Black Carbon 101 for Air Quality Managers

Webinar

June 21, 2012

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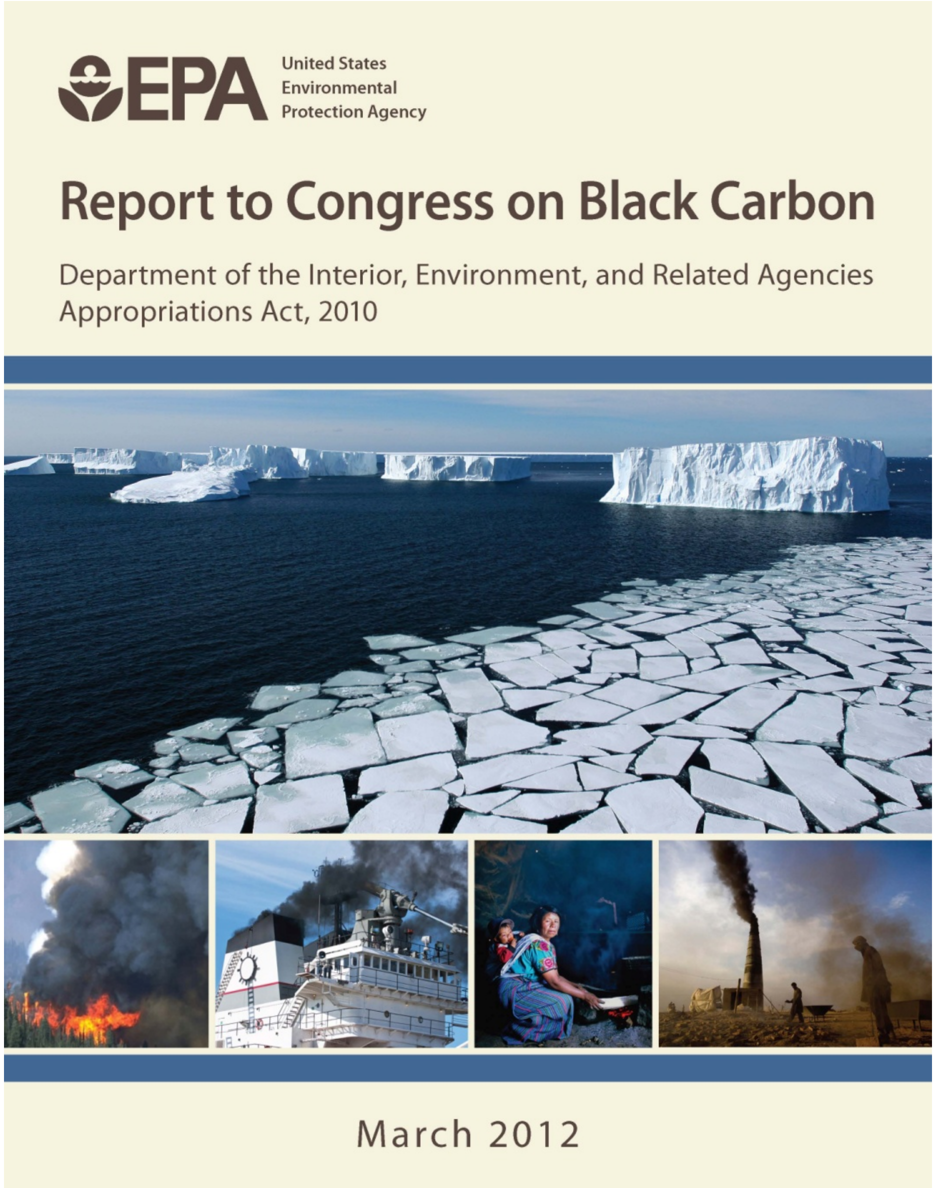
Background:
EPA's Report to Congress on Black Carbon


- In October 2009, Congress requested that EPA conduct a comprehensive study on black carbon to evaluate domestic and international sources, and climate/health impacts.
- EPA completed this report on March 30, 2012.
- Available online at: www.epa.gov/blackcarbon.



The Report:

- Defines black carbon (BC) and describes its role in climate change.
- Characterizes the full impacts of BC on climate, public health, and the environment based on recent scientific studies.
- Summarizes data on domestic and global BC emissions, ambient concentrations, deposition, and trends.
- Discusses currently available mitigation approaches and technologies for four main sectors:
  - Mobile Sources
  - Stationary Sources
  - Residential Cooking and Heating
  - Open Biomass Burning
- Considers the potential benefits of BC mitigation for climate, public health, and the environment.

Today’s Webinar:

- Focus will be on black carbon in the U.S. air quality management framework.
- Key Topics:
  - Climate impacts of black carbon
  - Emissions and ambient measurements of black carbon in the U.S. (including trends)
  - Black carbon mitigation options and public health co-benefits
  - Special emphasis on U.S. mobile source programs: new engine standards and retrofits

Summary of Key Messages from Today's Presentation

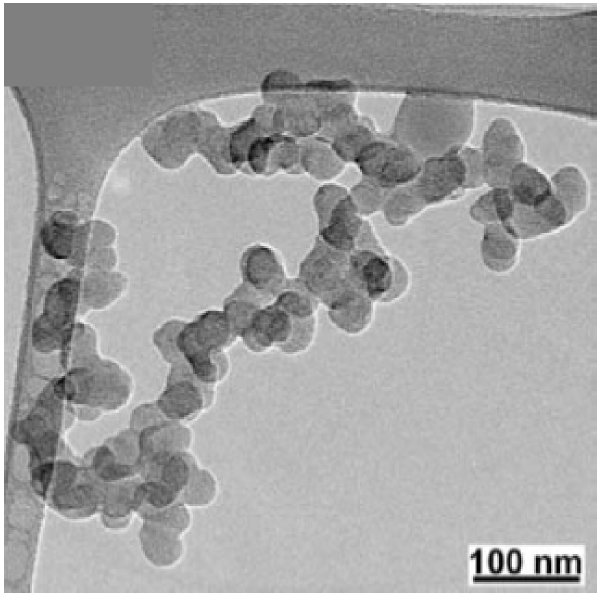
- Black carbon emissions affect the Earth in a number of significant ways.
- Targeted reductions in black carbon (BC) emissions can provide significant near-term climate benefits, and the health and environmental co-benefits are very large.
- Effective control technologies and approaches are available to reduce BC emissions from a number of key source categories.
- U.S. BC emissions have been declining, and additional reductions are expected by 2030 due to controls on mobile diesel engines.
- Measurements indicate that ambient BC has declined and $PM_{2.5}$ air quality has improved due to these emissions reductions.
- Controlling direct $PM_{2.5}$ emissions from sources can be a highly effective air quality management strategy, with major public health benefits.

Source: Reuters

Part 1:
Black Carbon Climate Impacts

Ben DeAngelo, OAP

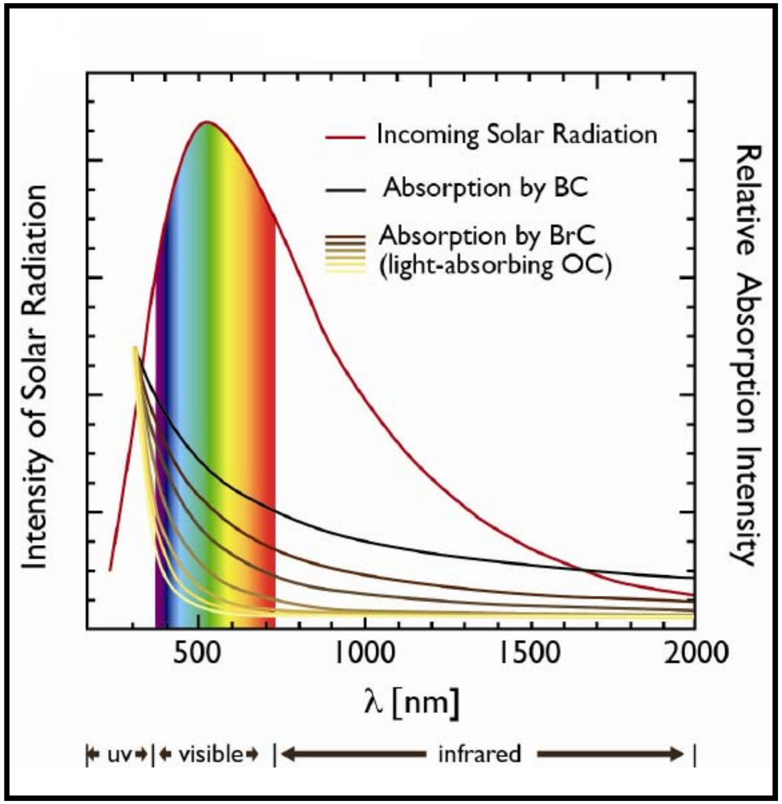
What is Black Carbon?



- Black Carbon (BC) is a solid form of mostly pure carbon absorbs solar radiation (light) at all wavelengths. It is formed by incomplete combustion of fossil fuels, biofuels, or biomass.
- BC is one of the types of particles which constitute particulate matter (PM), and is one of the key components of soot.
- BC is co-emitted with other particles and gases with diverse climate impacts.
- BC has several effects on the climate, including:
  - Directly absorbing light (contributing to warming)
  - Changing the brightness of snow and ice (contributing to warming)
  - Affecting cloud formation and lifetime (with both a cooling and warming effect)
  - Contributing to surface dimming and changes in precipitation patterns

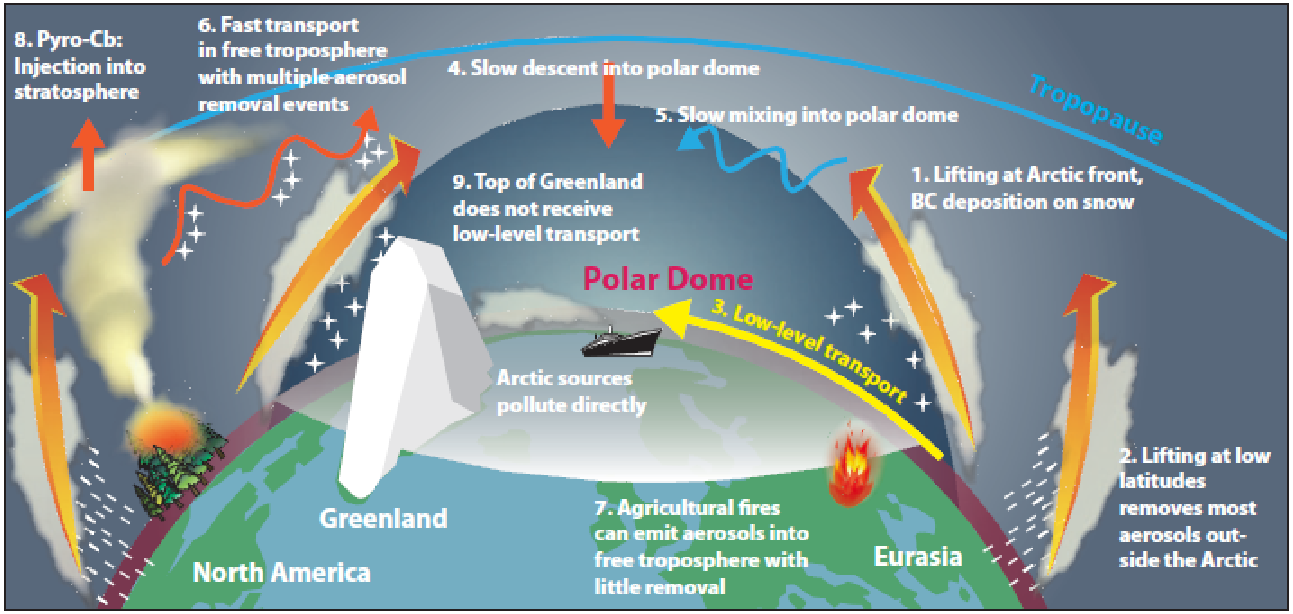
Ambient Atmospheric BC

- Ambient BC is the most strongly light-absorbing component of PM.
- Quantities of BC have a significant effect on local RF.
- Unlike long-lived greenhouse gases, BC has a limited atmospheric lifetime (on the order of days).
- BC does not become well mixed, and its effects are not easy to aggregate to the global scale.
- BC in the atmosphere can also contribute to surface dimming in the form of Atmospheric Brown Clouds.



Black Carbon Deposition Affects Surface Albedo

- BC deposition on snow and ice darkens the surface, and increases absorption of solar energy.
- Snow and ice in sensitive regions like the arctic and the Himalayas are especially at risk from BC deposition.
- BC in snow and ice may be more effective than well-mixed GHGs in warming the atmosphere:
  - Energy absorbed by BC in snow and ice goes directly into melting rather than dissipating throughout the atmosphere
  - BC may persist at the surface, contributing to longer-term warming, or
  - Snow and ice may melt, leaving behind a darker surface (such as rock or ocean)



Source: AMAP, 2011

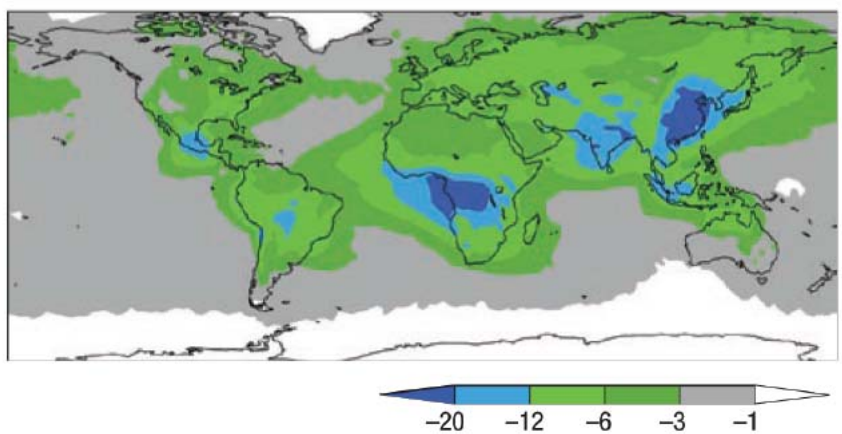
Indirect and Semi-Direct Effects on Clouds:

Black Carbon's effects on clouds are many, but understanding is low

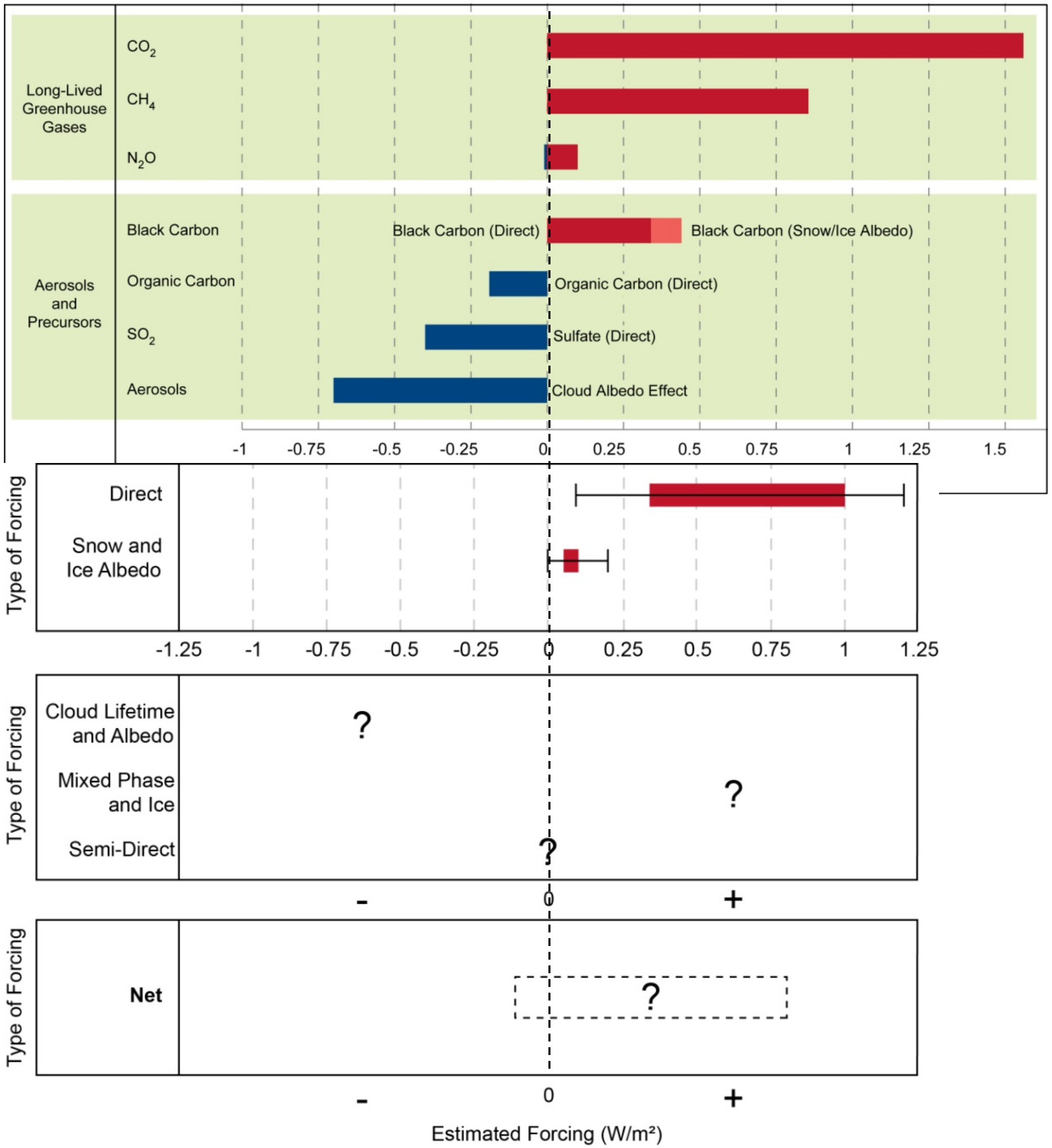
- BC particles can lead to the formation of more, smaller water droplets in clouds.
  - Smaller droplets make clouds more reflective, producing a cooling effect.
  - Smaller droplets can also delay precipitation, increasing cloud lifetime, and extending the cooling effect.
- Smaller droplets in mixed-phase (clouds with liquid and ice droplets) can delay freezing, with uncertain implications for warming.
- BC in clouds can also contribute to cloud instability by absorbing solar radiation, and warming the cloud. This is called the "semi-direct" effect, and has uncertain implications for warming.
- BC in super-cooled liquid clouds can accelerate precipitation by acting as a nucleus for crystal formation, thereby shortening the lifespan of a cloud, and contributing to warming.

Atmospheric Brown Clouds and Precipitation

- In high concentrations, and when combined with other pollutants, BC can form Atmospheric Brown Clouds (ABCs).
- BC in ABCs can contribute to surface dimming by absorbing and scattering incoming radiation.
- ABCs have been linked to a decrease in vertical mixing, which exacerbates air pollution episodes.
- ABCs may contribute to changes in precipitation patterns, including a slowing of the monsoon circulation over the Indian Ocean.



Net Radiative Forcing for BC is Still Highly Uncertain



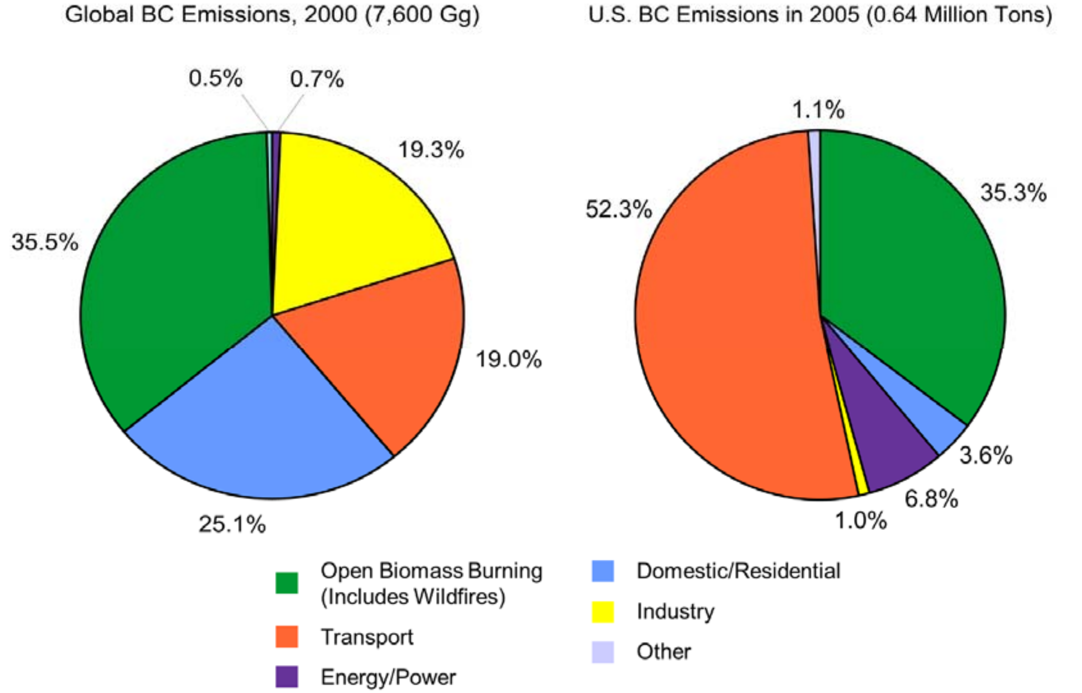
- IPCC (2007) used an estimate of 0.34 Wm^{-2} for direct BC RF, and estimated an additional 0.1 Wm^{-2} RF for snow and ice deposition.
- The IPCC estimate does not account for indirect and semi-direct cloud forcing.
- Recent studies have suggested greater possible warming for the direct effect.
- Several recent studies have suggested a lower RF for snow and ice effects.
- Total BC RF is still dominated by uncertainty about potentially significant indirect effects on clouds.

Part 2:
Understanding BC Emissions, Measurements and Observational Data

Neil Frank, OAQPS

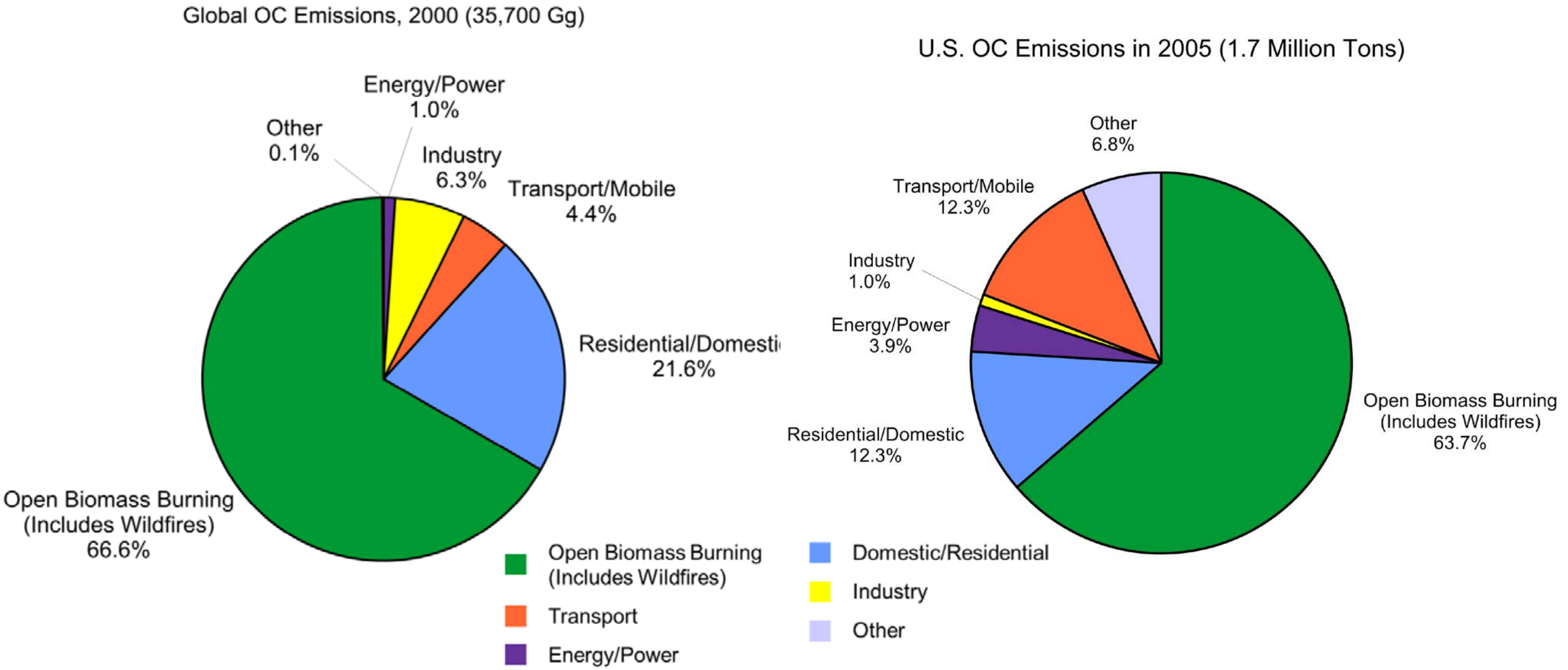
Black Carbon Emissions - Global versus U.S.

~ 8.4 Million Tons



- In the US, there is estimated, in 2005, to be about 0.64 tons of BC emitted by all sources.
- Globally, about 8.4 million tons of BC is emitted.
- Distribution of sources in US is different than globally for BC.
- In the US, BC emissions, generally, are derived from $PM_{2.5}$ emission inventories, via use of speciation factors.

Organic Carbon Emissions - Global versus U.S.



- OC always co-emitted with BC, must be considered in any control and/or mitigation scenarios.
- Most of OC comes from burning, and is considered to be reflective (cooling).
- How much of OC is light-absorbing (warming BrC)?

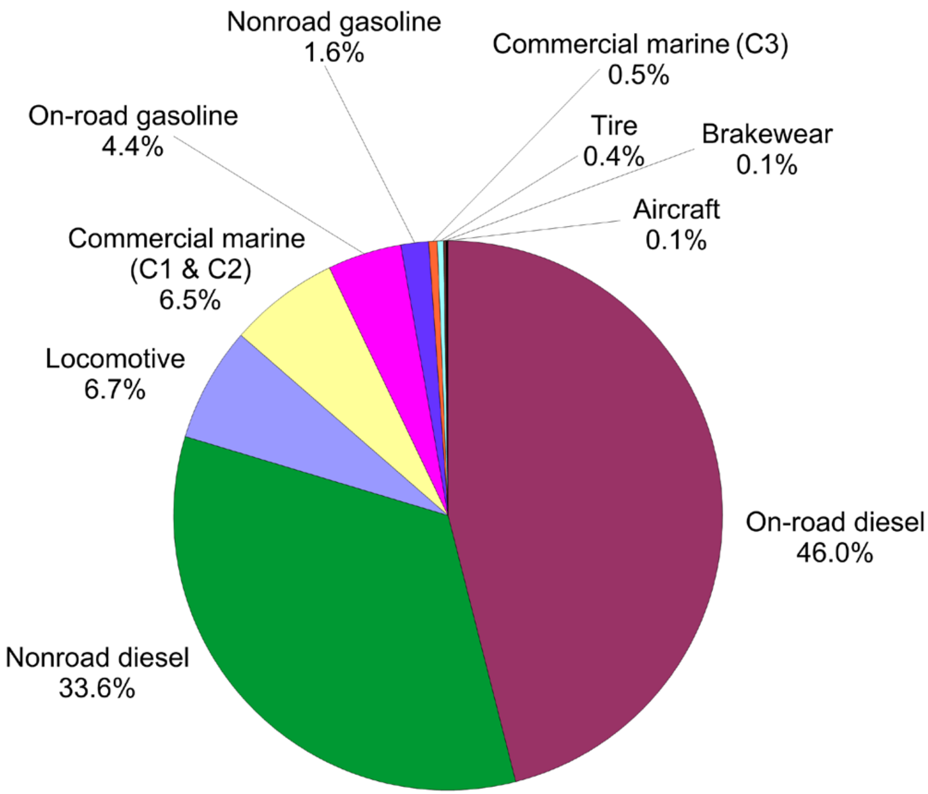
Ratio of OC to BC Varies by Emission Source Category

Mega' Source Category	PM2.5	BC	OC		OC/BC	BC/PM2.5
================	========	========	========		========	========
Open Biomass Burning	2,266,513	224,608	1,058,494		4.7	0.10
Residential	464,063	22,807	204,160		9.0	0.05
Energy/Power	712,438	43,524	65,138		1.5	0.06
Industrial	219,460	6,085	16,234		2.7	0.03
Mobile Sources	626,859	333,405	205,171		0.6	0.53
Other	1,232,123	6,743	112,967		16.8	0.01
	========	========	========		========	========
Totals (Short Tons)	**5,521,456**	**637,172**	**1,662,164**		**2.61**	**0.12**
Gigagrams (Gg)	**5,009**	**578**	**1,508**			

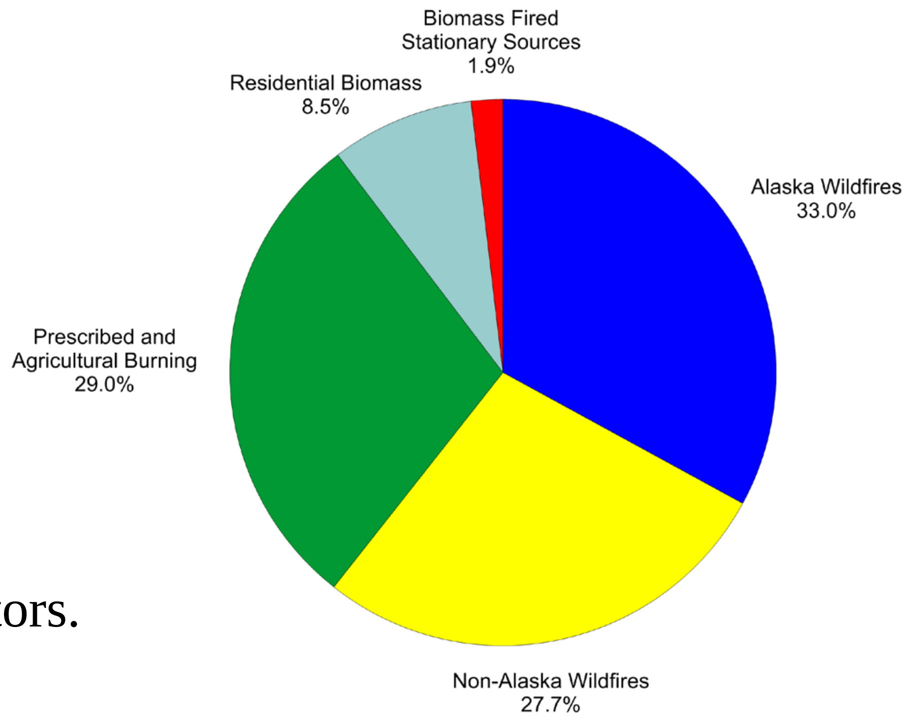
➢ Mobile sources are the only category for which there is more BC than OC estimated to be emitted. This is largely due to the composition of diesel emissions. The OC:BC ratio is one of the indicators for climate mitigation purposes.

➢ Open biomass burning has significant BC emissions, but a lot more OC emissions.

➢ Nationally, in the US, about 12% of PM2.5 emissions is estimated to be BC. About 30% is co-emitted OC.



- Mobile source BC dominated by diesels (~ 90% of total contribution).
- As diesels become more controlled, % of other sources will grow in future.



- Biomass burning BC dominated by prescribed and wild fires.
- AK wildfires particularly important in “bad” years, and even more important considering proximity to arctic areas.
- RWC and other sources small contributors.

Black Carbon & its Confusing Terminology

Black Smoke Shade

Brown Carbon
(BrC)

Light Absorbing Carbon
(LAC)

NIOSH

Elemental Carbon
(EC)

TOT

TOR

Light Absorbing Aerosols

SOOT

BLACK CARBON
(BC)

Organic Carbon

British Smoke
(BS)

THE NAME GAME

Generic Terms

Light Absorbing Aerosols **Black Carbon** **Soot**

Dust (Soil), incl. Fe

Light Absorbing Carbon

Measurement Method Terms

Optical Methods

Brown Carbon **Black Carbon**

British Smoke
(Black Smoke Shade)

Crustal Elements
Fe

XRF

Thermal Analysis (Thermal Optical Analysis)

Organic Carbon **Elemental Carbon**

From the Report to Congress…

Terminology

Black carbon (BC) is a solid form of mostly pure carbon that absorbs solar radiation (light) at all wavelengths. BC is the most effective form of PM, by mass, at absorbing solar energy, and is produced by incomplete combustion.

Organic carbon (OC) generally refers to the mix of compounds containing carbon bound with other elements like hydrogen or oxygen. OC may be a product of incomplete combustion, or formed through the oxidation of VOCs in the atmosphere.[2] Both primary and secondary OC possess radiative properties that fall along a continuum from light-absorbing to light-scattering.

Brown carbon (BrC) refers to a class of OC compounds that absorb ultraviolet (UV) and visible solar radiation. Like BC, BrC is a product of incomplete combustion.[3]

Carbonaceous PM includes BC and OC. Primary combustion particles are largely composed of these materials.

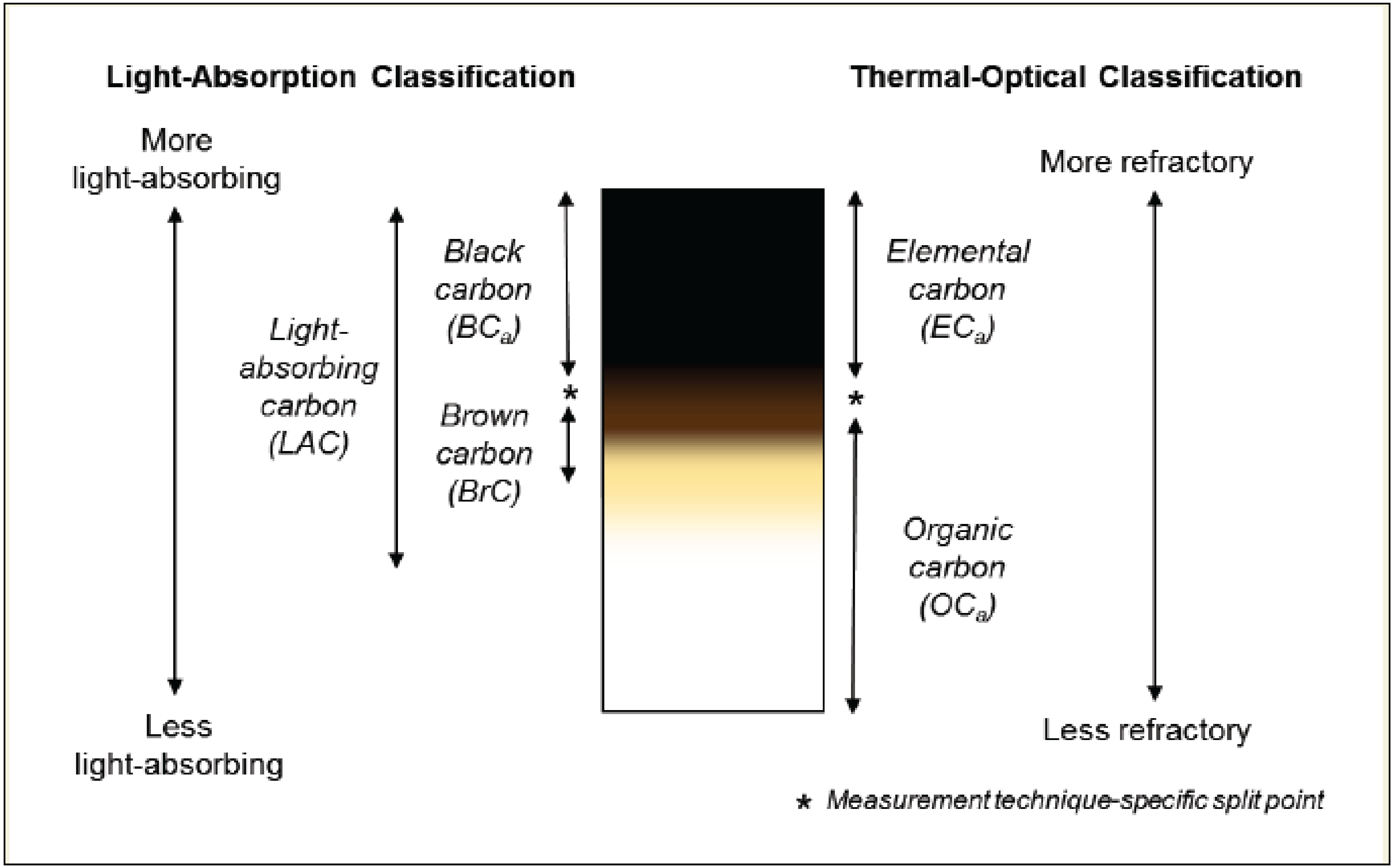
Light absorbing carbon (LAC) consists of BC plus BrC.

Soot, a complex mixture of mostly BC and OC, is the primary light-absorbing pollutant emitted by the incomplete combustion of fossil fuels, biofuels, and biomass.

- BC is a component of $PM_{2.5}$ and the most efficient absorber per unit mass.
- BrC is part of OC.
- Soot component of $PM_{2.5}$ is mostly BC and OC.

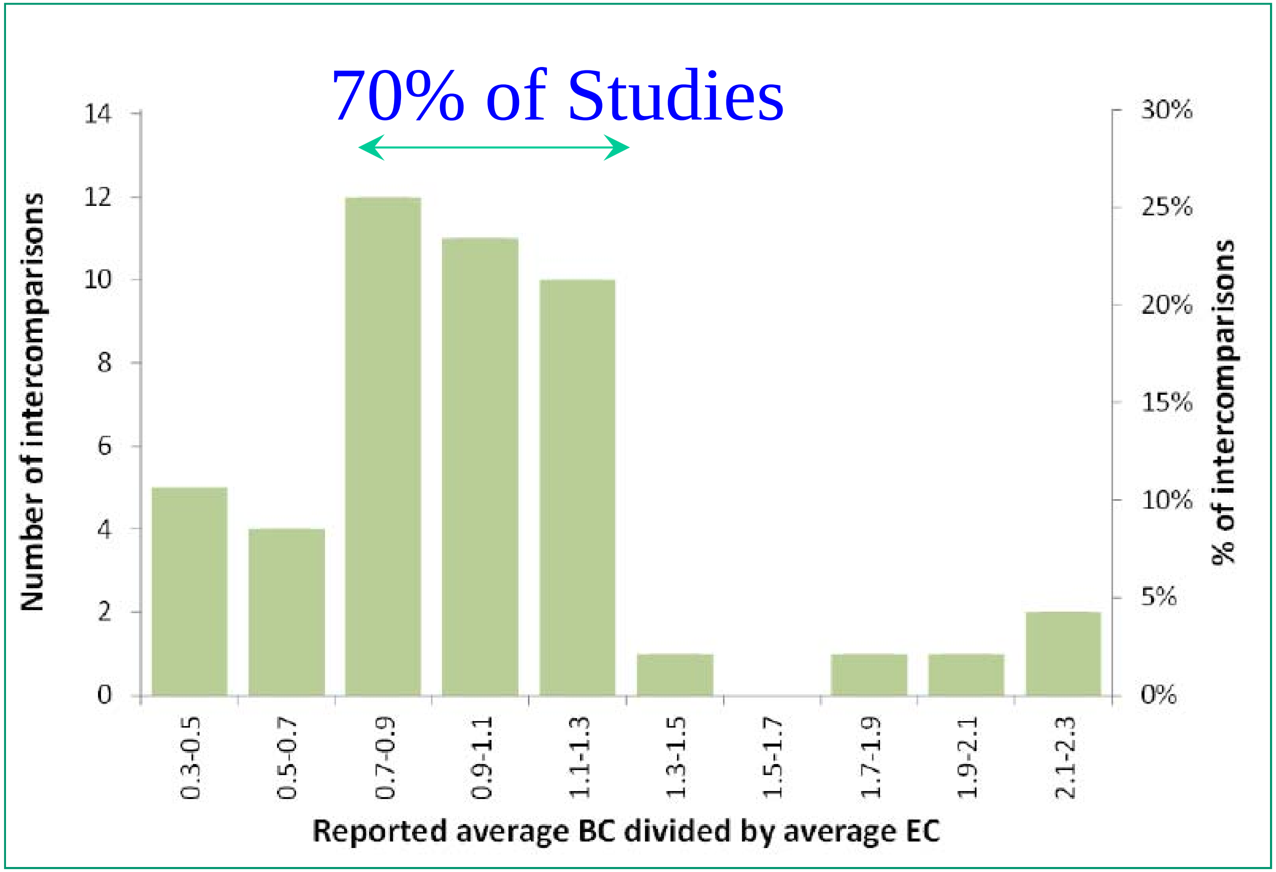
The Terms “BC” and “EC”

Relate to the Common Indicator Measurements of Black Carbon

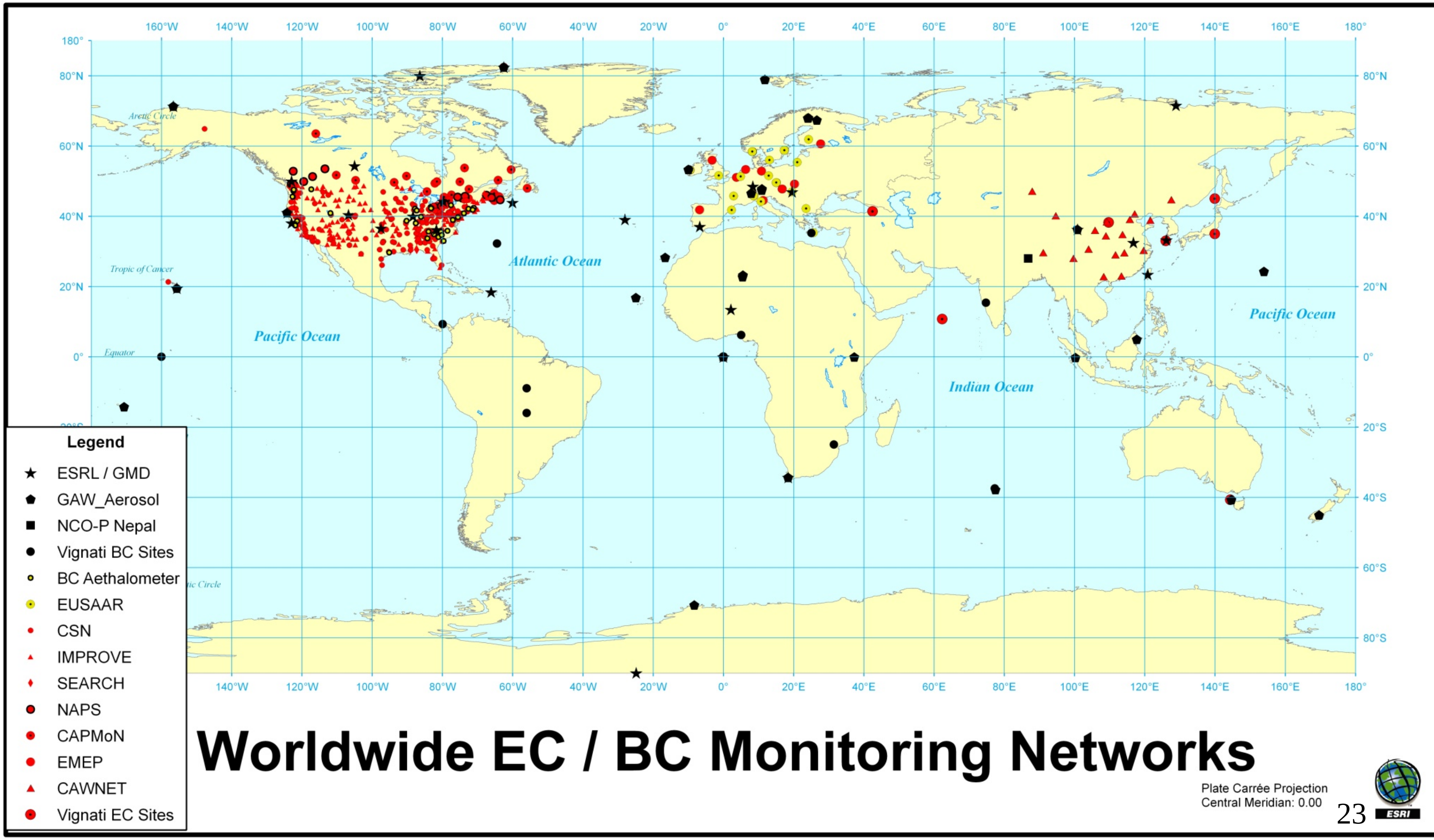


Note: “Bca”, “Eca” and “Oca” denote their “apparent” values derived thru the measurements

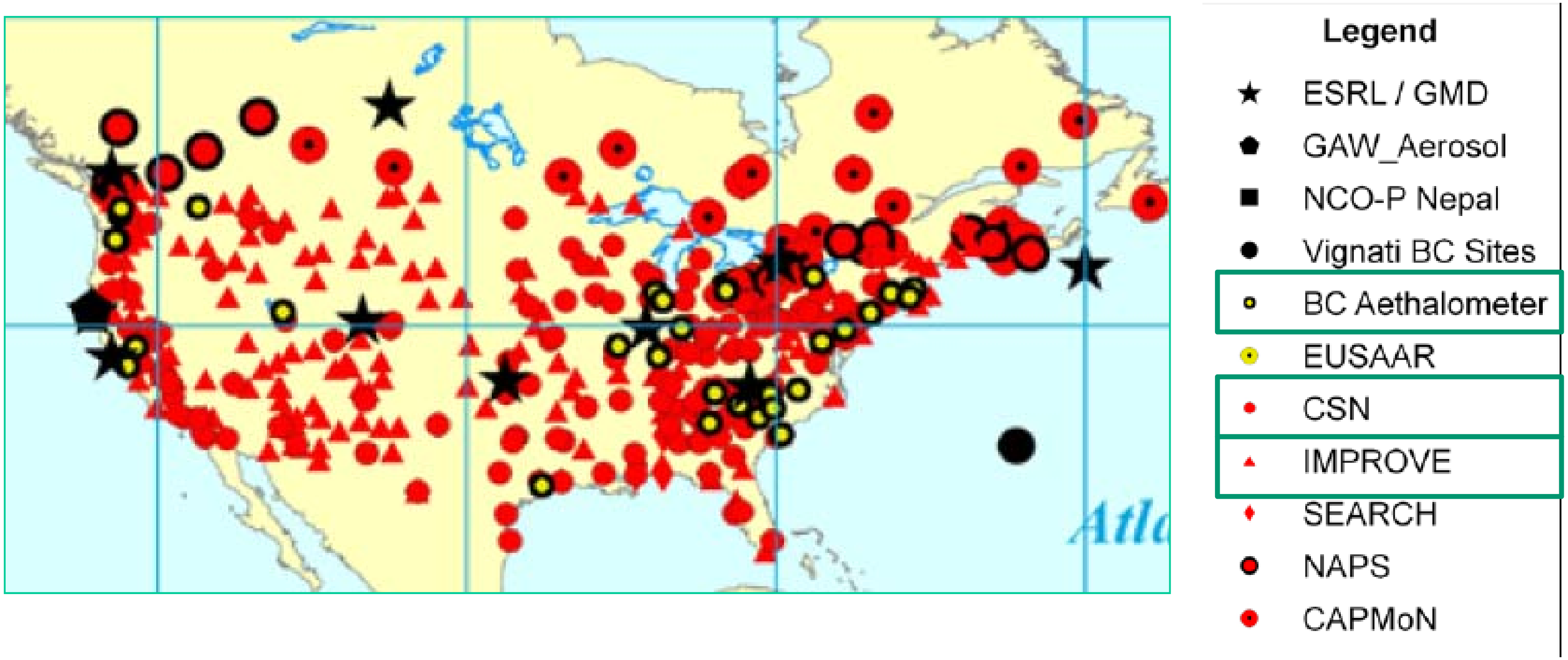
Recent Studies show that BC and EC are highly correlated & the ratio of BC to EC typically range from 0.7 – 1.3



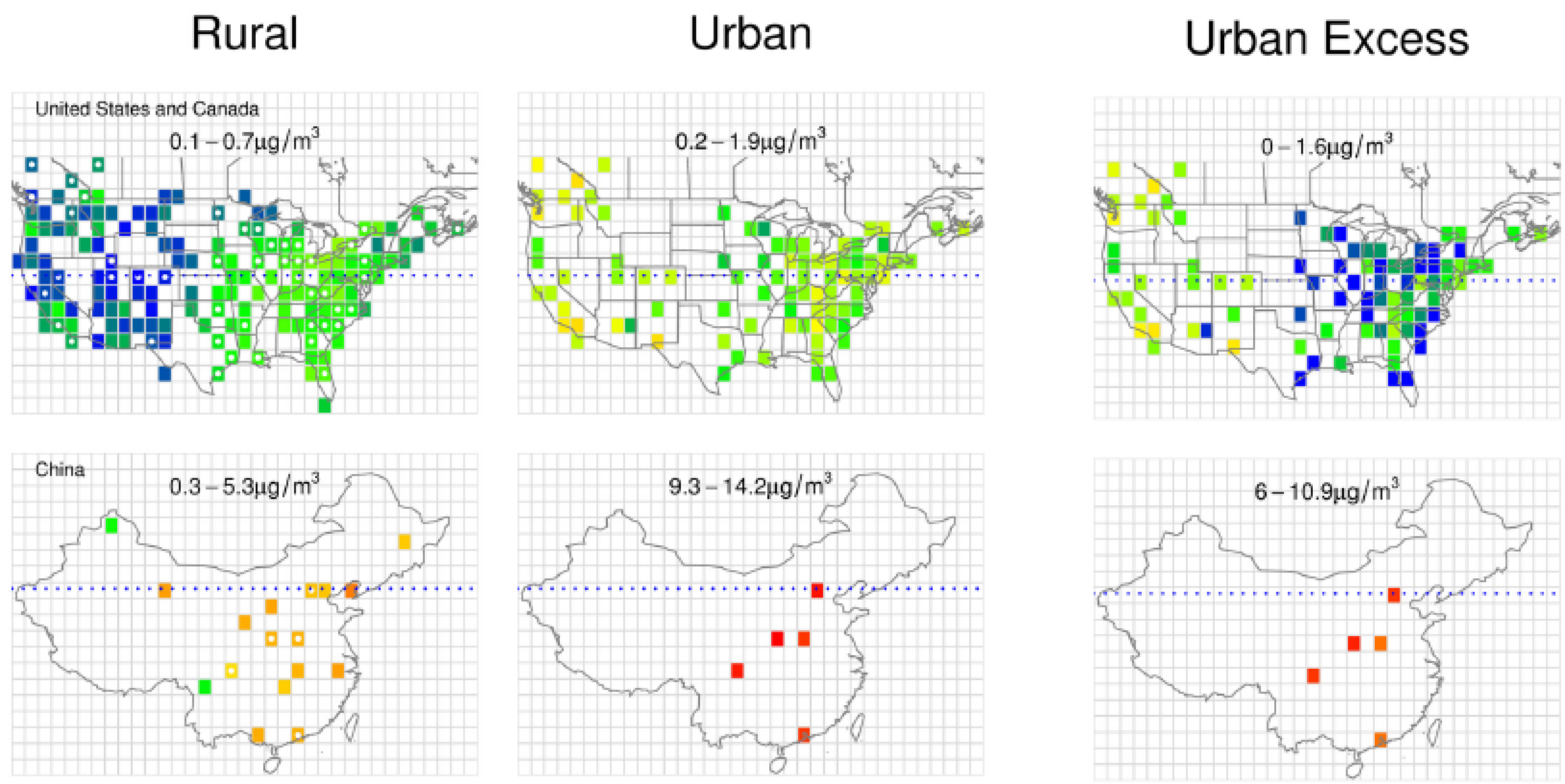
The Global Observational Data Base

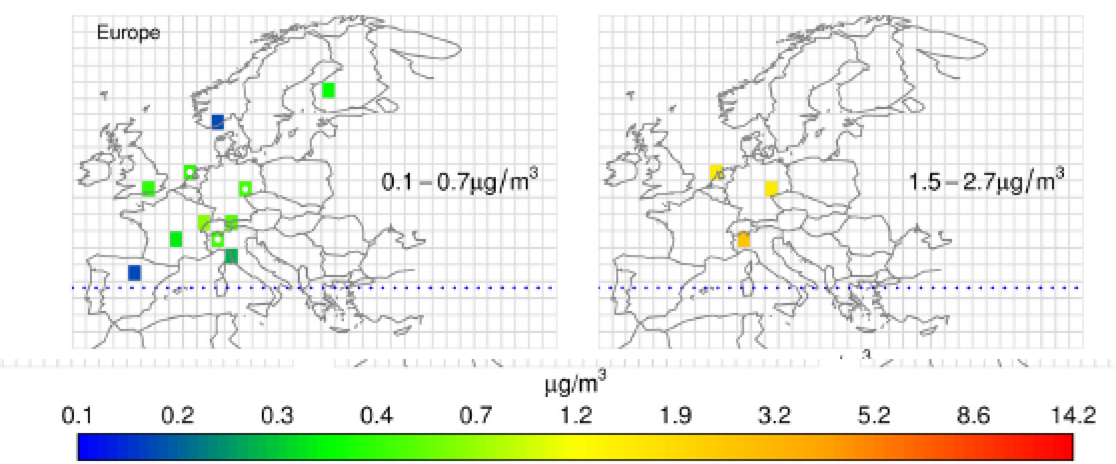


Black Carbon Observational Data in the US
are mostly from CSN and IMPROVE(ECa) and Aethalometer (BCa)



Spatial Distribution of Global BC (2005-07)





BC Concentrations are:

- Similar in the US and Europe
- Much higher in China

Urban BC concentrations are generally higher than concentrations in surrounding rural areas

With dense urban monitoring, New sources of BC can be identified

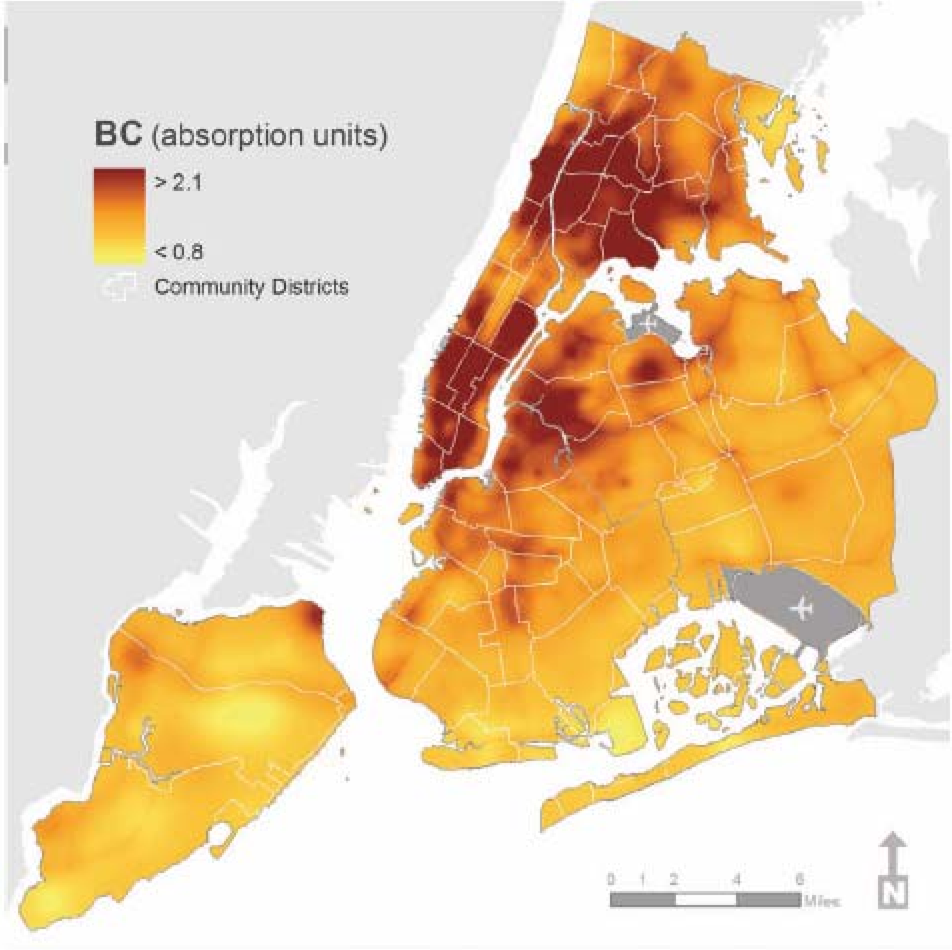
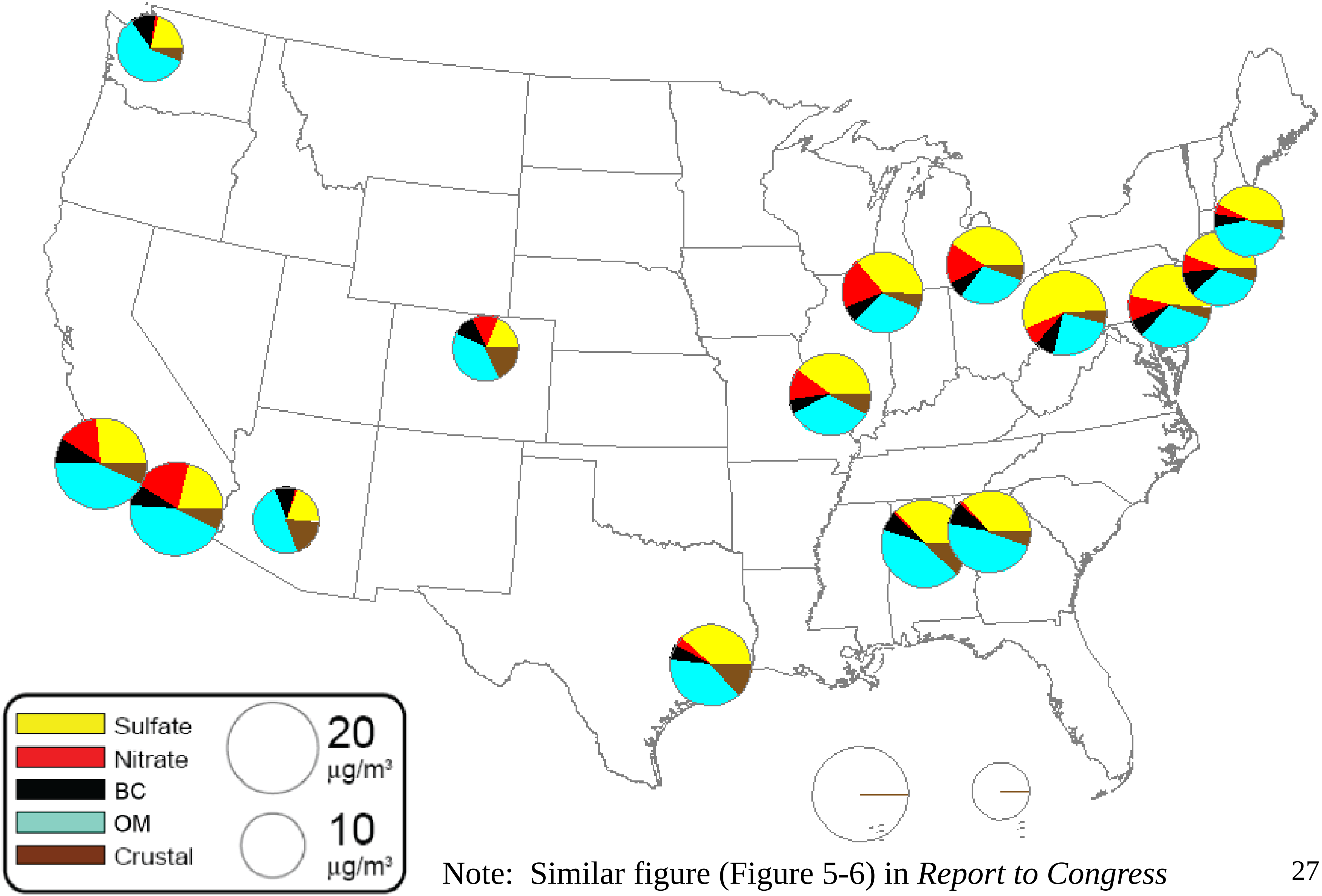


Figure 5-5. Urban BC Gradients for New York City.
(Source: The New York City Community Air Survey, Results from Winter Monitoring 2008-2009, http://www.nyc.gov/)

BC is a small component of $PM_{2.5}$

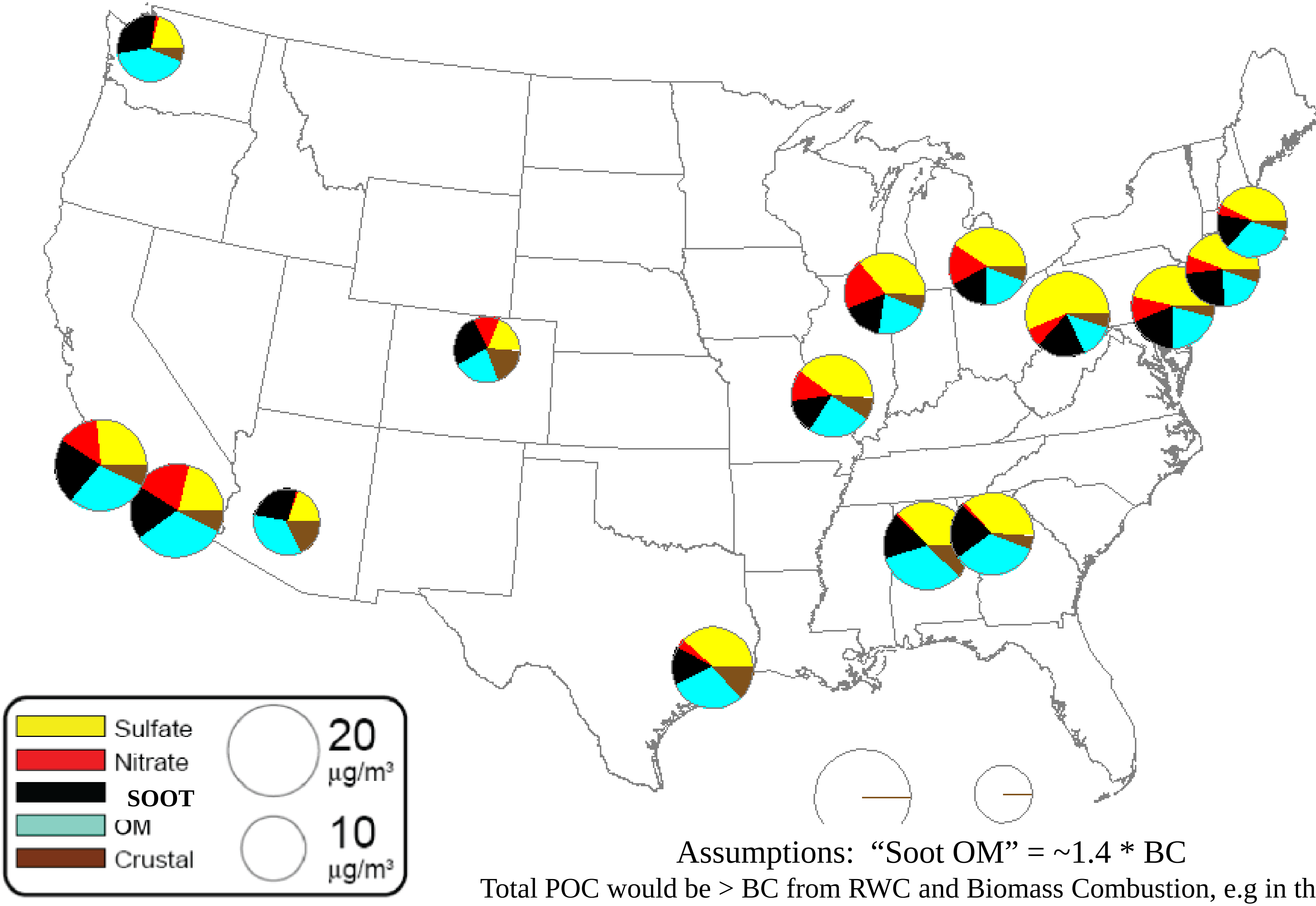
6-11% of mass in 15 selected urban areas, 2008-10



Note: Similar figure (Figure 5-6) in *Report to Congress* represented data from 2005-2007

Directly Emitted Soot in PM2.5 (an initial estimate)

~ 14-28% of PM2.5 mass, 2008-10

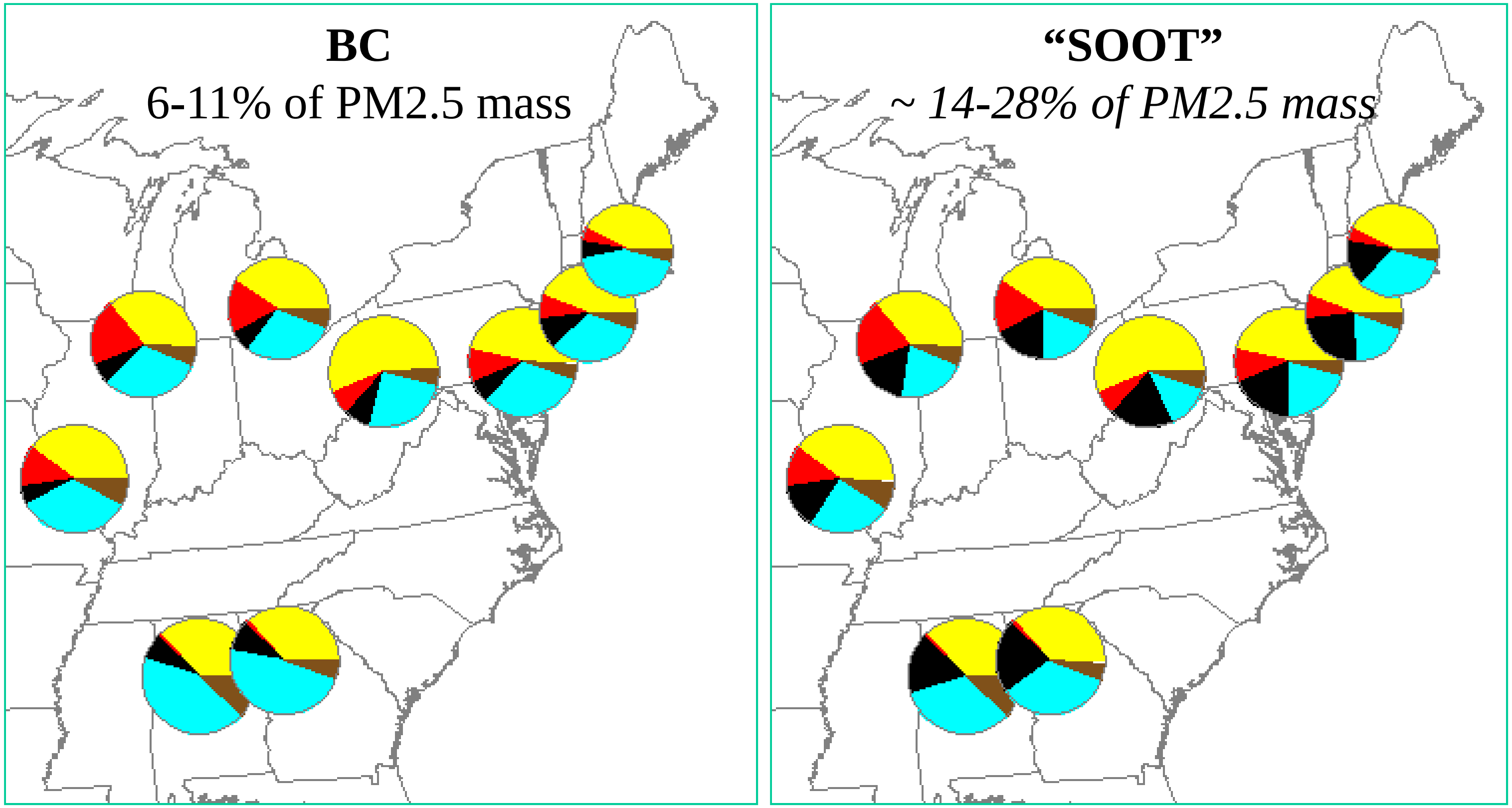


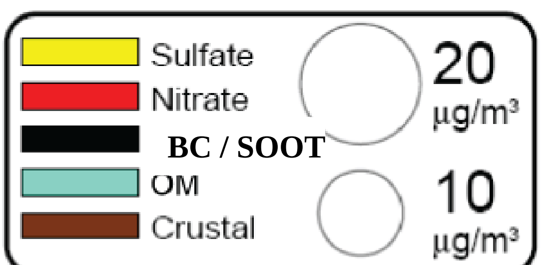
Assumptions: "Soot OM" = ~1.4 * BC

Total POC would be > BC from RWC and Biomass Combustion, e.g in the NW

DRAFT – This has not been peer reviewed

Directly Emitted BC vs. “Soot” in Ambient $PM_{2.5}$





Assumptions: “Soot OM” = ~1.4 * BC

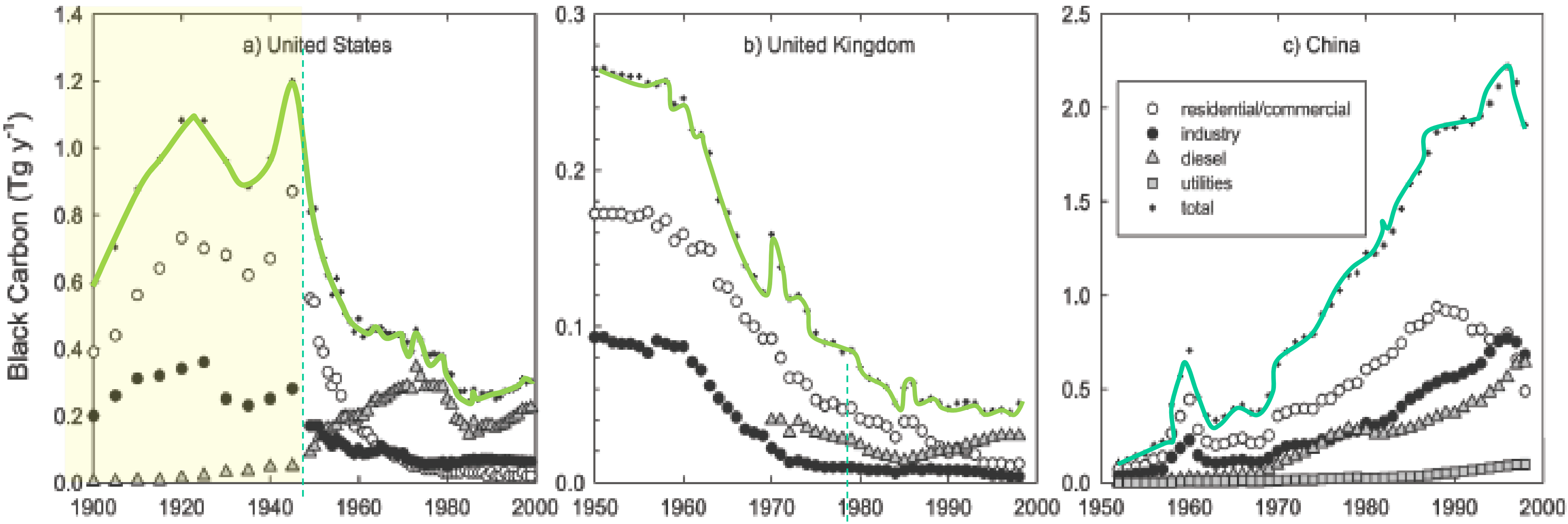
Total POC would be > BC from RWC and Biomass Combustion, e.g in the NW

DRAFT – This has not been peer reviewed

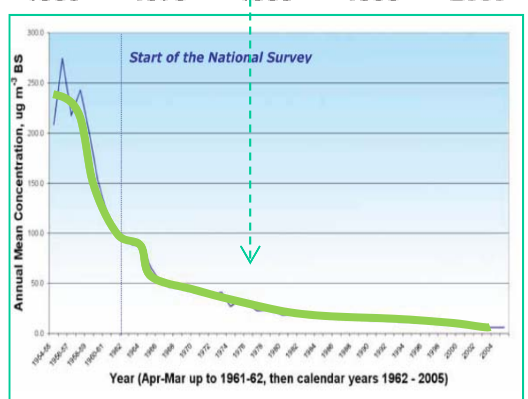
How has BC Changed Over Time?

U.S. U.K. China

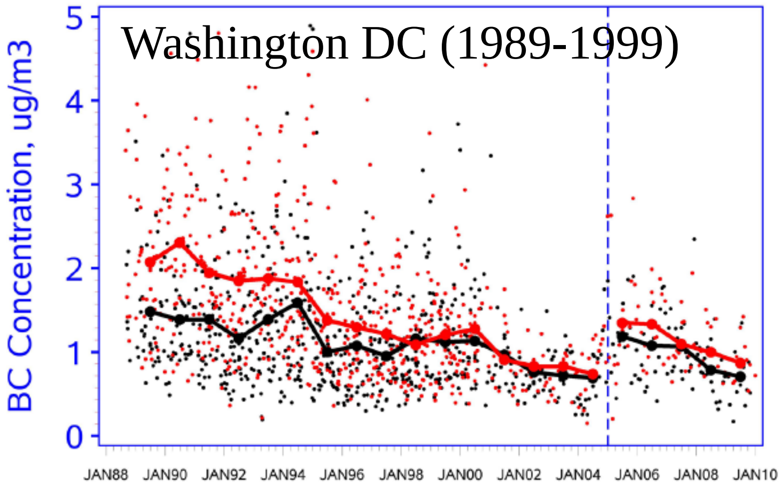
BC Emissions (Tg/y)



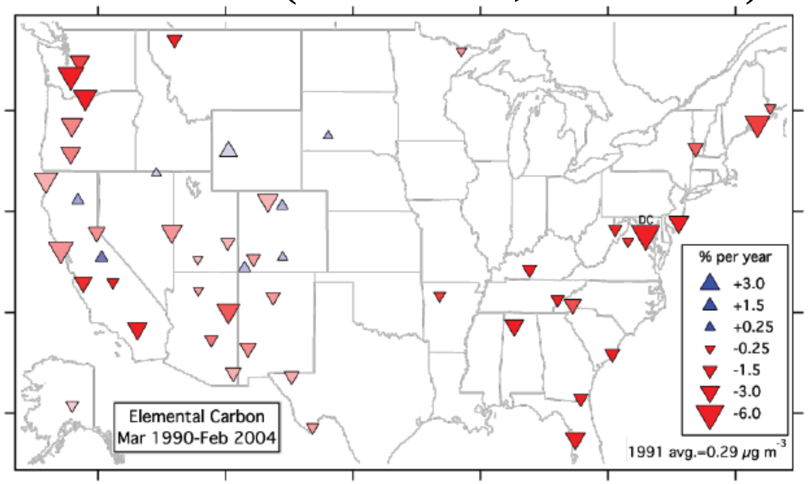
Ambient "Black Smoke" in the U.K., 1960-2005

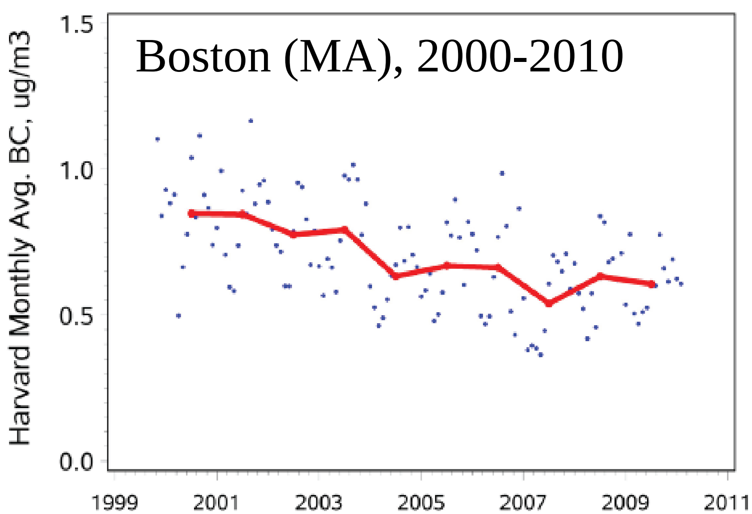


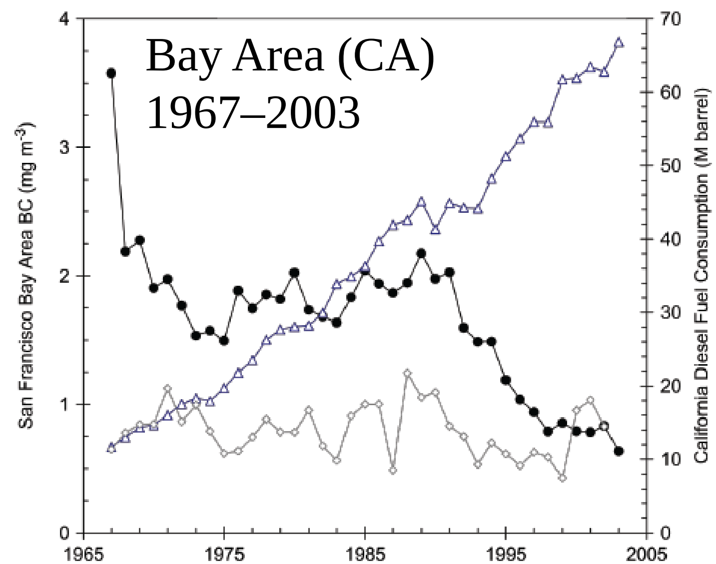
What was the U.S. Trend in Ambient BC?



Rural Areas (IMPROVE, 1990-2004)

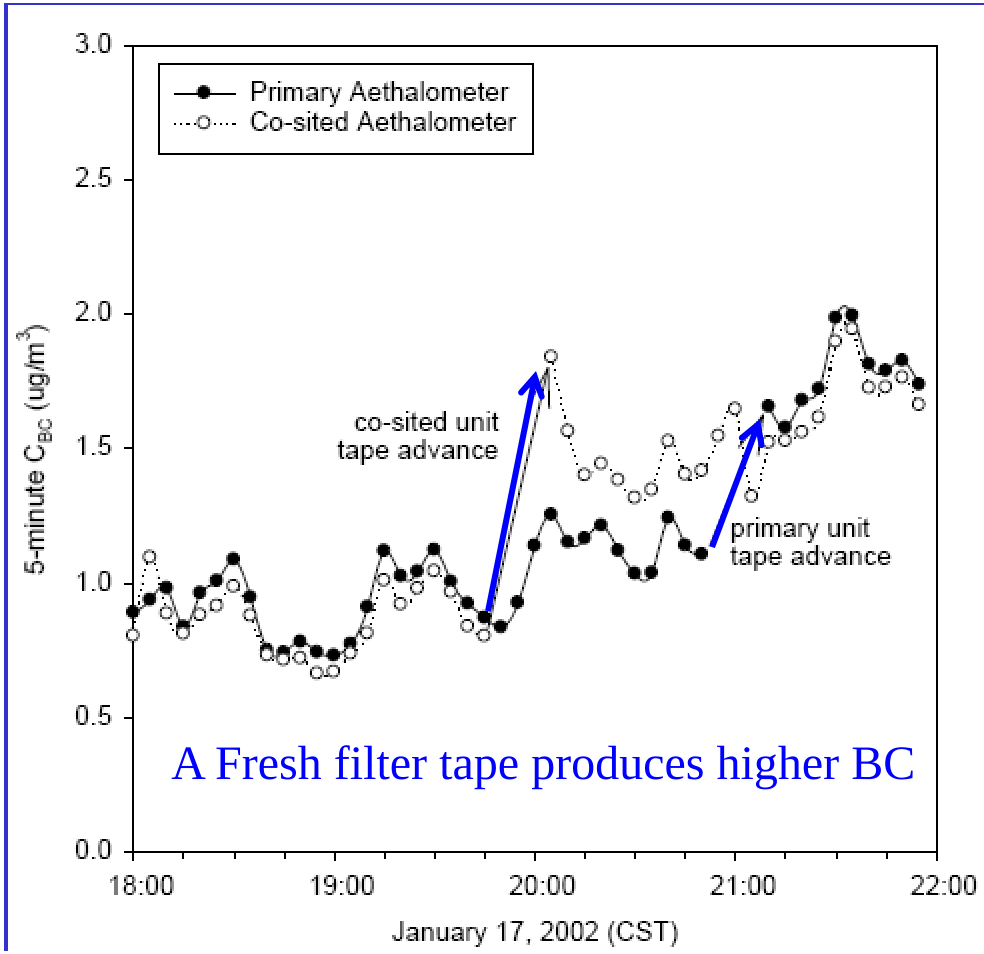






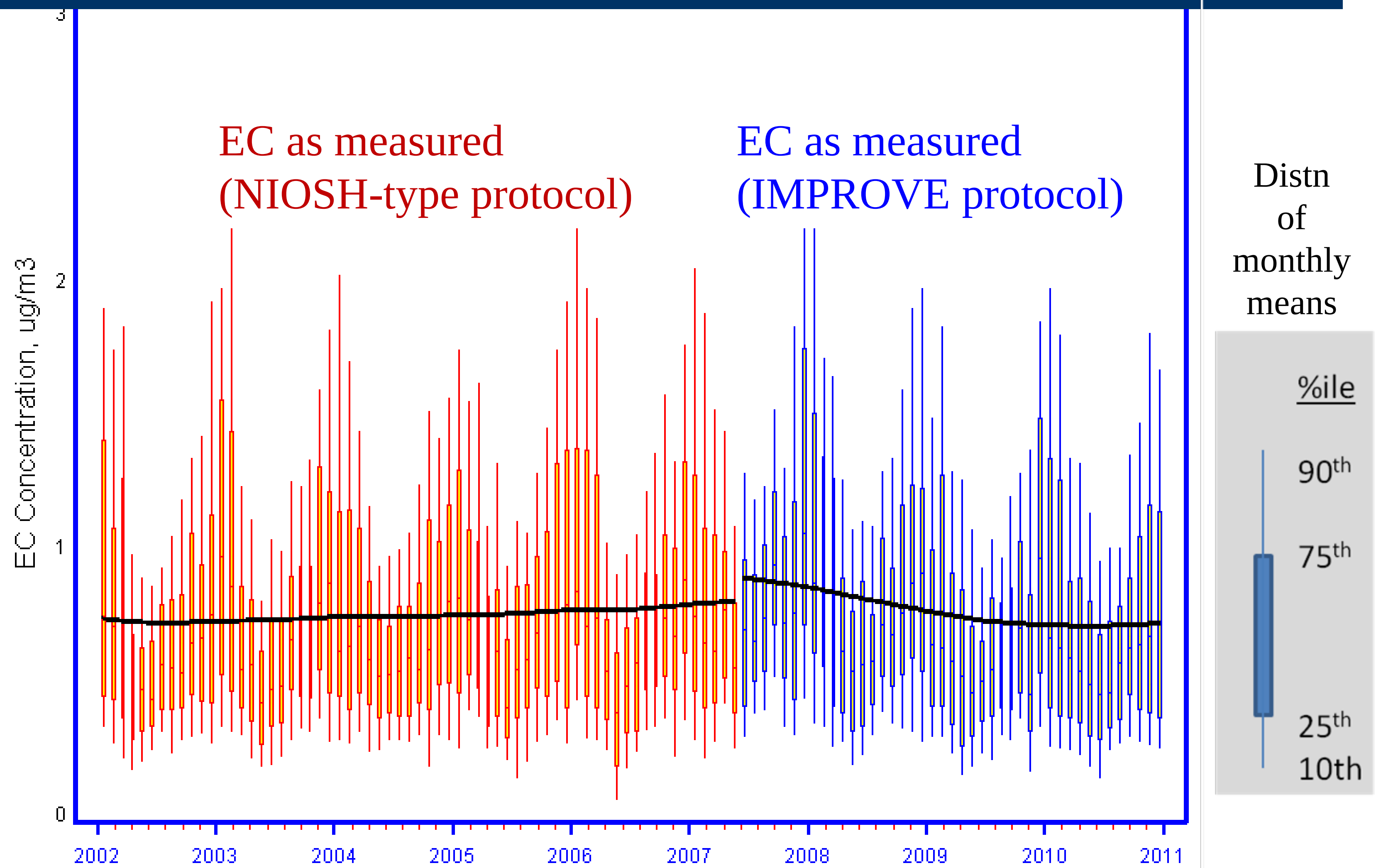
Potential Issues with existing Aethalometer BC (a filter-based optical measurement)

- Known artifacts due to "optical saturation effect".
- EPA has funded a study to examine existing Aethalometer data in the US (Jay Turner, George Allen and STI).
- Preliminary results show that adjustments may be needed to best describe ambient concentrations.
- Magnitude of the "spot loading correction" depends on operational parameters.
- The adjustments (e.g. increase winter-time levels) can alter seasonality and potentially change the trend.
- A report will be forthcoming.



Note: the newest generation Aethalometer may not have this issue

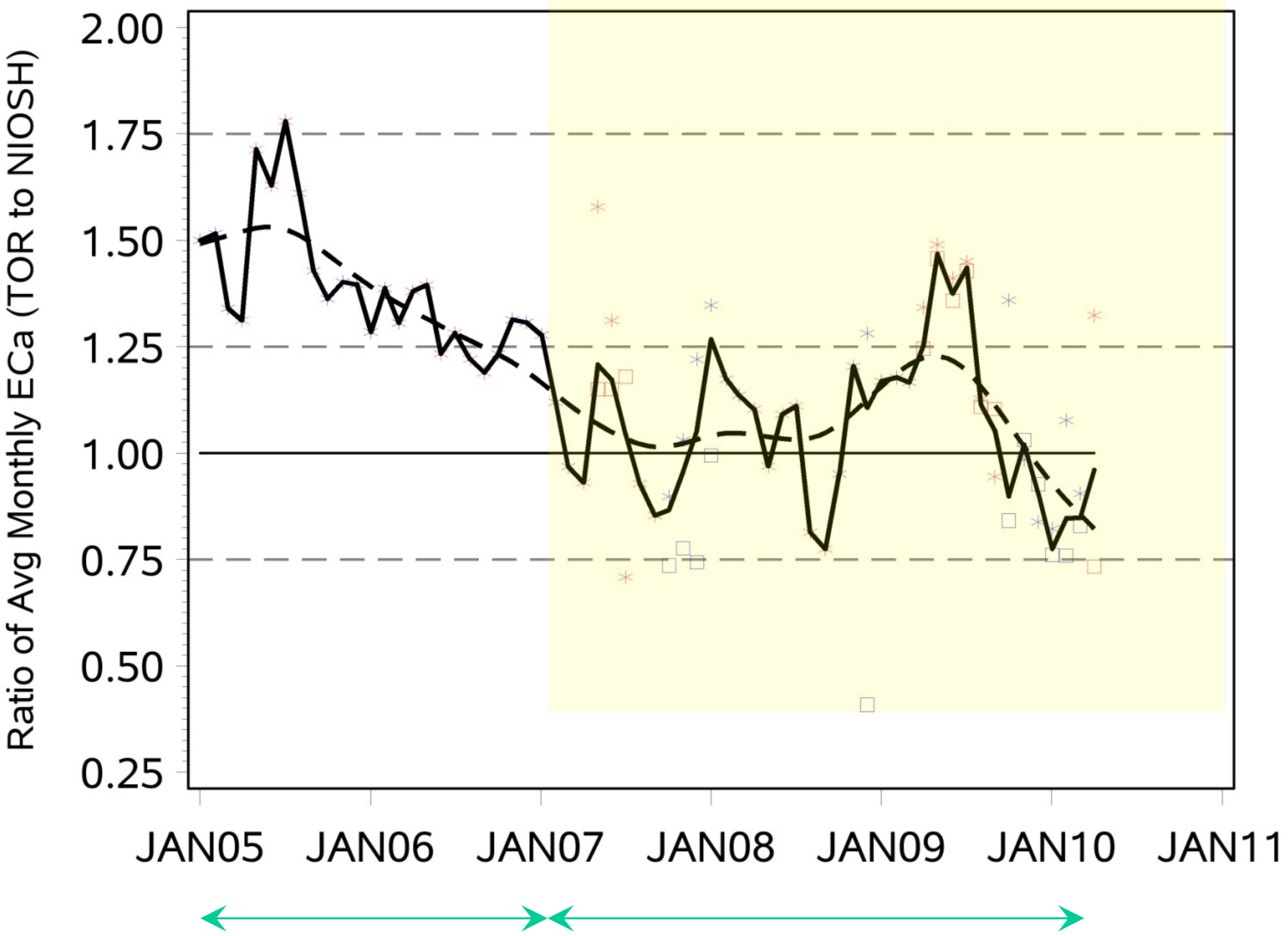
Urban Black Carbon, based on EC measurements
from CSN data as reported to EPA (15 sites)



CSN's Carbon measurement protocol changed after 2007
(new IMPROVE like samplers and IMPROVE analytical protocol)

Ratio of IMPROVE EC to NIOSH EC changed from 2005 to 2010

Monthly average ratio at all collocated urban locations

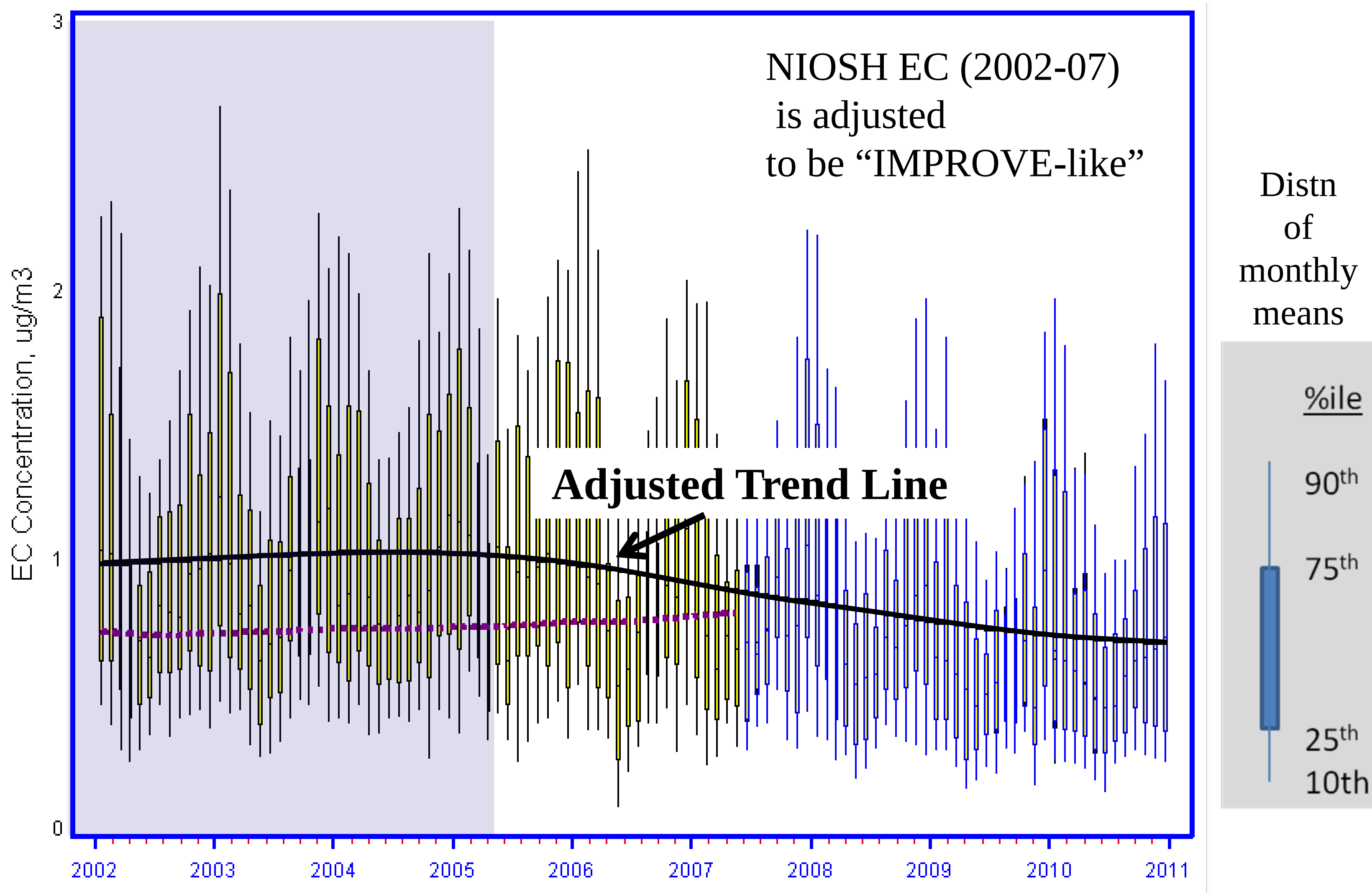


14 IMPROVE sites paired with CSN NIOSH, 2005-2006

5 IMPROVE & 168 CSN (TOR) sites paired with CSN NIOSH, 2007-2010

The U.S. Urban BC Trend, 2002-2010

based on "**adjusted EC**" at 15 CSN sites (-32% change in Average EC)



Average ratio of CSN MPROVE to CSN NIOSH for 2005
was used for Pre-2005 adjustment

Lessons Learned

- “Optical BC” and “Thermal EC” measurements can both describe ambient Black Carbon (and Soot)
  - Data harmonization and or adjustments can be helpful
- While BC, as measured, is a small component of $PM_{2.5}$, directly emitted soot may be ~2.5x larger
- More measurements both in the US and globally would be helpful to better characterize the spatial distribution of BC and its emission sources, particularly within urban areas
- Ambient BC has declined and $PM_{2.5}$ air quality has improved as result of soot emission reductions; more to come.

Part 3:
Black Carbon Mitigation

Erika Sasser, OAQPS

Benefits of BC Mitigation

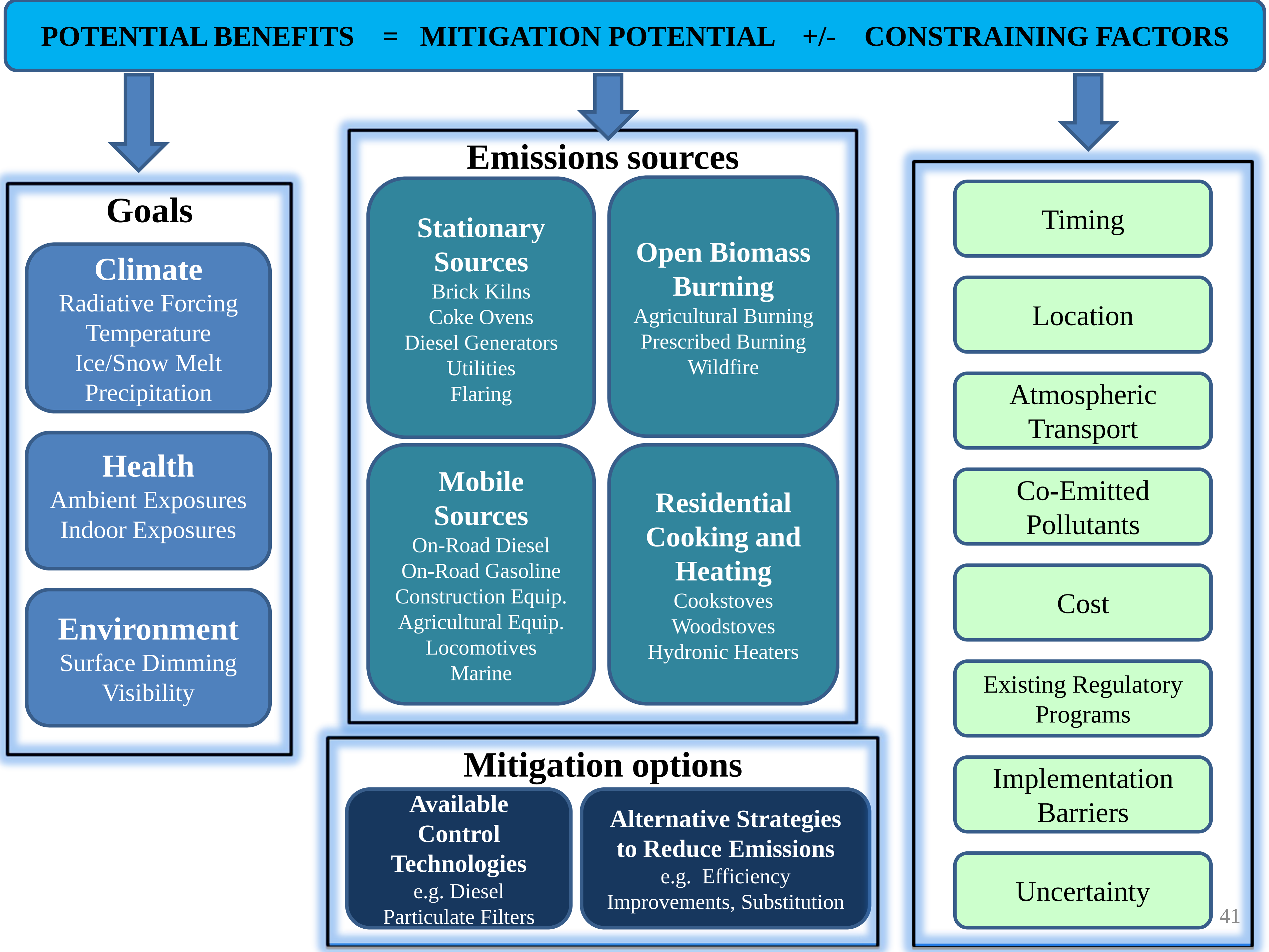
- Targeted strategies to reduce BC emissions can be expected to provide climate benefits within the next several decades, and may be particularly important for sensitive regions such as the Arctic.
- Reductions in BC and GHGs are complementary strategies for mitigating climate change.
- BC is reduced via controls on direct $PM_{2.5}$ emissions, and the health and environmental co-benefits of these reductions are substantial.

Health Benefits of Reducing BC

- Health effects associated with BC are consistent with those associated with $PM_{2.5}$.
  - Includes respiratory and cardiovascular effects and premature death.
- Emissions and ambient concentrations of directly emitted $PM_{2.5}$ are often highest in urban areas, where large numbers of people live.
- Average public health benefits of reducing directly emitted $PM_{2.5}$ in the U.S. are estimated to range from \$290,000 to \$1.2 million per ton $PM_{2.5}$ in 2030.
- Globally, BC mitigation measures could potentially lead to hundreds of thousands of avoided premature deaths each year.

Mitigating BC: Key Considerations

- Available control technologies can reduce BC, generally by improving combustion and/or controlling direct $PM_{2.5}$ emissions from sources. Historically, fuel switching has also been critical.
- For both climate and health, it is important to consider the location and timing of emissions and to account for co-emissions.
- Some state and local areas in the U.S. have already identified direct $PM_{2.5}$ controls as particularly effective strategies for meeting air quality goals (e.g., California).
  - Though costs vary, many reductions can be achieved at reasonable costs.
  - Controls applied to reduce BC will help reduce total $PM_{2.5}$ and other co-pollutants.



POTENTIAL BENEFITS = MITIGATION POTENTIAL +/- CONSTRAINING FACTORS
Goals
Climate
Radiative Forcing
Temperature
Ice/Snow Melt
Precipitation
Health
Ambient Exposures
Indoor Exposures
Environment
Surface Dimming
Visibility
Emissions sources
Stationary Sources
Brick Kilns
Coke Ovens
Diesel Generators
Utilities
Flaring
Open Biomass Burning
Agricultural Burning
Prescribed Burning
Wildfire
Mobile Sources
On-Road Diesel
On-Road Gasoline
Construction Equip.
Agricultural Equip.
Locomotives
Marine
Residential Cooking and Heating
Cookstoves
Woodstoves
Hydronic Heaters
Mitigation options
Available Control Technologies
e.g. Diesel Particulate Filters
Alternative Strategies to Reduce Emissions
e.g. Efficiency Improvements, Substitution
Timing
Location
Atmospheric Transport
Co-Emitted Pollutants
Cost
Existing Regulatory Programs
Implementation Barriers
Uncertainty

BC Mitigation Opportunities in the U.S.

- U.S. BC emissions have declined more than 70% since the early 1900s (due to controls on industrial and mobile sources, improvements in technology and broader deployment of cleaner fuels such as natural gas).

- The U.S. will achieve substantial additional BC emissions reductions by 2030, largely due to controls on new mobile diesel engines (see Part 4 of this presentation).

- Other U.S. source categories have more limited mitigation potential due to smaller remaining emissions in these categories, or limits on the availability of effective BC control strategies.

Stationary Sources

- Regulations limit direct PM emissions (including BC) from more than 40 categories of industrial sources in the U.S., including coke ovens, cement plants, industrial boilers, and stationary diesel engines.

- Available control technologies and strategies include:
  - Use of cleaner fuels.
  - Direct $PM_{2.5}$ reduction technologies (e.g. fabric filters (baghouses), electrostatic precipitators (ESPs), and diesel particulate filters (DPFs)).
  - The control technologies range in cost-effectiveness from \$48/ton $PM_{2.5}$ to \$685/ton $PM_{2.5}$ (2010\$) or more, depending on the source category. However, they also may involve tens of millions in initial capital costs.

Residential Heating and Cooking

- Emissions from residential wood combustion are currently being evaluated as part of EPA's ongoing review of emissions standards (NSPS) for residential wood heaters, including hydronic heaters, woodstoves, and furnaces.

- Mitigation options include replacing or retrofitting existing units, or switching to alternative fuels such as natural gas.
  - New EPA-certified wood stoves have a cost-effectiveness of about \$3,600/ton $PM_{2.5}$ reduced, while gas fireplace inserts average \$1,800/ton $PM_{2.5}$ reduced (2010\$).

Open Biomass Burning

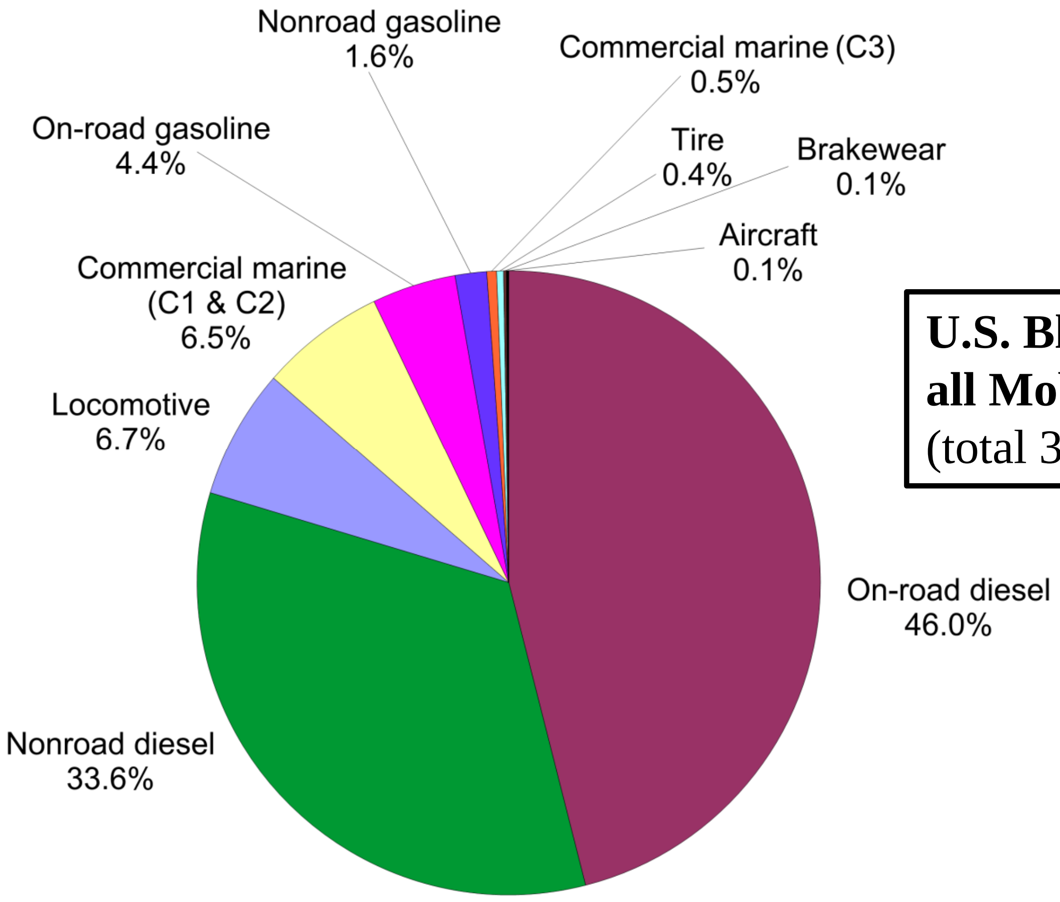
- Open biomass burning is the largest source of BC emissions globally, although large percentage is due to wildfire (e.g., U.S. Alaskan fires).
- $PM_{2.5}$ emissions reductions techniques (e.g., smoke management programs) may help reduce BC emissions.
- Appropriate mitigation measures depend on the timing and location of burning, resource management objectives, vegetation type, and available resources.
- Expanded wildfire prevention efforts may help to reduce BC emissions worldwide.

Part 4:
Mobile Sources:
Impact of New Engine Standards on Mobile Source BC Emissions

Joe Somers, OTAQ

Mobile Sources

- U.S. mobile source BC comes mainly from diesels
- Gasoline exhaust is a smaller source of BC



U.S. Black Carbon Emissions from all Mobile Source Categories, 2005 (total 333,400 tons)

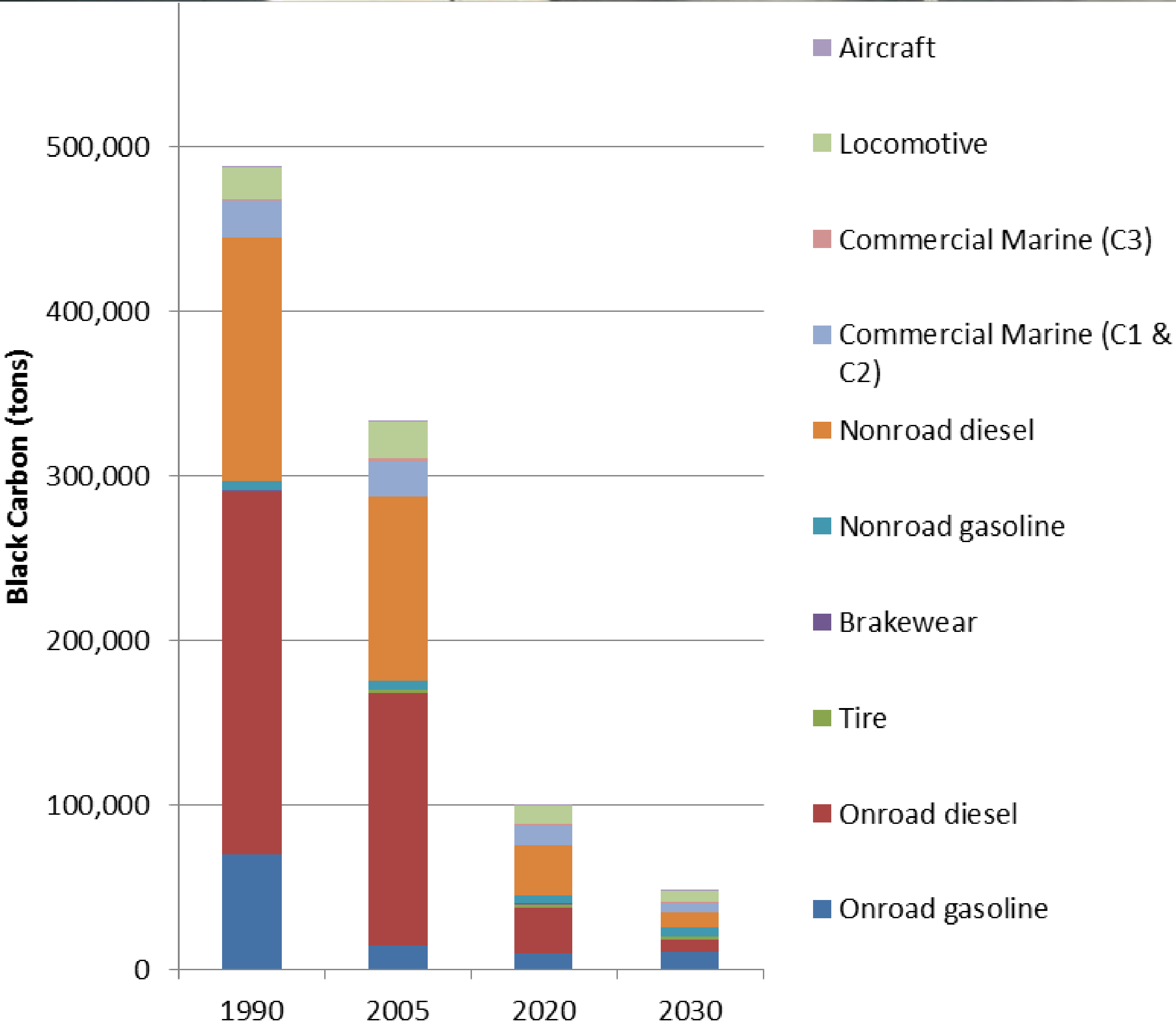
Reducing BC from Mobile Sources

- BC emissions from U.S. mobile diesel engines controlled via:
  - **Emissions standards** for new engines, including requirements resulting in use of diesel particulate filters (DPFs) in conjunction with ultra low sulfur diesel fuel.
    - Standards are for PM and are "technology forcing."
    - Reductions estimated from emissions models used in regulatory packages
      - On road BC, OC, PM inventory from MOVES
      - Nonroad BC inventory from PM for NONROAD model
      - Locomotive, commercial marine, and aircraft emissions estimated separately from models
  - **Retrofit programs** for in-use mobile diesel engines, such as EPA's National Clean Diesel Campaign and the SmartWay Transport Partnership Program.
- EPA presently has minimal standards for gasoline PM; however, EPA VOC/other standards do reduce gasoline PM

U.S. EPA Diesel Standards

- On road diesel PM standards – 2007 model year
  - 99% reduction in diesel PM for 2012 diesel track compared to a 1970 pre-control diesel truck
  - On road diesel PM and BC reduced by 91% and 95% respectively from 2005-2030
  - Diesel particulate filters preferentially reduce BC
  - Earlier diesel PM standards also reduced BC
  - Fleet turnover needed to achieve full PM/BC reductions
- Similar standards for nonroad diesels starting in 2012
- Similar standards for locomotives and commercial marine (categories 1 and 2 but not ocean going)
- EPA has estimated the cost of controlling $PM_{2.5}$ from new diesel engines at ~ $14,000/ton (2010$).
- Similar diesel controls being phased in internationally
- Gasoline PM is also reduced in future years

Projected Decline in BC Emissions from Mobile Sources



Emissions from U.S. Mobile Sources

Total U.S. mobile source BC emissions are projected to decline by 86% by 2030 due to regulations already promulgated.

Mobile Source Emissions Reductions 1990-2030

BLACK (ELEMENTAL) CARBON	1990	2005	2020	2030	1990--->2005	2005--->2030
Onroad gasoline	69,629	14,510	9,538	10,027	-79%	-31%
Onroad diesel	219,958	153,477	28,175	7,615	-30%	-95%
Tire	809	1,198	1,435	1,720	48%	44%
Brakewear	290	475	569	682	64%	44%
Nonroad gasoline	5,420	5,444	4,702	5,174	0%	-5%
Nonroad diesel	148,537	112,058	31,254	9,356	-25%	-92%
Commercial Marine (C1 & C2)	22,122	21,652	11,595	5,440	-2%	-75%
Commercial Marine (C3)	1,262	1,681	864	1,306	33%	-22%
Locomotive	19,317	22,495	11,349	5,684	16%	-75%
Aircraft*	283	410	457	553	45%	35%
Total	487,628	333,400	99,940	47,557	-32%	-86%

Part 5:
Reducing BC Emissions from In-Use Mobile Sources

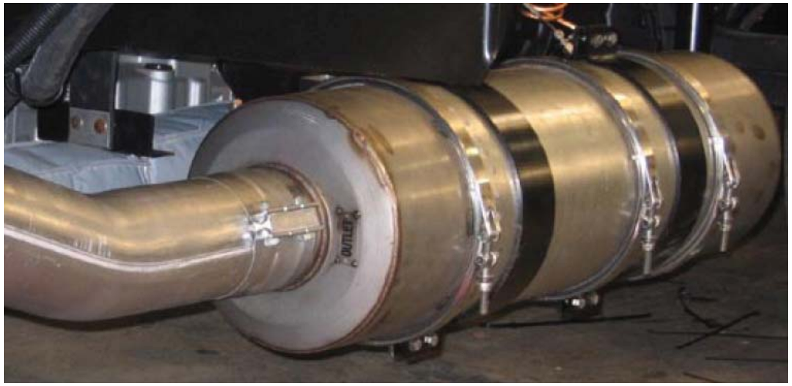
Mike Geller, OTAQ

In-Use Diesel Programs

- The tightest standards on new diesel engines can not clean up the existing fleet
- Goal: reduce emissions from the legacy fleet of 11 million diesel engines
- National Clean Diesel Campaign components:
  - Diesel Emissions Reduction Program (DERA): Install exhaust control devices
  - SmartWay Transport Program: Promote fuel saving technologies; less fuel = emissions reductions

Technology Verification

- Cost-effective verified and certified clean diesel strategies
  - Maximize public health benefits
  - Provide immediate, quantifiable emissions reductions
  - Key technologies include:
    - Exhaust controls (DOCs, DPFs, CCVs, SCRs)
    - Engine upgrade kits, engine repowers
    - Cleaner fuels
    - Vehicle replacements
    - Idle reduction technologies
    - Hybrid vehicle technologies



Retrofit Best Practices

- Require ULSD fuel
- Must be very carefully matched to the vehicle and engine by vendor
- Require monitoring of temperature and backpressure
- Engine and vehicle maintenance critical
- Require occasional cleaning for ash

Engine Upgrades

- Diesel engines designed for multiple rebuilds
- Older engines can be fitted with newer components
- Fuel economy can be improved
- NO_x and PM lowered
- Verified kits in US reduce PM and NO_x 25% or more for specific engines
- Could enable exhaust technologies.

Diesel Emission Reduction Act Highlights

- Under the Energy Policy Act (EPAct 2005) the Diesel Emission Reduction Program was appropriated funds from 2008-2012
- DERA was reauthorized in January, 2011 for FY 2012 – FY 2016
- Accomplishments to date
  - National
    - EPA has awarded over 500 grants across the U.S. totaling over $500 Million
  - State
    - DERA funds have provided States with $165 Million for clean diesel projects in All 50 States, plus D.C. and the 5 island territories
- 2012 Funding
  - State Allocation Program
    - $9 Million available for new State grants
    - Changes under the reauthorization now allow States to fund local and state mandated projects
  - National Competition-$20 Million (closed June 4)
    - 93 applications were received requesting $7 for every $1 available

DERA Benefits

- Emissions Reduced
  - EPA estimated these projects have reduced well over 7,000 tons of PM, 150,000 tons of NOx and 1,465,000 tons of CO_2
- Health benefits
  - Annual public health benefits of up to $4 Billion
  - For every dollar invested in reducing diesel exhaust, a community may achieve an estimated 13 dollars in public health benefits
- Job Creation
  - DERA ARRA funded projects are estimated to have created or retained more than 3,000 clean diesel related jobs, as reported by the grant recipients.

Thank You!

- This concludes today's presentation.
- **Questions?** Please type them into the question box on your screen.
- For additional information, please contact today's presenters:
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