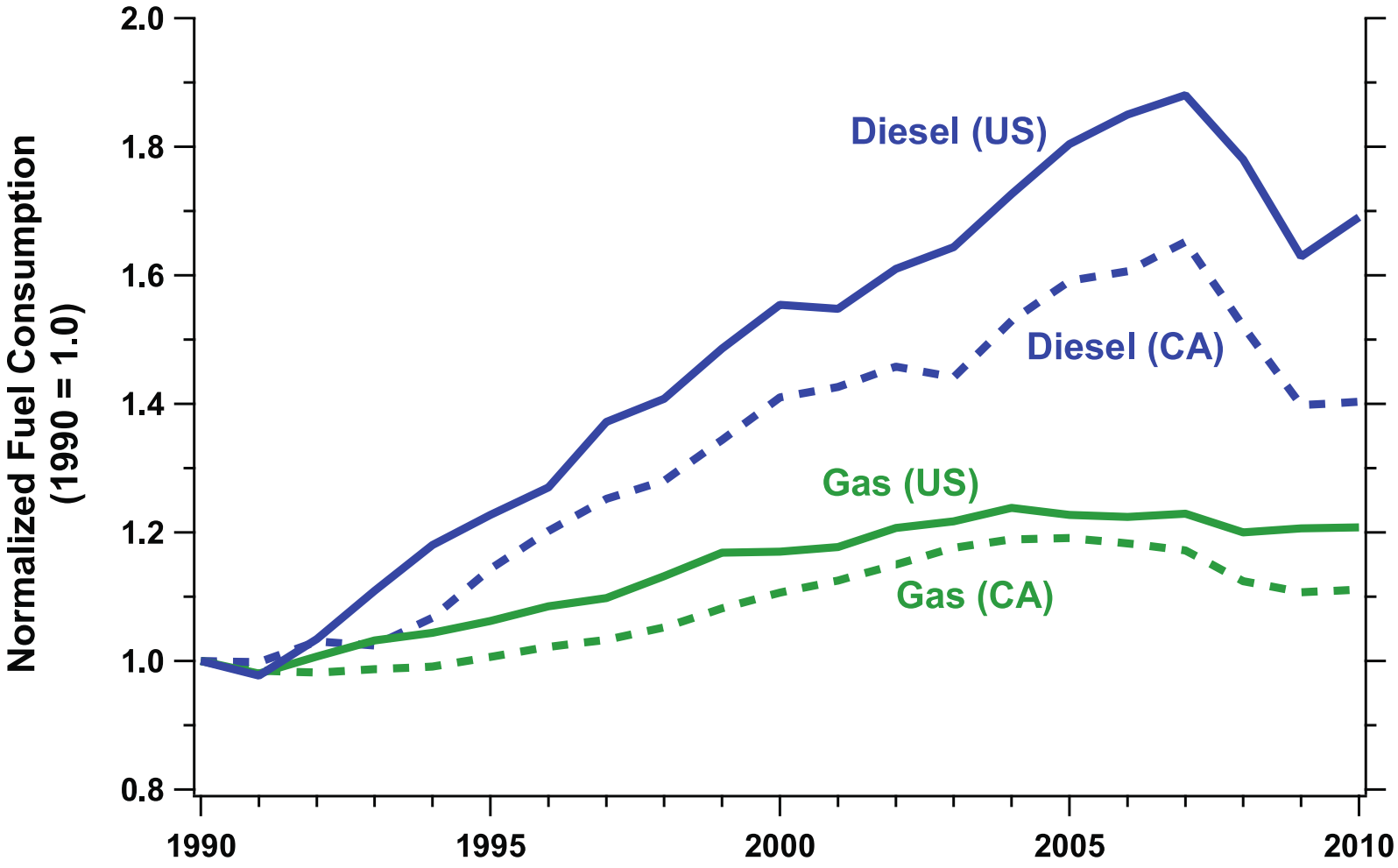


# $NO_x$ and $NO_2$ Emission Trends

- Mobile sources (gasoline and diesel engines) are major emitters of $NO_x$
  - Diesel contribution rising as emissions from gasoline engines and stationary sources are controlled
  - First round of diesel $NO_x$ control efforts in the 1990s failed to achieve expected emission reductions
- Use of diesel particle filters to control PM emissions has led to increased primary emissions of $NO_2$

# Trends in Fuel Use by On-Road Vehicles

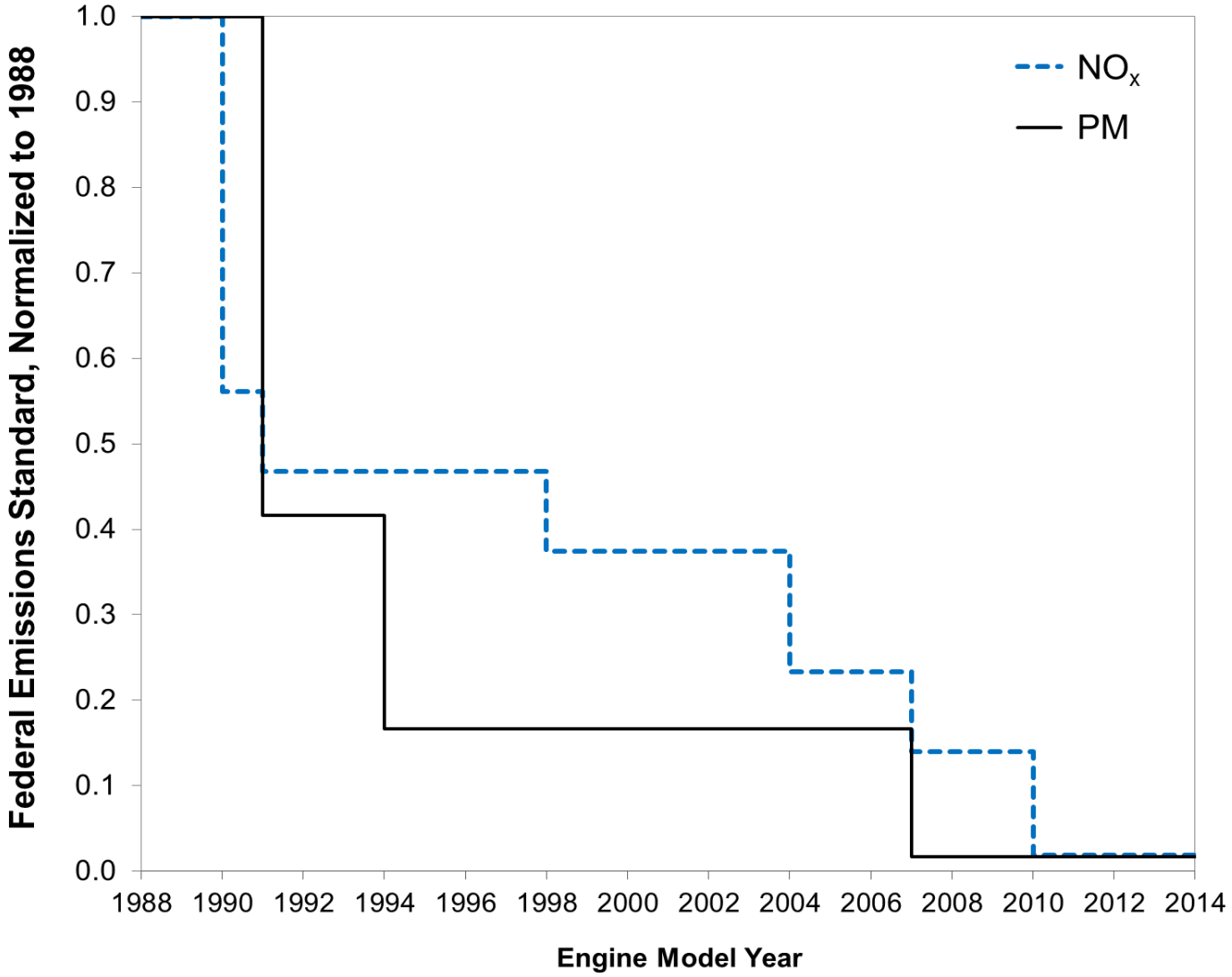
(From State and National Fuel Excise Tax Data)




McDonald et al. (JGR 2012)

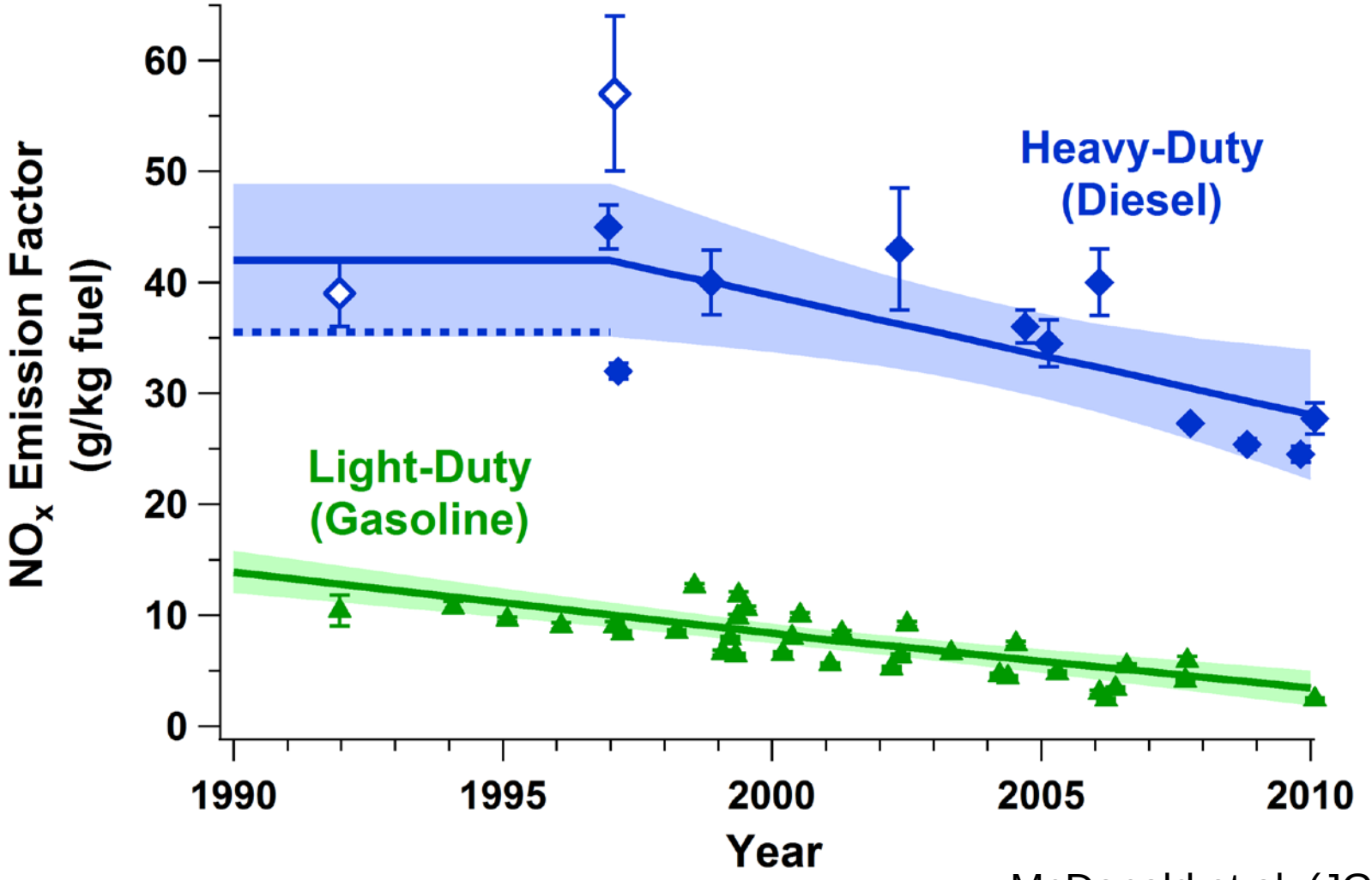
# Heavy-Duty Diesel Emission Standards

(For New On-Road Engines -- by Model Year)



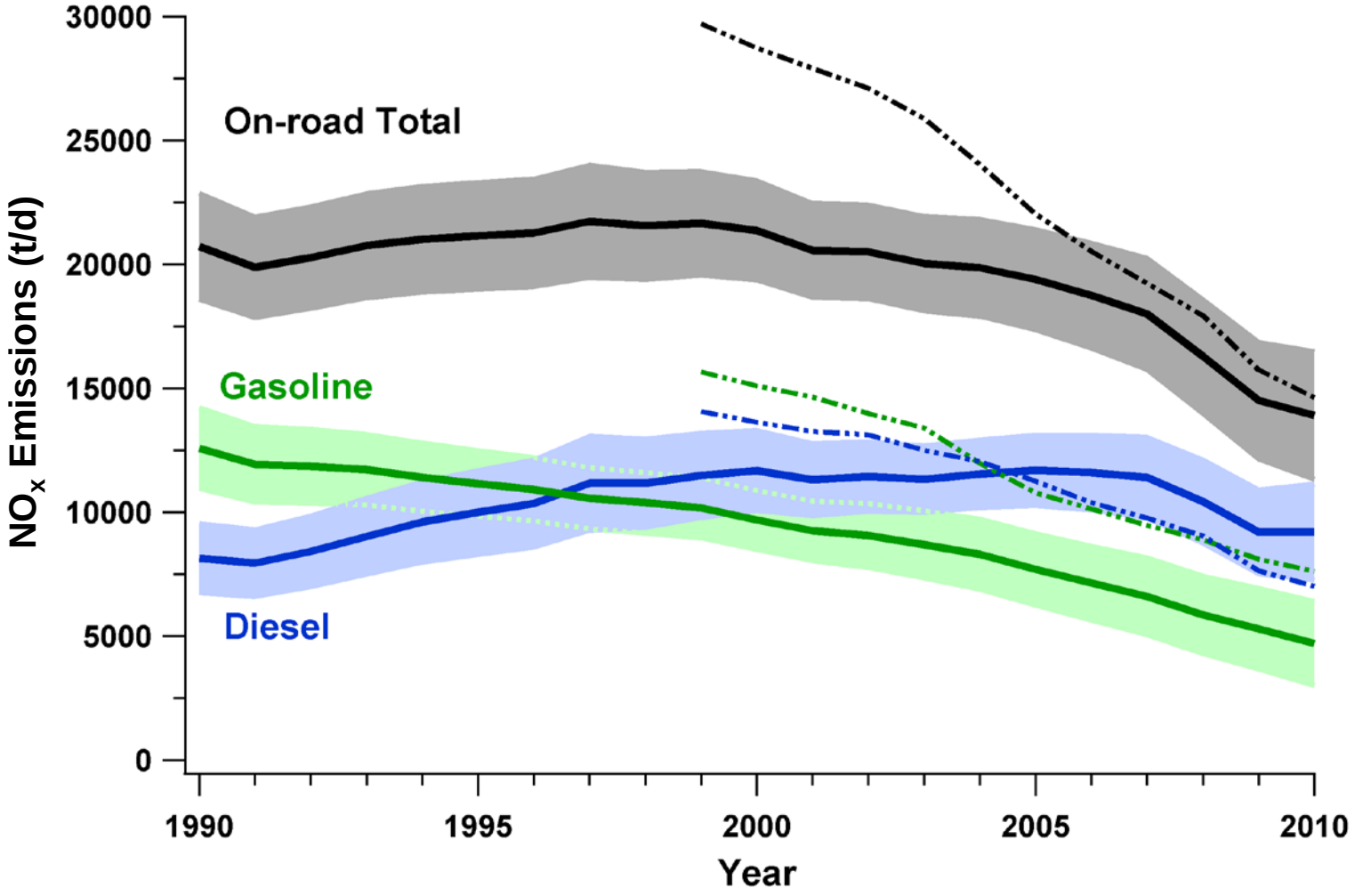
# $NO_x$ Emission Factor Trends

Tunnel and Roadside Measurements of In-Use Emissions




McDonald et al. (JGR 2012)

# National $NO_x$ Emission Trends
(On-Road Gasoline and Diesel Engines Only)



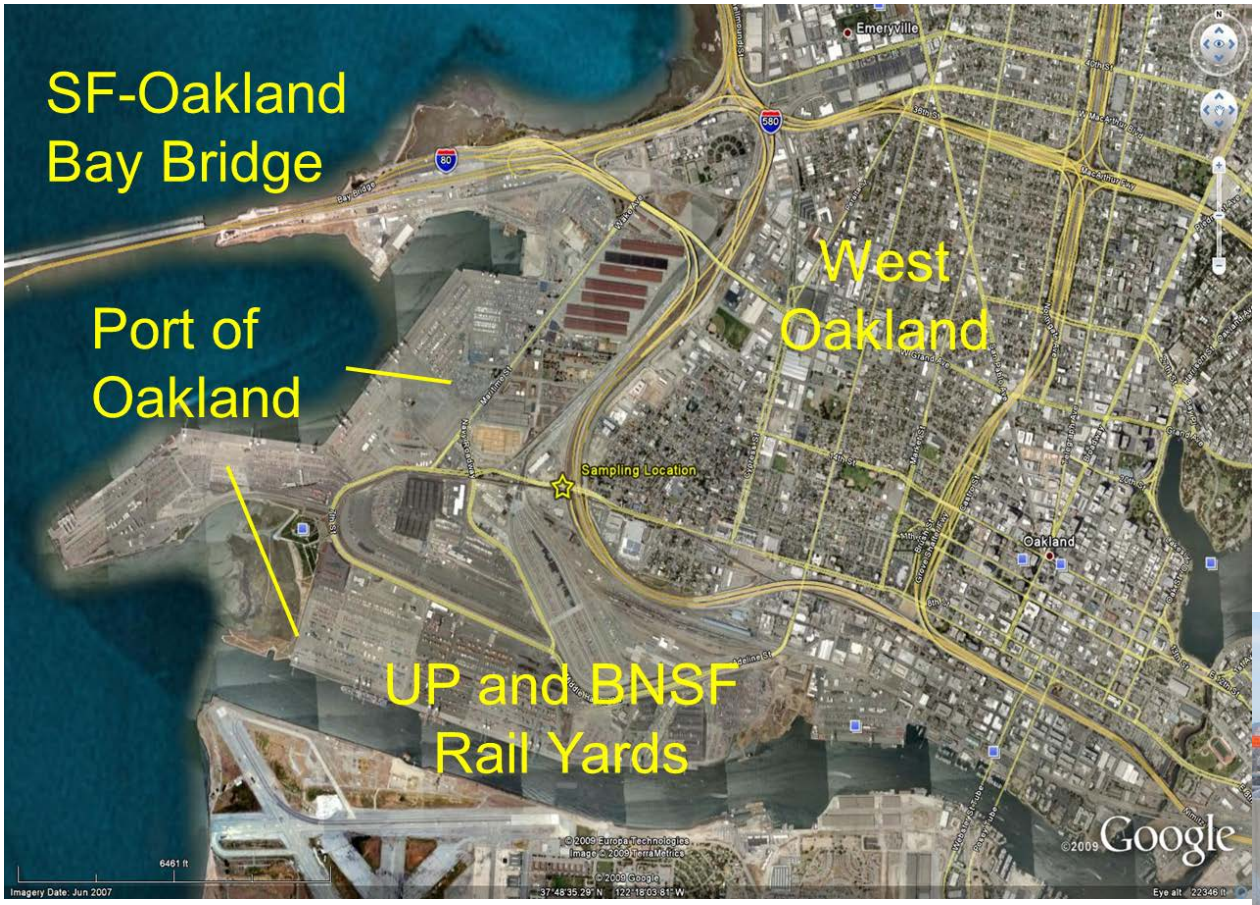

McDonald et al. (JGR 2012)

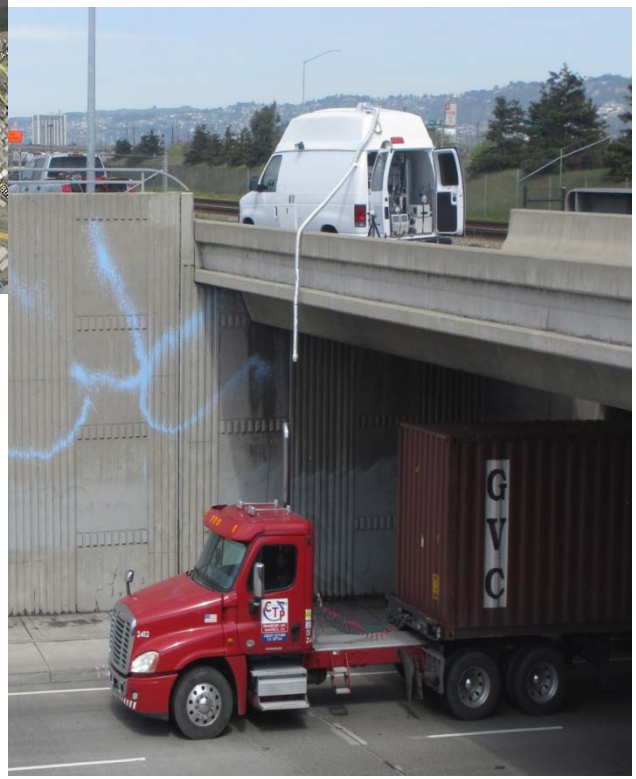
# National $NO_x$ Emission Trends
(Including Stationary and Off-Road Mobile Sources)

McDonald et al. (JGR 2012)

# California Ports: Preview of Future Changes in Diesel Emissions

- Accelerated retrofit / replacement of older diesel engines is required in California
  - Near-universal PM and $NO_x$ emission control required by 2016 and 2023, respectively
  - Early action item: drayage trucks in short-haul freight service to / from ports and rail yards “fixed” by 2013


SF-Oakland
Bay Bridge
Port of
Oakland
West
Oakland
UP and BNSF
Rail Yards
Sampling Location
Emeryville
Oakland
©2009 Google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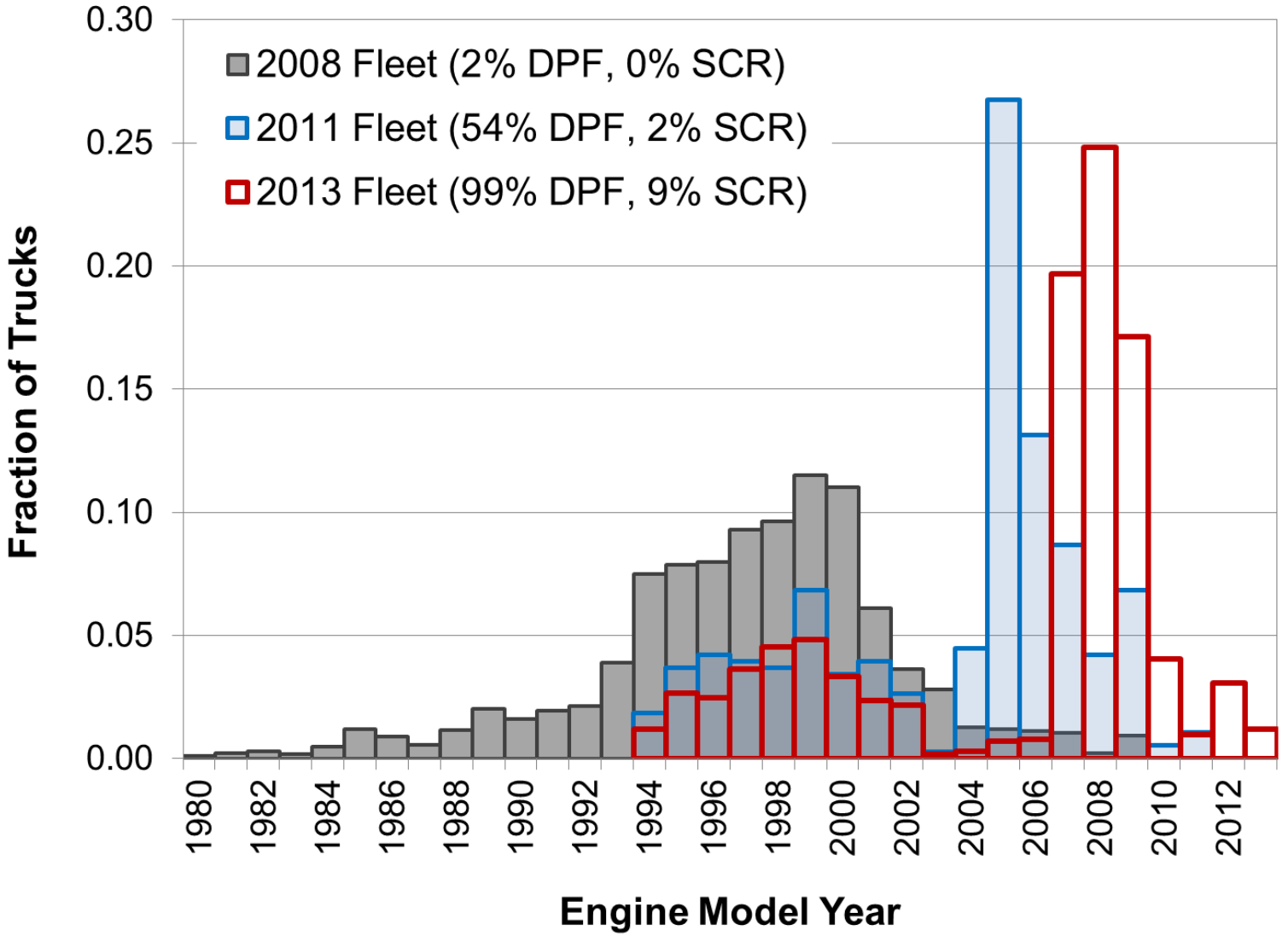
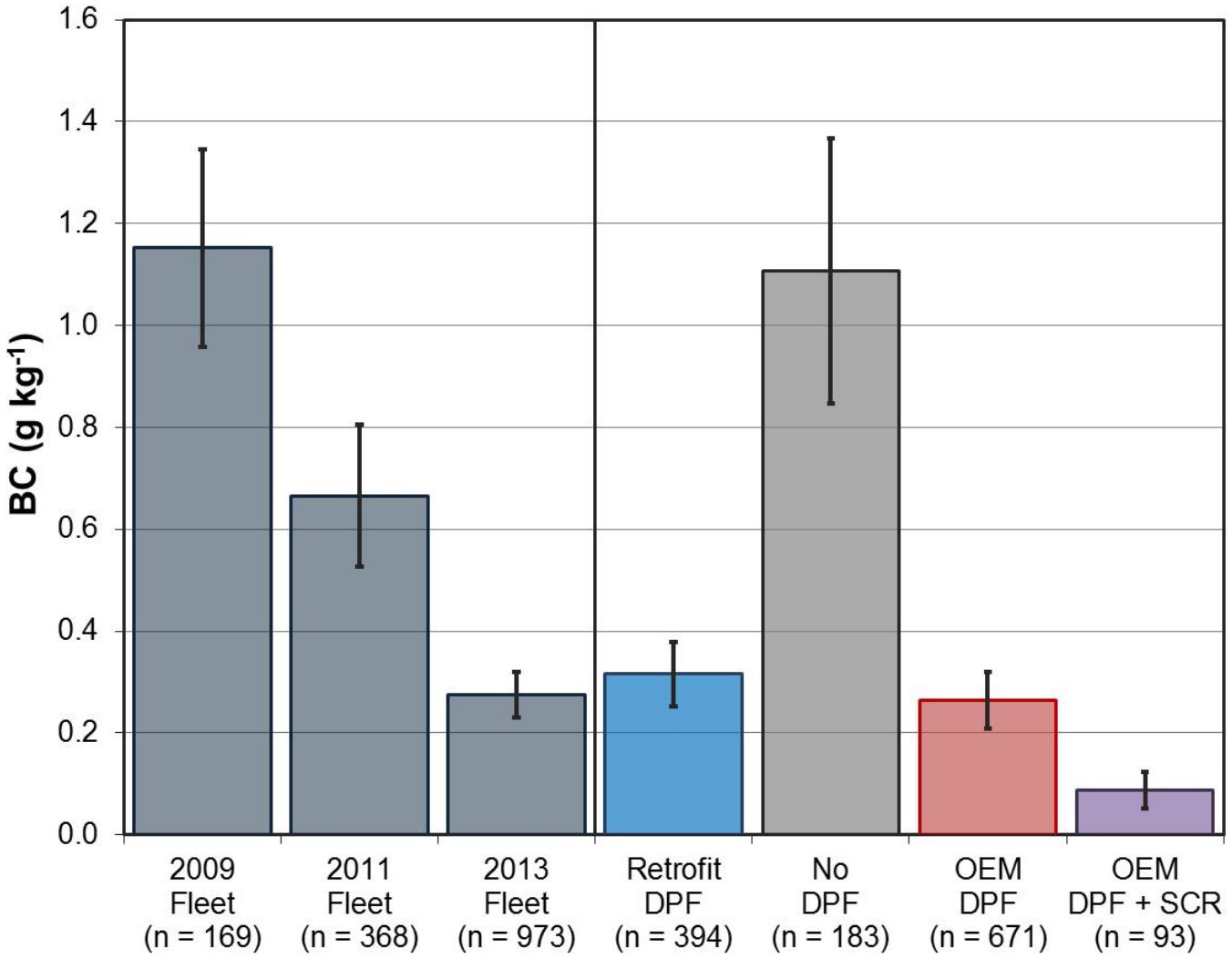
# Port Truck Age Distribution



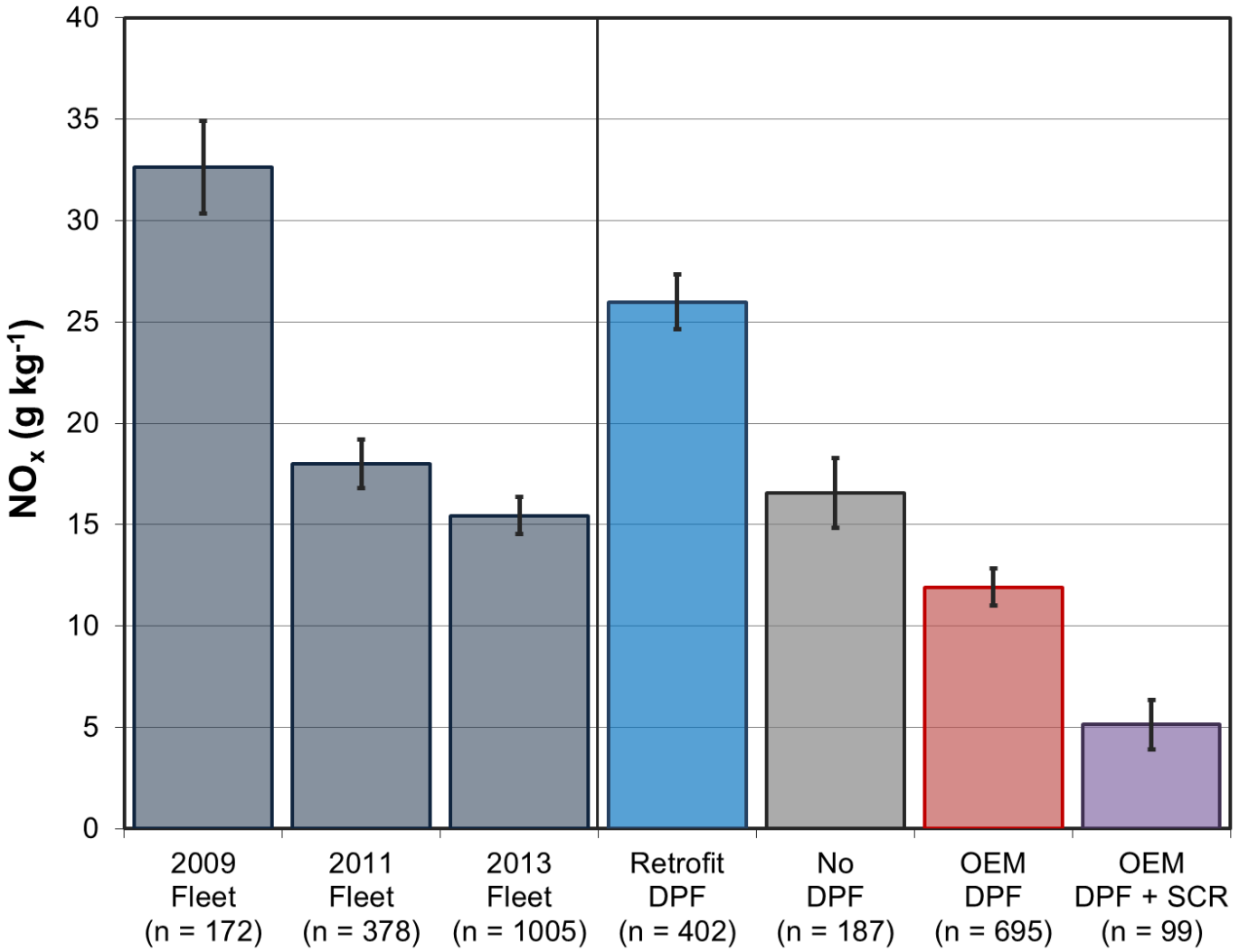
# Black Carbon Emission Factors

Decreased by 76 ± 22% between 2009 and 2013



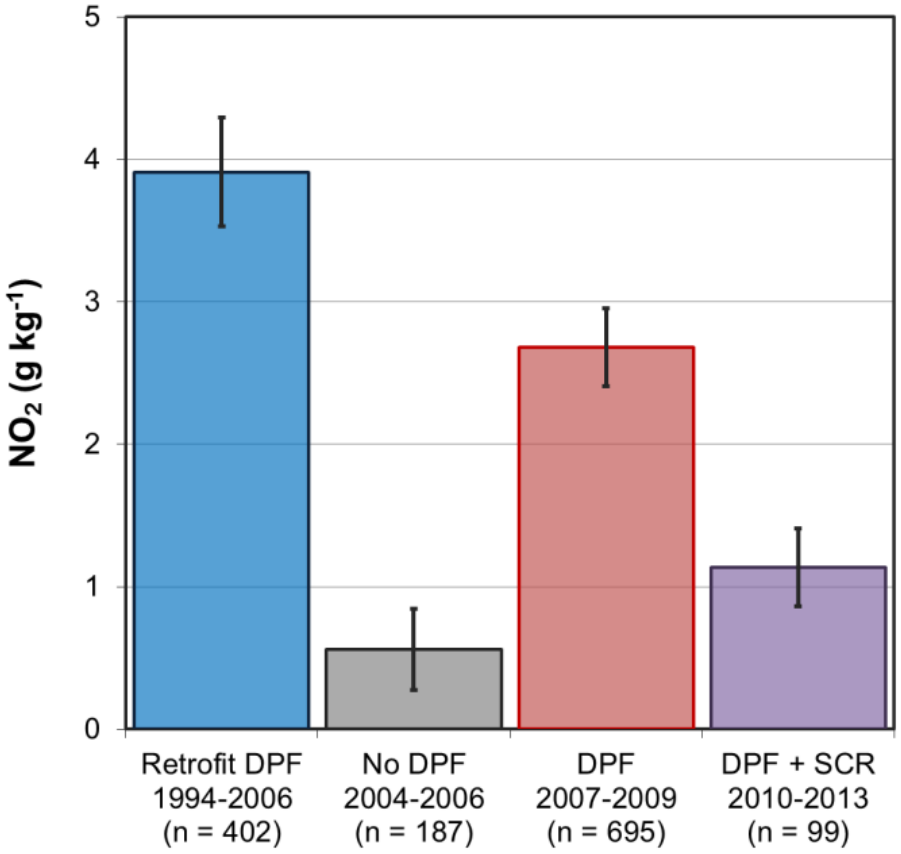
# $NO_x$ Emission Factors

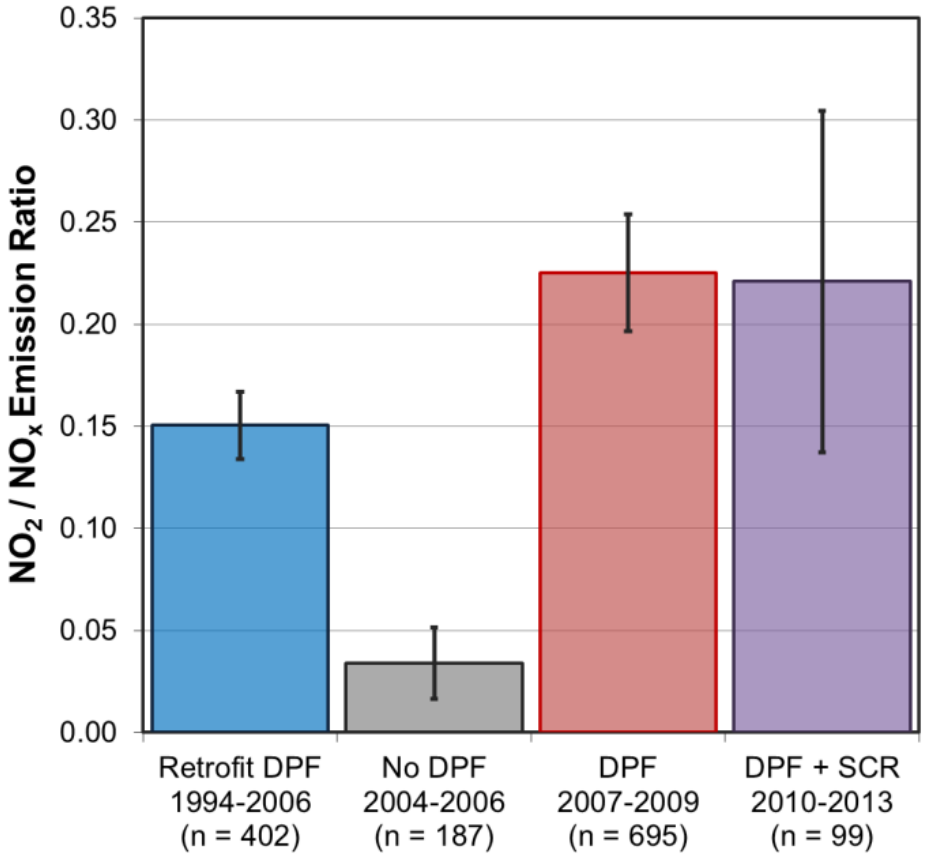
## Decreased by 53 ± 8% between 2009 and 2013



# $NO_2$ Emissions and $NO_2/NO_x$ Ratio

## $NO_2$ increased from 3 to 18% of total $NO_x$ emissions

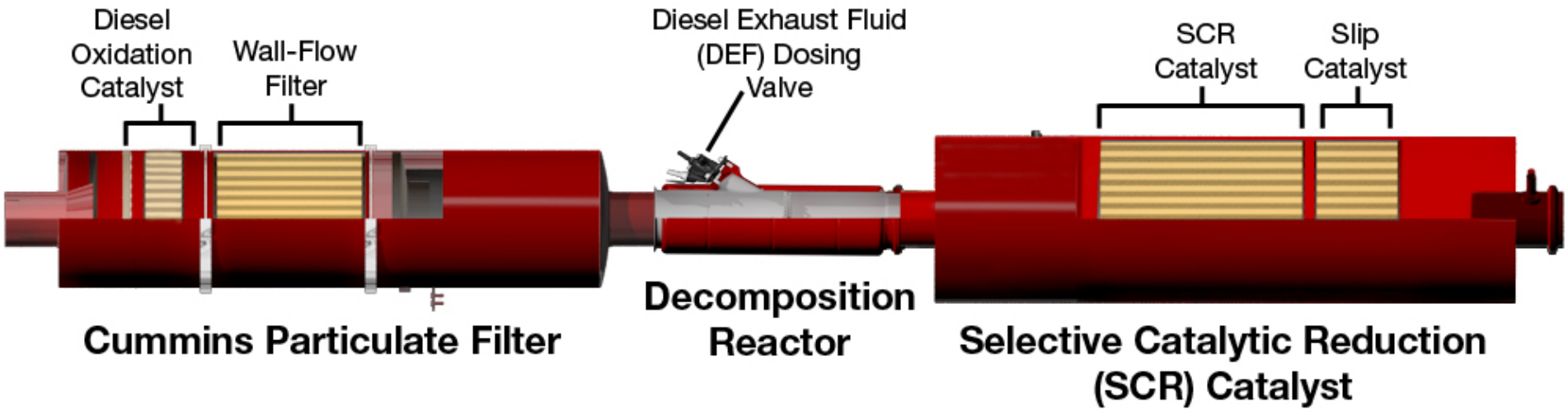


# Summary

- In summer, $NO_2$ appears to be mostly formed via atmospheric oxidation of NO rather than directly emitted
  - Winter situation may be more affected by increased primary $NO_2$
- Rapid changes in diesel emissions at Port of Oakland:
  - Black carbon (BC) decreased by 76 ± 22%
  - $NO_x$ decreased by 53 ± 8% (due to fleet modernization)
  - $NO_2$ increased from 3 to 18% of total $NO_x$ emissions (due to DPF)
- Advanced $NO_x$ controls (e.g., selective catalytic reduction) will help to mitigate increases in primary $NO_2$ emissions associated with widespread use of diesel particle filters

# Diesel Particle Filter (DPF) & Selective Catalytic Reduction (SCR)




Used on 2007 & newer engines
(DPF retrofits possible on older engines)

PM from engine exhaust trapped on filter

$NO_2$ oxidizes trapped carbon particles
(this helps to regenerate the filter)

Used on 2010 & newer engines
(SCR is difficult to add as a retrofit)

DEF = mixture of urea + water
Urea converted to 2 $NH_3$ + $CO_2$

$NH_3$ reacts with $NO_x$ to form $N_2$