Black Carbon and the Regional Climate of California

A Multi-Institutional CARB Funded Project

CARB Chair's Lecture

V. Ramanathan and L.M. Russell

Scripps Inst. of Oceanography, University of California at San Diego

Sacramento, July 23, 2013

Outline

- **Part I:** Decadal Trends and Implications for Climate Change
- **Part II:** Changes in Cloud Properties due to BC-Cloud Interactions
- **Part III:** Implications for Global Climate Change Mitigation and Future Work

Multi-year, Multi-Institution study funded by California Air Resources Board (CARB)

Contract Report 08-323

http://www.arb.ca.gov/research/single-project.php?row_id=64841

Principal Investigator: V. Ramanathan

Co-Authors of this Report

- **Scripps Institution of Oceanography, UCSD (V. Ramanathan & R. Bahadur)**
- **Department of Chemistry and Biochemistry, UCSD (K. Prather/A/ Cazorla)**
- **Lawrence Berkeley National Laboratories (T. Kirchstetter/O. Hadley)**
- **Pacific Northwest National Laboratories (R. Leung/C. Zhao)**
- **In addition…5 PGRs and 4 graduate students.**

Study Coordinator: R. Bahadur (UCSD)

Grant Manager: N. Motallebi (CARB)

Part I: Decadal Trends and Implications for Climate Change
Overall Summary of Ramanathan et al CARB-08-323, 2013 Report

A. Approach:

Significance: The first such attempt to estimate the REGIONAL radiative forcing of black carbon and brown carbon, both from a bottom-up approach and a top-down approach

B. Major Findings: Climate Change Mitigation

- **Detection: The control of BC from diesel is an effective means of mitigating near-term global climate change**
- **Attribution: BC emission and concentration reductions observed in California since the 1980s, mostly from diesel engines as a result of air quality programs, are equivalent to reducing CO_2 emissions by 5 % to 13% of the total direct CO_2 annual emissions of 393 million metric tons***

The equivalence with CO_2 emission is for only illustrative purposes; comparing emissions of short lived black carbon with long-lived CO_2 is not straight forward and can be misleading if taken out of context

Major Topics

- **Black Carbon Trends in California:**
  - ***Detection and Attribution***
- **Brown Carbon (BrC) Identification:**
  - ***Organic aerosols that absorb solar radiation are called BrC***
- **Source Identification**
- **Radiative Forcing by Black and Organic Carbon Aerosols**
- **Regional Climate Effects**
- **Mitigation of Global Warming**

Ramanathan et al, 2013: CARB 08-323

Part 1-A: The Approach
Significance of the study: Why California ?

- **First and largest study of its kind, constrained by field measurements that documents black carbon reductions from the transportation sector on a large scale**
- **Inclusion of historical data makes it an "accountability study"**
  - **Demonstration of "benefits reaped" in addition to future prospects**
- **Test-Case in a well sampled region provides a robust framework for future studies**

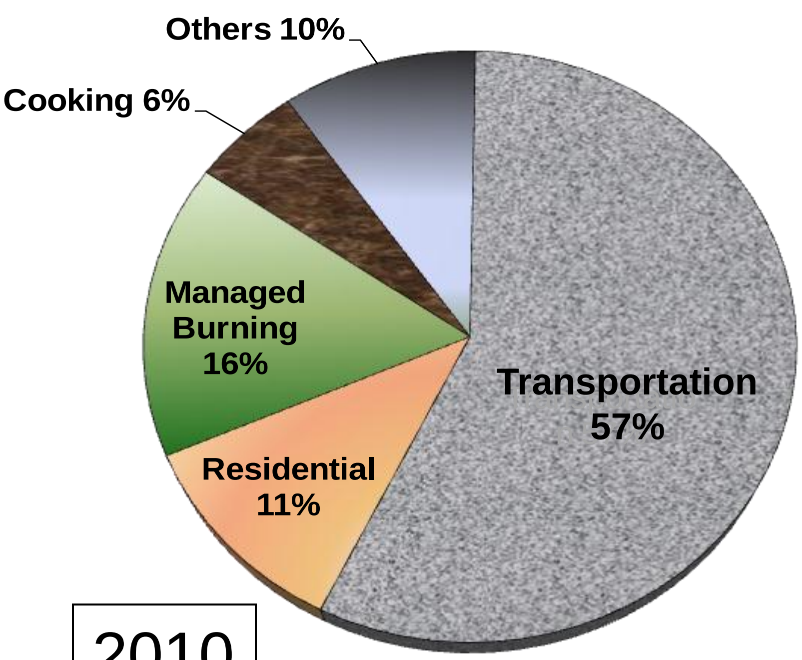
Ramanathan et al, 2013: CARB 08-323

Black Carbon (BC): Product of Incomplete Combustion

- **BC is an aerosol (particle) ranging in size from tens of nanometers to hundreds of nanometers**
- **The major component of PM from the Diesel Transportation Sector**
- **About 75% of PM from Diesel Mobile sources is BC**
- **The second largest contributor to global warming**
- **Contributes directly to melting of snow packs, glaciers, and sea ice**


Ramanathan et al, 2013: CARB 08-323

Anthropogenic Black Carbon Sources (Exclude wildfire and biogenic)



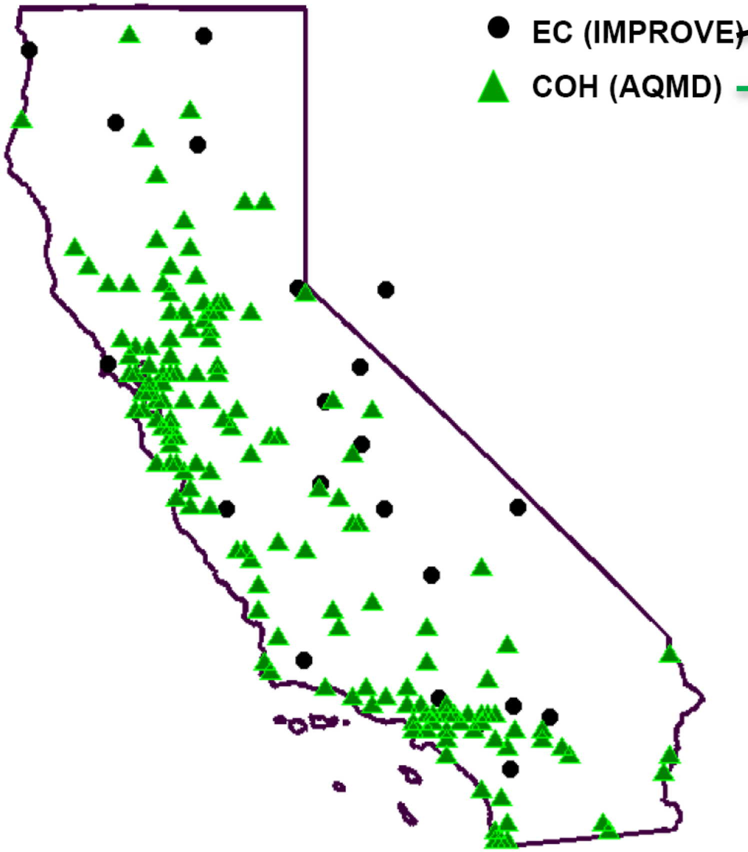
2010

Statewide
BC ~ 18,200 tons per year

Transportation (57%), managed burning, and residential fuel combustion are the dominant contributors to the black carbon inventory

Source: California Air Resources Board

Black Carbon Trends in California: Detection



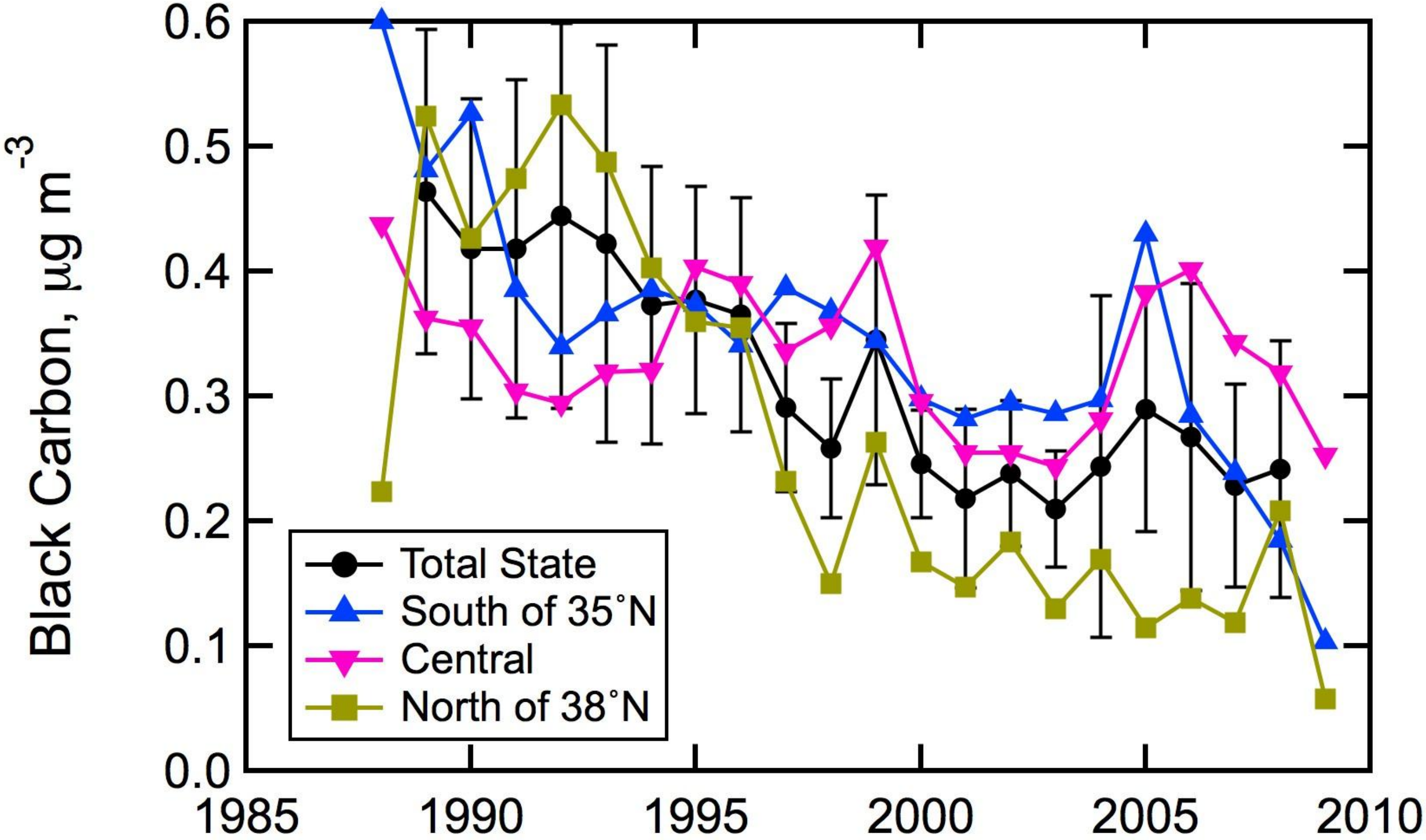
Remote sites

Mostly Urban sites

Ramanathan et al, 2013: CARB 08-323

Statewide BC Trends in California-Annual Mean (Remote Sites)

Trend is consistent in North, Central, and South California

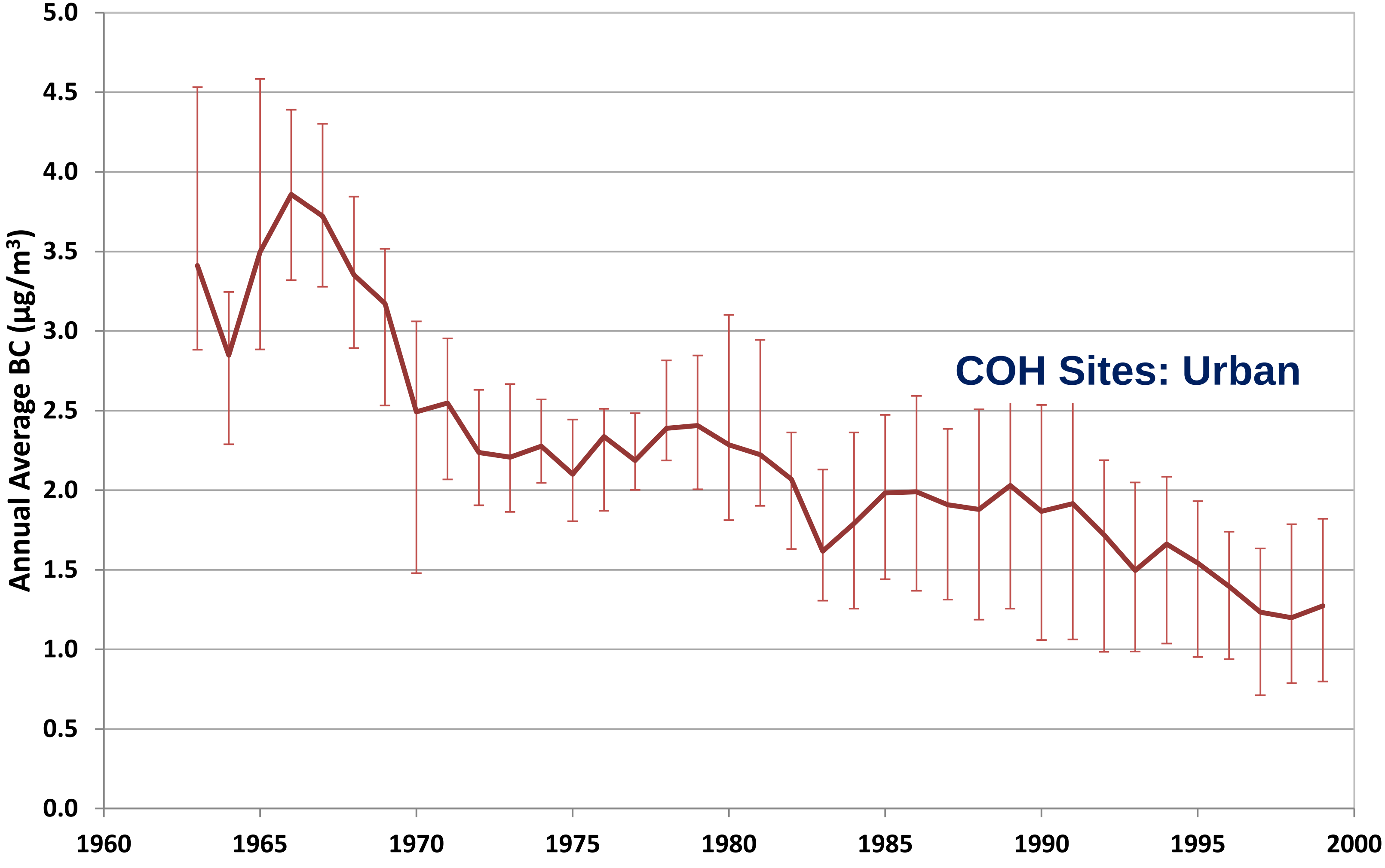


Source: Bahadur et al, 2010

Ramanathan et al, 2013: CARB 08-323

Declining Black Carbon Concentrations in Urban California

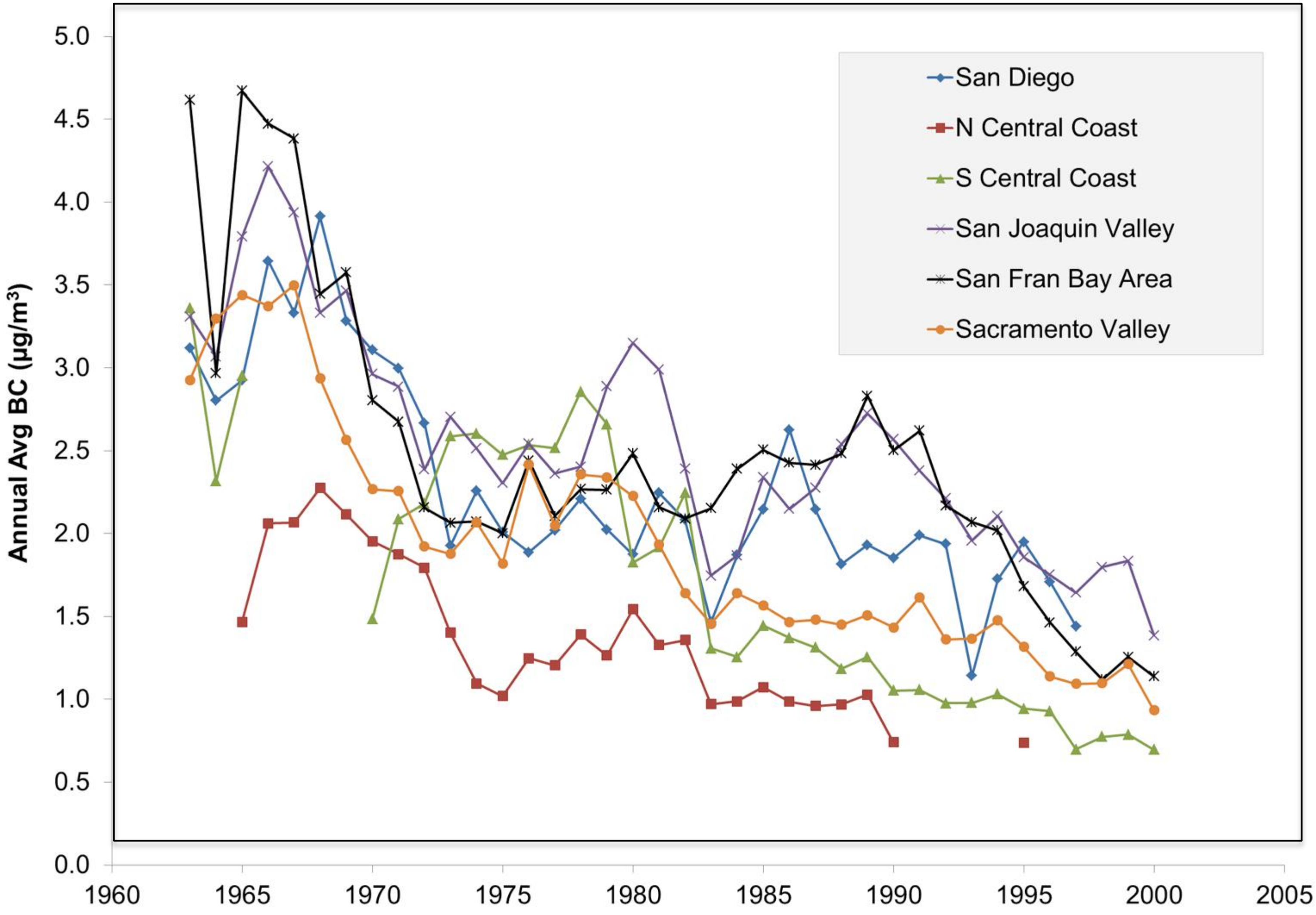
Urban concentrations of BC are larger than those at Remote Sites by a factor of 3 to 5



Source: Kirchstetter et al, 2012

Ramanathan et al, 2013: CARB 08-323

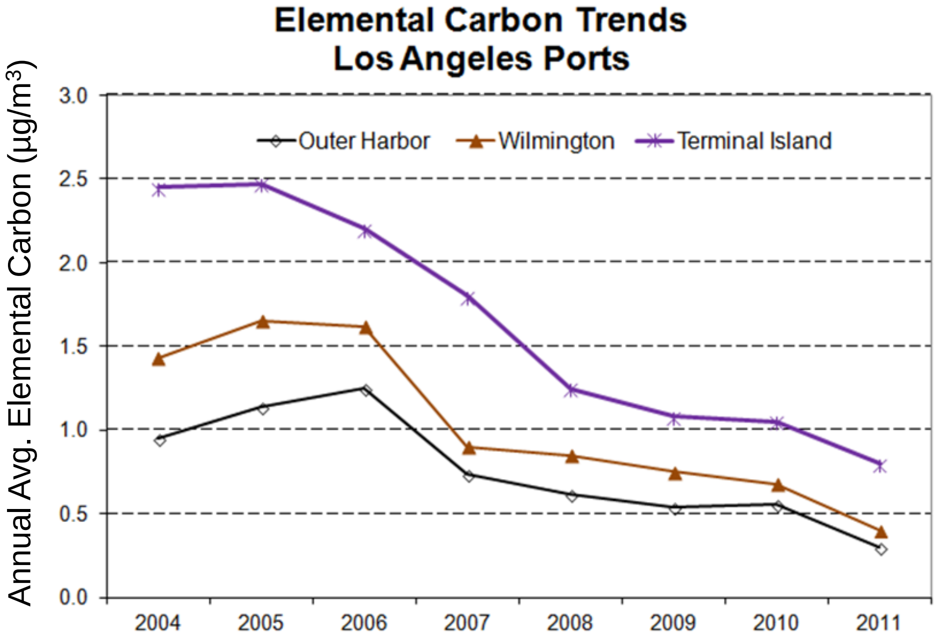
Trends in BC concentrations resolved by air basin from COH sites

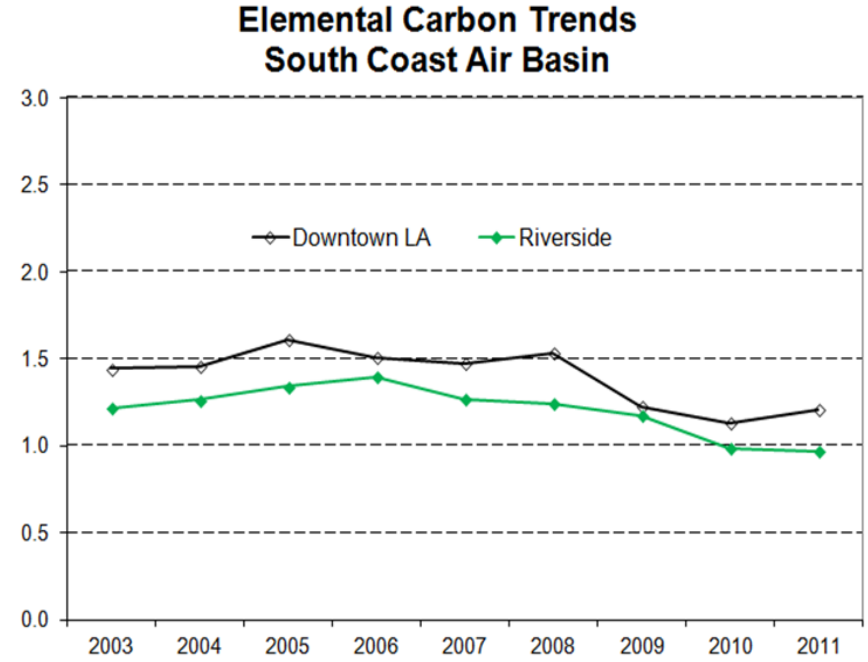


Source: Kirchstetter et al, 2012

Ramanathan et al, 2013, CARB 08-323

Negative trends are continuing to the present





Source: California Air Resources Board, 2013

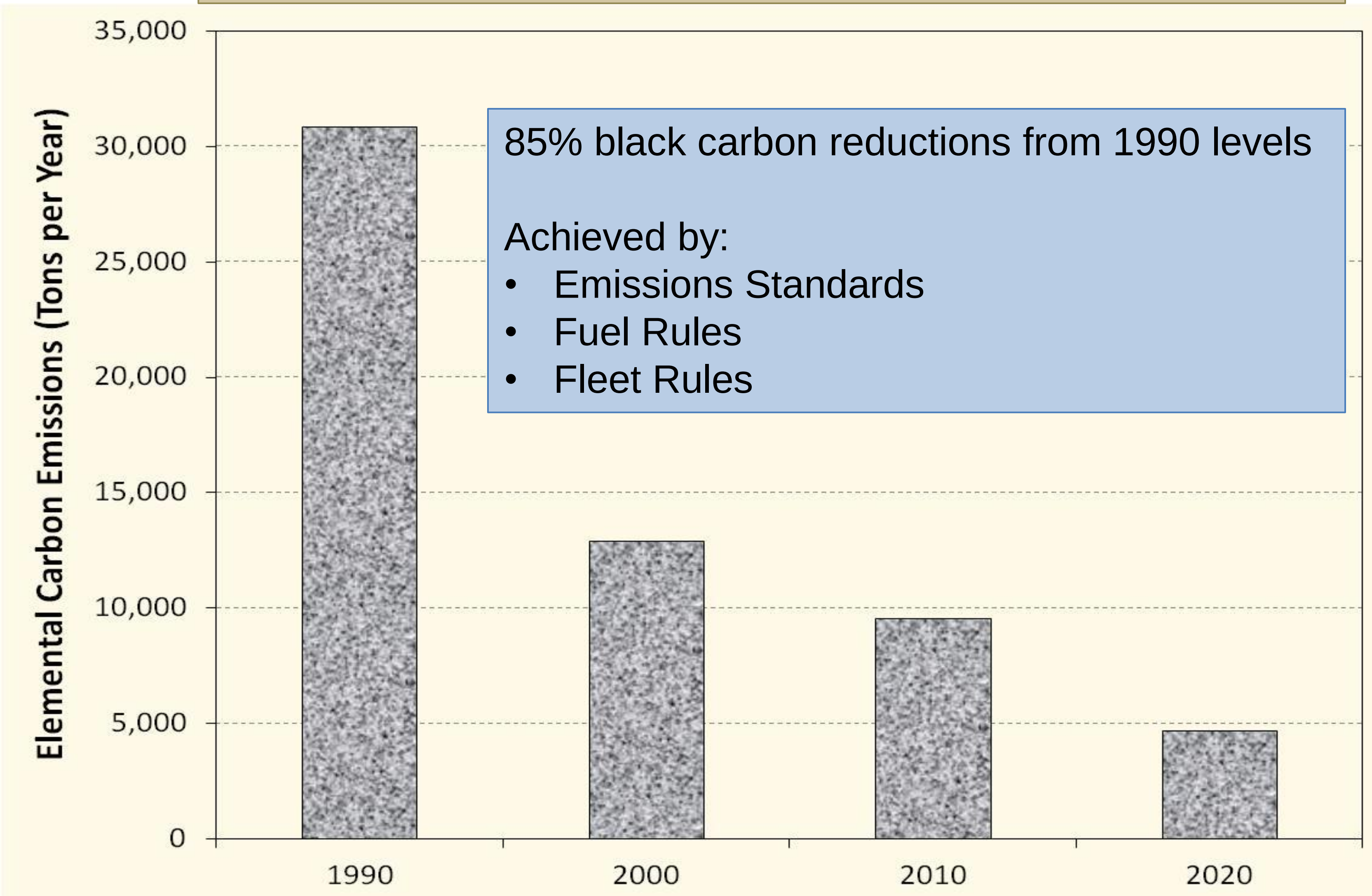
Part I-B Major Finding: Detection

Ramanathan et al, 2013 CARB 08-323

- **Statewide BC concentrations in California have decreased from 0.46 μgm^{-3} in 1989 to 0.24 μgm^{-3} in 2008 (about 50 % reduction)**
- **Fossil Fuel and Diesel Emissions show a corresponding 50% reduction**
- **This trend extends further back, with the decrease being 72% from the late 1960s to 2000**
- **The negative trend is still continuing**

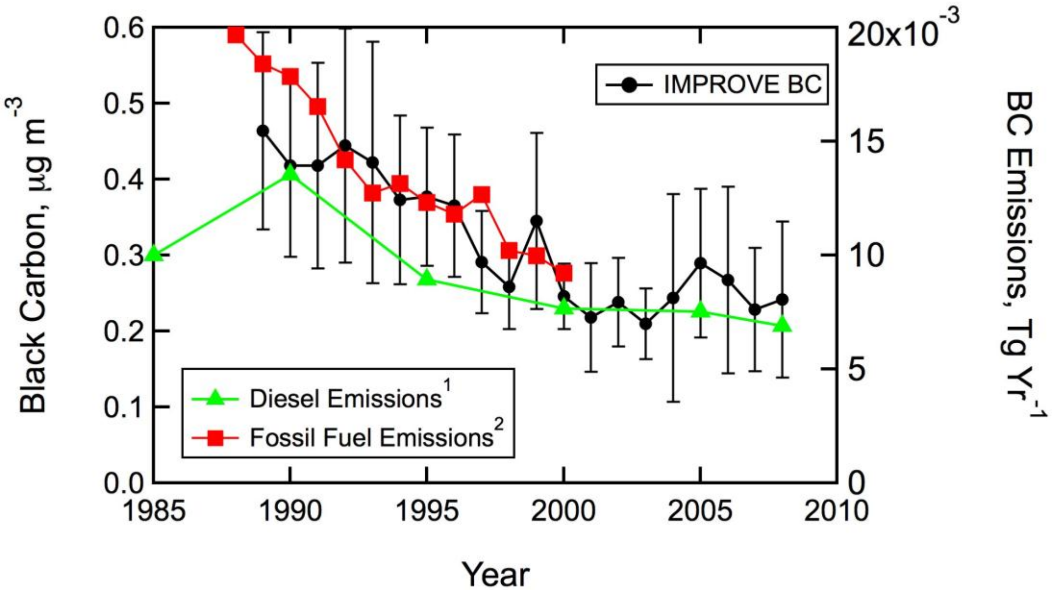
ATTRIBUTION: WHAT IS THE MAJOR SOURCE OF REDUCTION?

California's Diesel Program



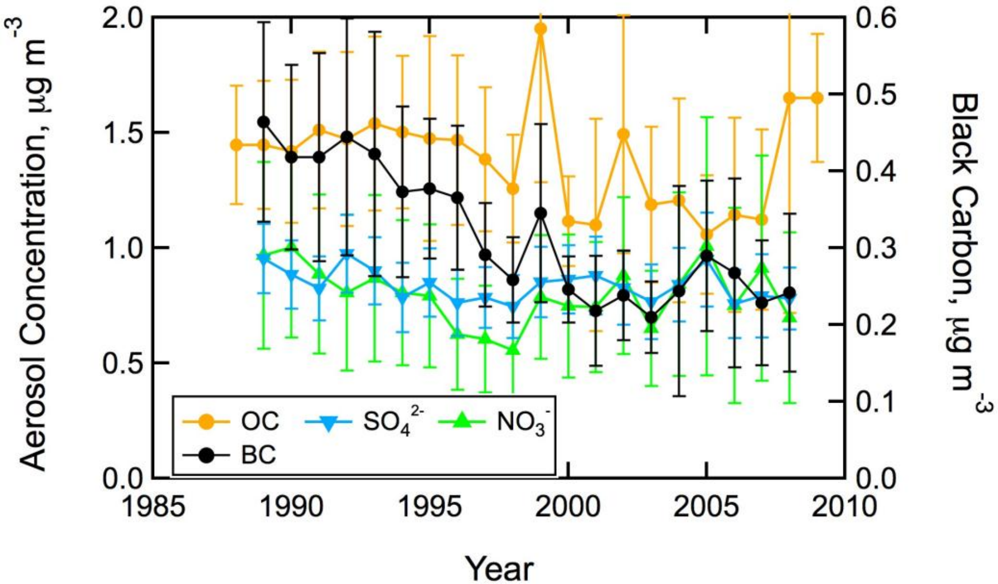
Source: California Air Resources Board

BC Trends in California: All IMPROVE Sites



Source: Bahadur et al, 2010

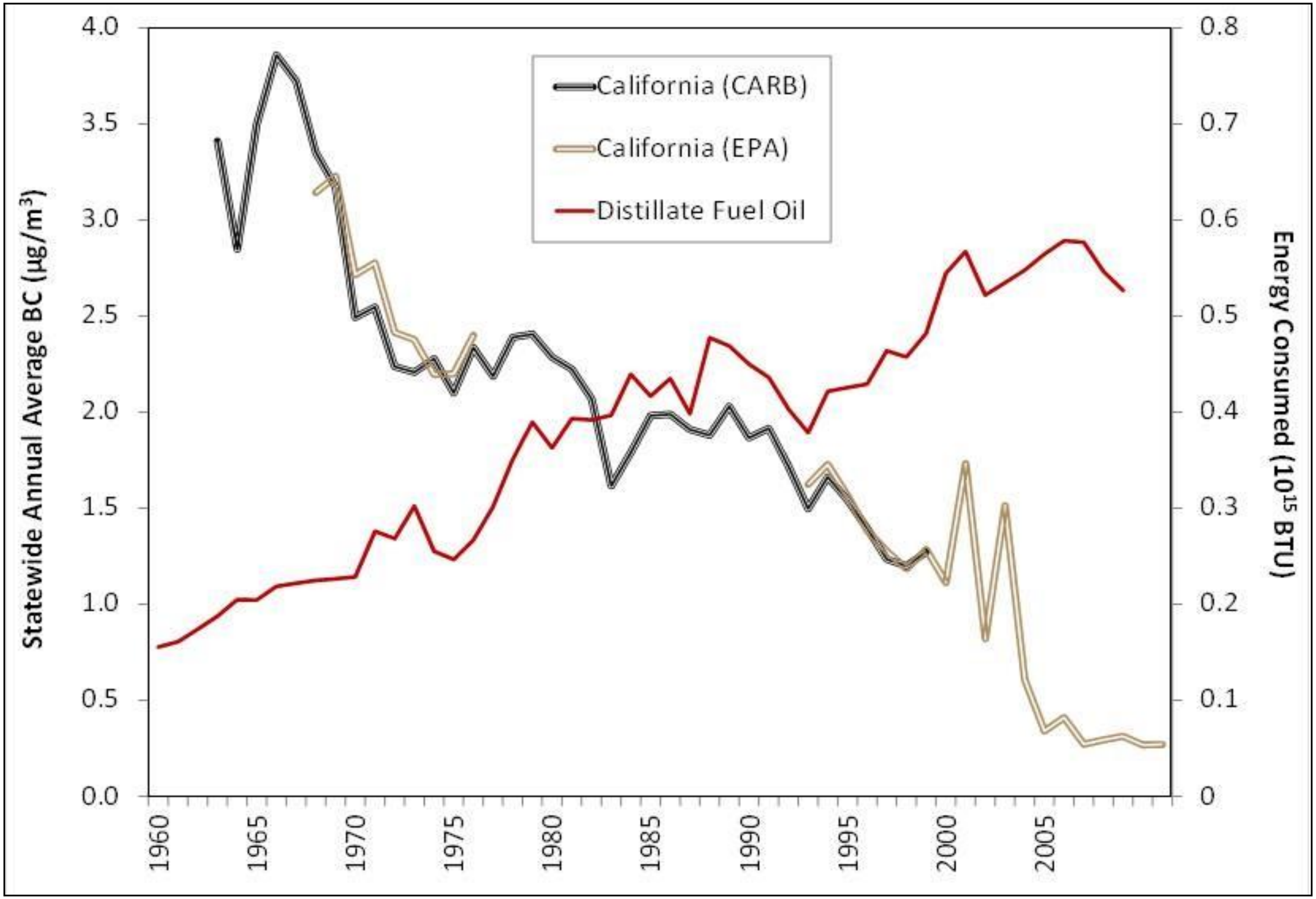
BC Trends are consistent with diesel BC emission trends



Lack of similar trends in other aerosols indicates: negative trends in BC is not due to meteorology

Ramanathan et al, 2013: CARB 08-323

40 Years of Progress on Diesel Soot



Source: Kirchstetter et al. (2011)

Ramanathan et al, 2013: CARB 08-323

Part I-B: Major Findings: Attribution

Ramanathan et al,2013: 08-323

- **BC has decreased even though total fuel consumption has steadily increased**
- **BC Trends are consistent with diesel BC emission trends**
- **Lack of similar trends in other aerosols indicates:**
  negative trends in BC is not due to meteorology
- **Clean-up attributed to reduced tail-pipe emissions, improved engines, and low-sulfur fuel as mandated by State policies**

Large negative trends in BC and lack of corresponding negative trends in co-emitted cooling aerosols gives compelling observational evidence that mitigation of diesel BC would be effective in mitigating global warming as inferred by modeling studies (e.g., Jacobson, 2010; Bond et al, 2013)

Observationally Constrained Forcing

- ***BC absorbs solar radiation***
- ***This adds solar energy to the atmosphere-surface system***
- ***This added energy is referred to as Radiative Forcing or simply Forcing***

Data sets:

Satellite Aerosol Optical Data (MISR)

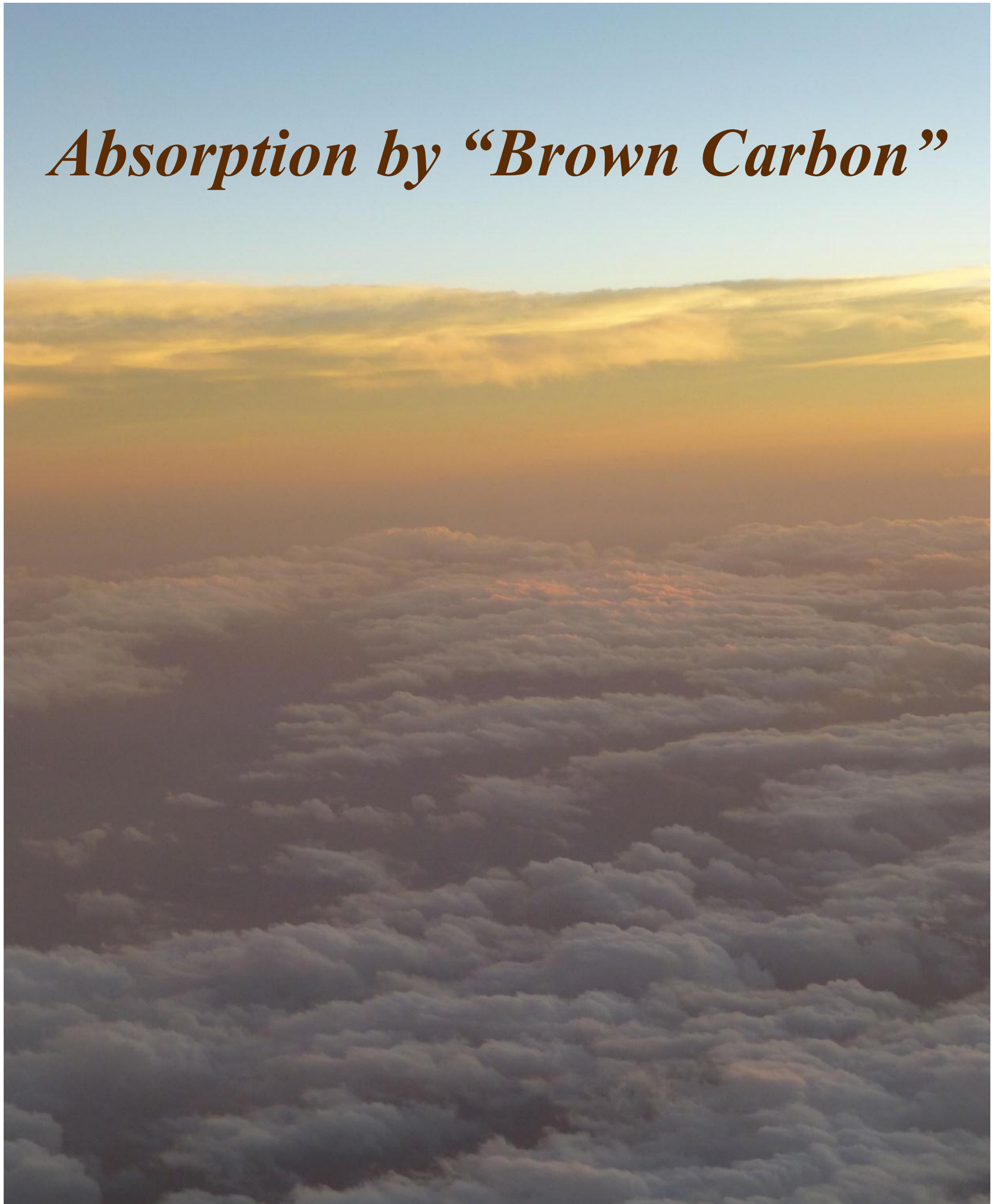
- **Give the total Scattering+ Absorbing effect of aerosols in the column**

NASA-Ground Network: AERONET:

- **Gives the absorbing component(BC, BrC, Dust) in the column**

Ramanathan et al, 2013, CARB 08-323

Absorption by “Brown Carbon”



Brown Clouds Over San Diego; Sylvia Somerville, 2013

Ramanathan et al, 2013, CARB 08-323

Brown Carbon:
Another Climate Warming Pollutant?

- **Black Carbon (soot)**
  - **Produced in high temperature flaming combustion from fuel containing carbonaceous material**

- **Brown Carbon**
  - **Produced in lower temperature smoldering combustion from fuel containing biomass and likely from secondary organics from fossil fuels**

(*polycyclic aromatics, tarballs, and organonitrates, likely many others*)

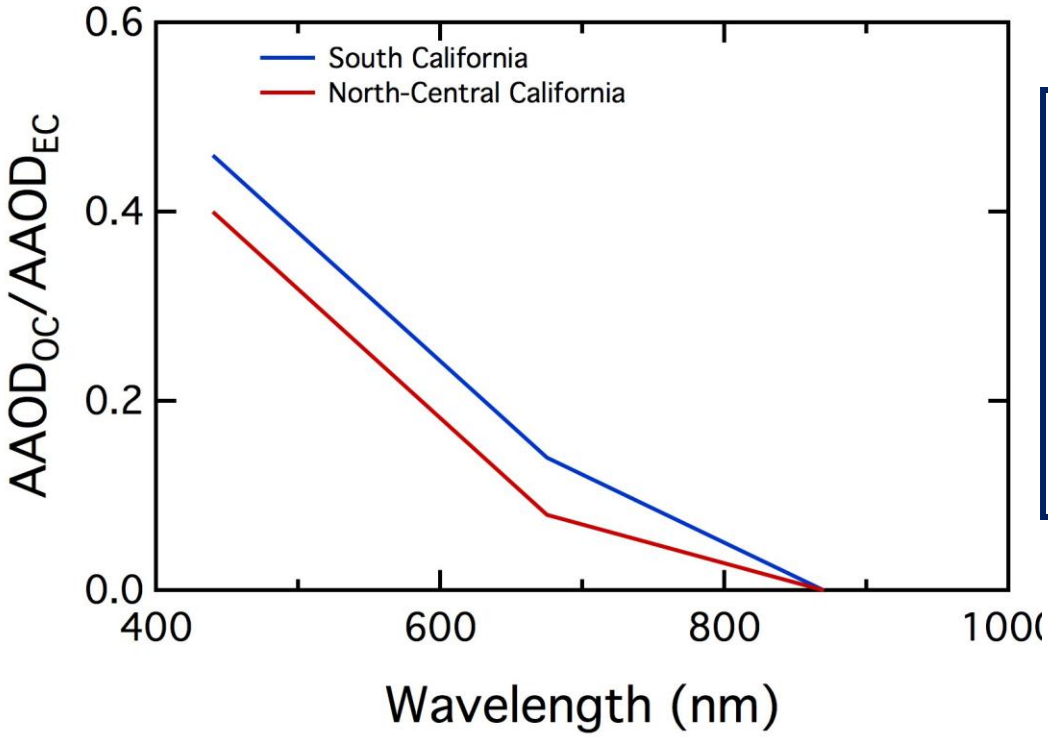
Ramanathan et al, 2013: CARB 08-323

<u>Brown Carbon:</u>

Significant OC absorption detected over California

Column Data (NASA-AERONET Ground Network):

Ratio of OC to BC Vertical Column Absorption



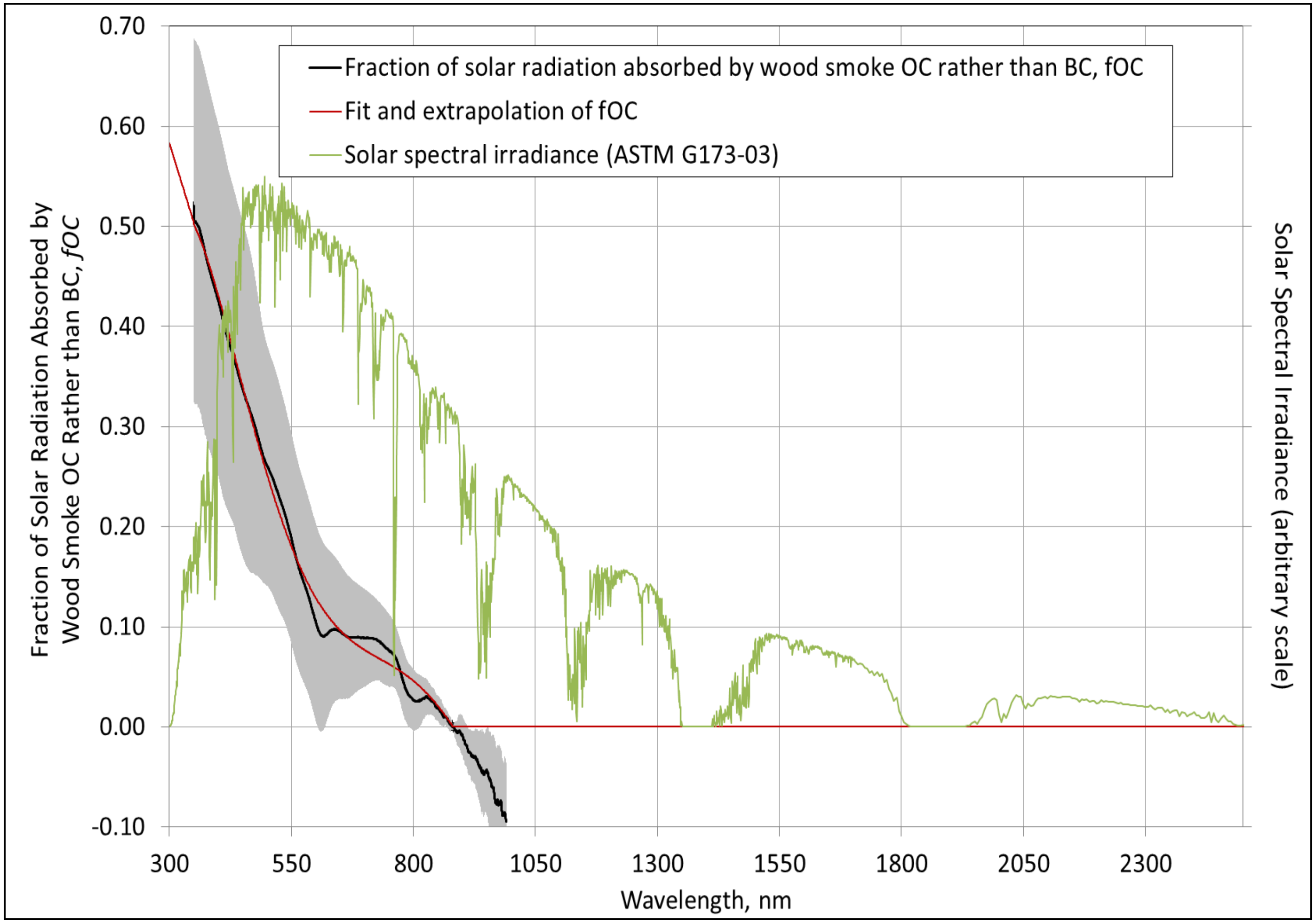
- ***Solar absorption by organics can be as much as 20% to 40% at visible wavelengths***
- ***Most climate models treat organics as pure scattering (cooling) aerosols***

Source: Bahadur et al. PNAS, 2012

Ramanathan et al, 2013: CARB 08-323

Brown Carbon: Independent in-situ data

Supporting Data from surface measurements of wood smoke in San Luis Obispo Region



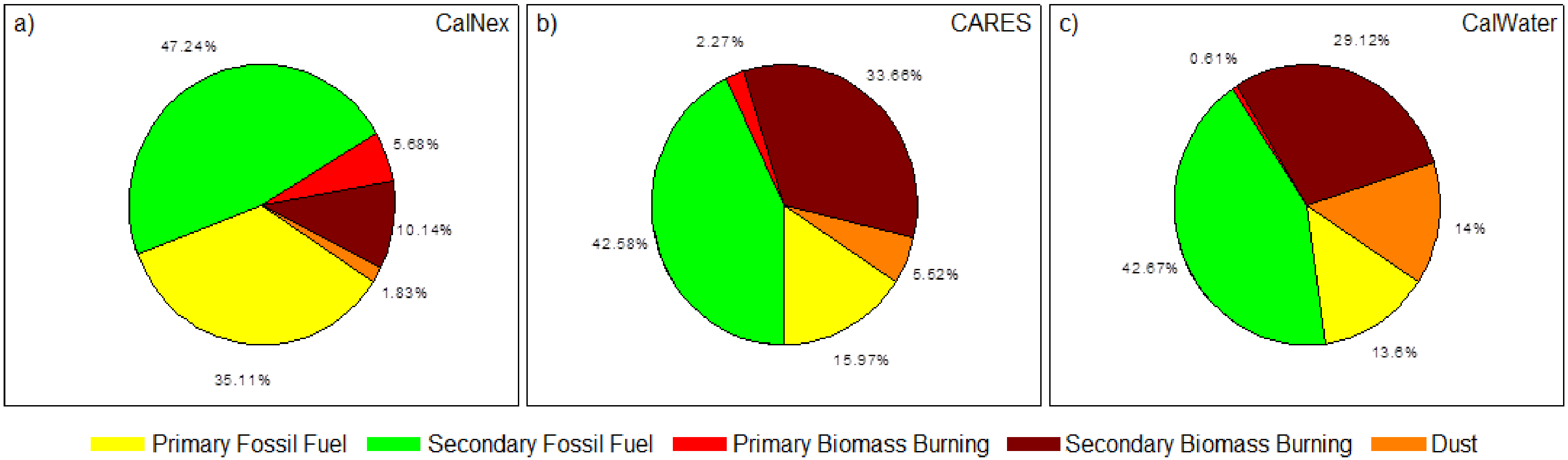
Source: Kirchstetter & Thatcher, ACP, 2012

Ramanathan et al, 2013: CARB 08-323

Source Identification: ATOMFS

Cazorla and Prather, submitted, ACPD 2013

S. California. Summer | N. California. Summer | N. California. Winter



S. California dominated by fossil fuels ⟵ ***N. CA: Biomass plays larger role*** ⟶

Ramanathan et al, 2013: CARB 08-323

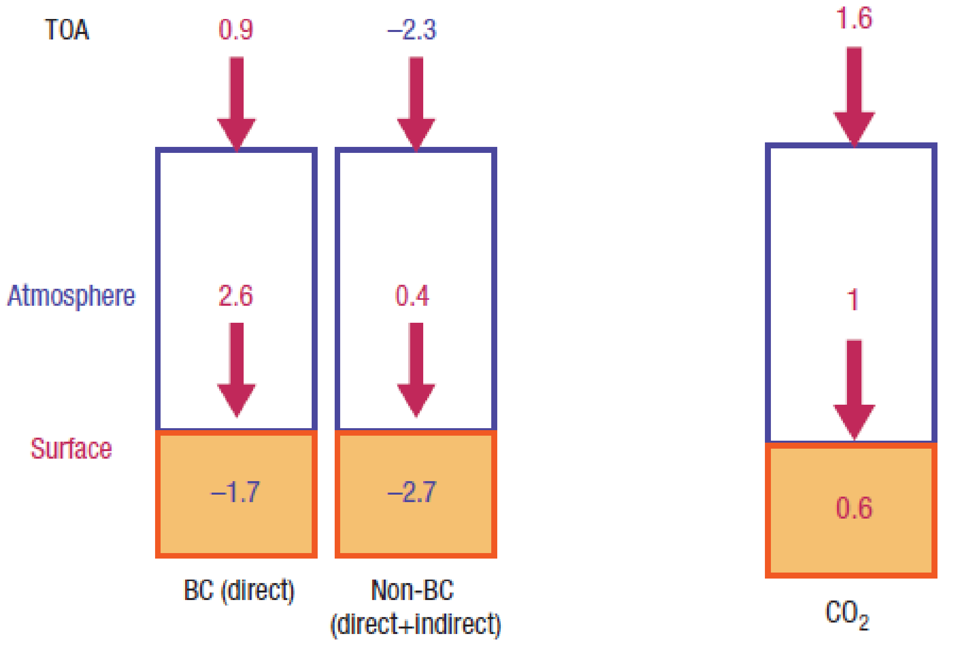
Global and regional climate changes due to black carbon

V. RAMANATHAN[1] AND G. CARMICHAEL[2]

nature geoscience | ADVANCE ONLINE PUBLICATION | www.nature.com/naturegeoscience

"..***Emissions of black carbon are the second largest contribution to current global warming, after carbon dioxide emissions..***"

0.9 Wm^{-2} **1.7 Wm^{-2}**

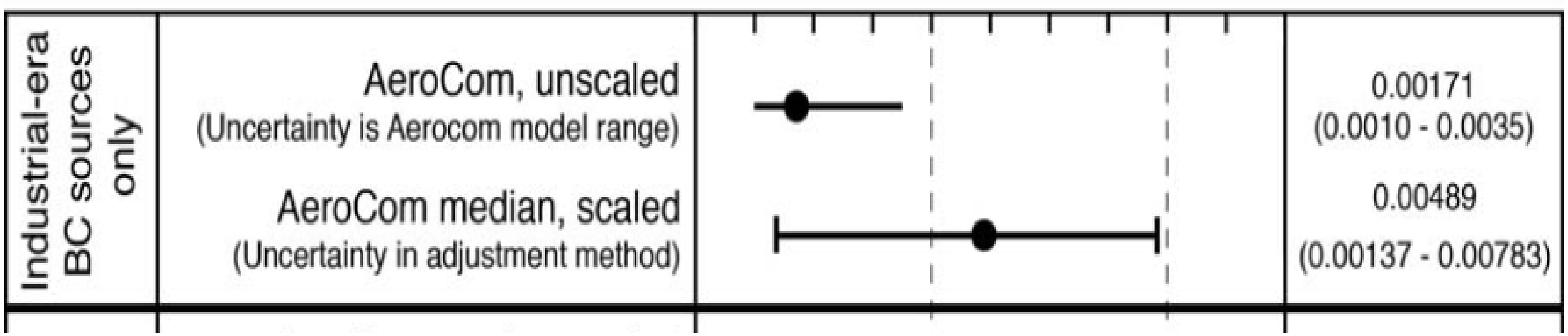


Bounding the role of black carbon in the climate system: A scientific assessment

T. C. Bond[1], S. J. Doherty[2], D. W. Fahey[3], P. M. Forster[4], T. Berntsen[5], B. J. DeAngelo[6], M. G. Flanner[7], S. Ghan[8], B. Kärcher[9], D. Koch[10], S. Kinne[11], Y. Kondo[12], P. K. Quinn[13], M. C. Sarofim[6], M. G. Schultz[14], M. Schulz[15], C. Venkataraman[16], H. Zhang[17], S. Zhang[18], N. Bellouin[19], S. K. Guttikunda[20], P. K. Hopke[21], M. Z. Jacobson[22], J. W. Kaiser[23], Z. Klimont[24], U. Lohmann[25], J. P. Schwarz[3], D. Shindell[26], T. Storelvmo[27], S. G. Warren[28], C. S. Zender[29]

JOURNAL OF GEOPHYSICAL RESEARCH: ATMOSPHERES, VOL. 118, 1–173, doi:10.1002/jgrd.50171, 2013

Global BC AAOD inferred from observations and models



"Global atmospheric absorption attributable to black carbon is too low in many models, and should be increased by a factor of 3"

Bounding the role of black carbon in the climate system: A scientific assessment

Bond et al, JGER, 2013

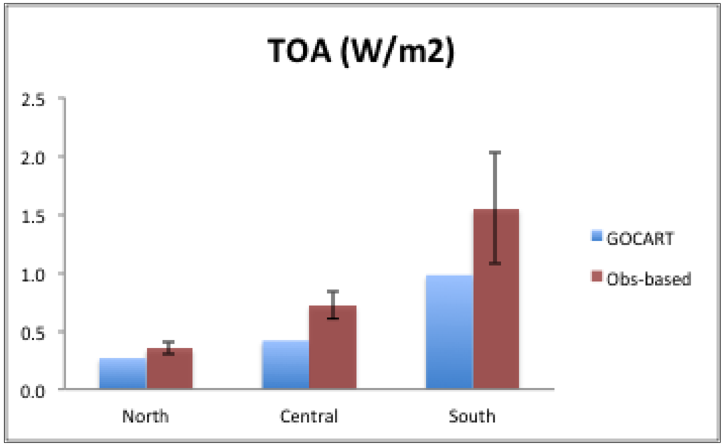
JOURNAL OF GEOPHYSICAL RESEARCH: ATMOSPHERES, VOL. 118, 1–173, doi:10.1002/jgrd.50171, 2013

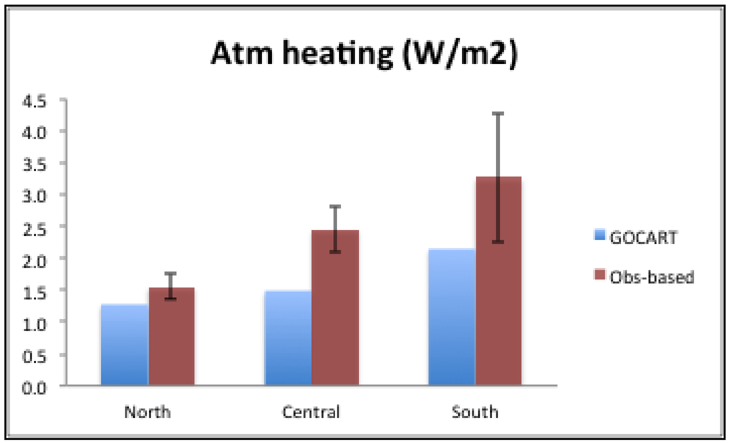
'Total direct forcing by all black carbon sources, …, is estimated as 0.88 (+0.17, +1.48) Wm^{-2} '

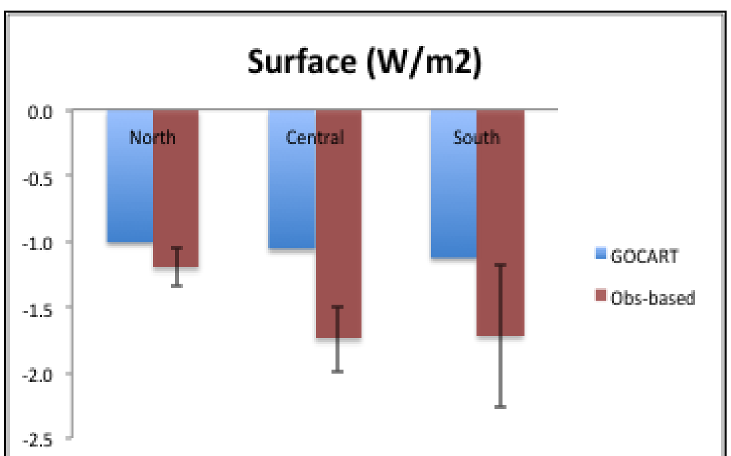
Confirmed Ramanathan and Carmichael value of 0.9 Wm^{-2}

"We confirm that black carbon, with a total climate forcing of +1.1 Wm^{-2}, is the second most important human emission in terms of its climate forcing in the present-day Atmosphere"

Confirmed Jacobson's, 2002 model finding and Ramanathan & Carmichael's, 2008 observationally based finding







Radiative forcing of BC

- **Blue:** Optical properties simulated by GOCART
- **Red:** Optical properties empirically derived from observations
- **Bars bracket:** Uncertainty estimate due to selection of SSA data

The forcing should have been larger by a factor of 2 in the 1980s and a factor of 4 in the 1960s

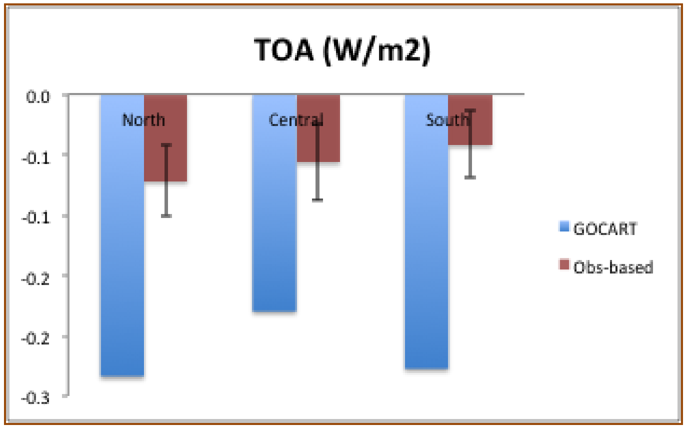
Ramanathan et al, 2013: CARB 08-323

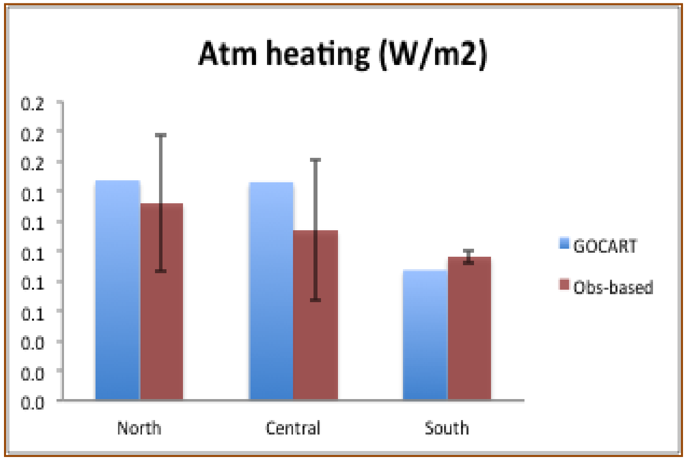
Regional Model underestimates absorption by a factor of 2 to 4 similar to Bond et al (2013) findings concerning Global Models

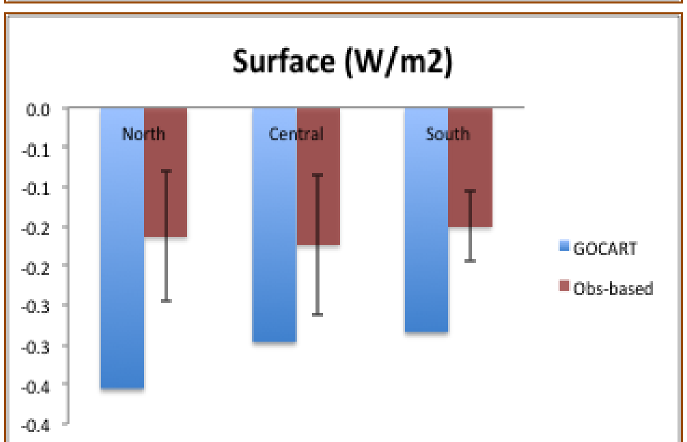
	Observationally Constrained Top-Down (OC_TD)		**Emission Inventory Based Bottom-Up (EI_BU)**	
	SSA from AERONET	SSA from GOCART	WRF_PNNL (1*BC)	WRF_PNNL (2*BC)
		TOA forcing		
North	0.20	0.28	0.09	0.16
Central	0.44	0.48	0.17	0.32
South	0.88	1.92	0.21	0.40
State	0.51	0.89	0.16	0.29
		Atmospheric heating, W m^{-2}		
North	1.73	1.79	0.60	0.82
Central	2.40	2.78	0.86	1.25
South	2.44	4.05	0.96	1.41
State	2.19	2.87	0.81	1.16

Source for Model Forcing: Zhao et al, 2013

Ramanathan et al, 2013 CARB 08-323







Radiative forcing of OC: Role of Brown Carbon

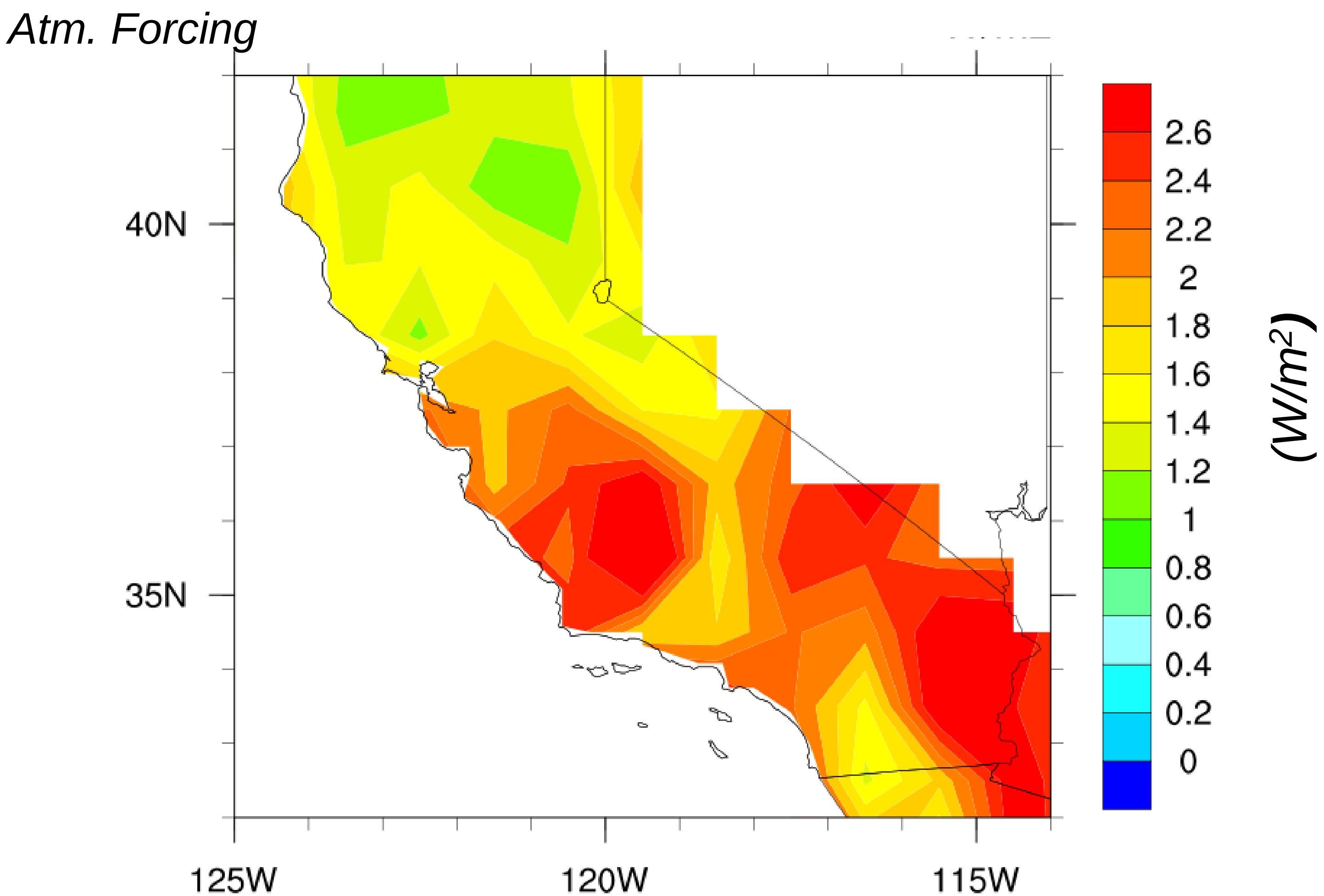
- **Blue:** Optical properties simulated by GOCART
- **Red:** Optical properties empirically derived from observations
- **Bars bracket:** Uncertainty estimate due to selection of SSA data

Climate models ignoring brown carbon significantly overestimate the cooling by organic aerosols

Ramanathan et al, 2013: CARB 08-323

Carbonaceous Aerosol (BC+OC) Atmospheric Forcing

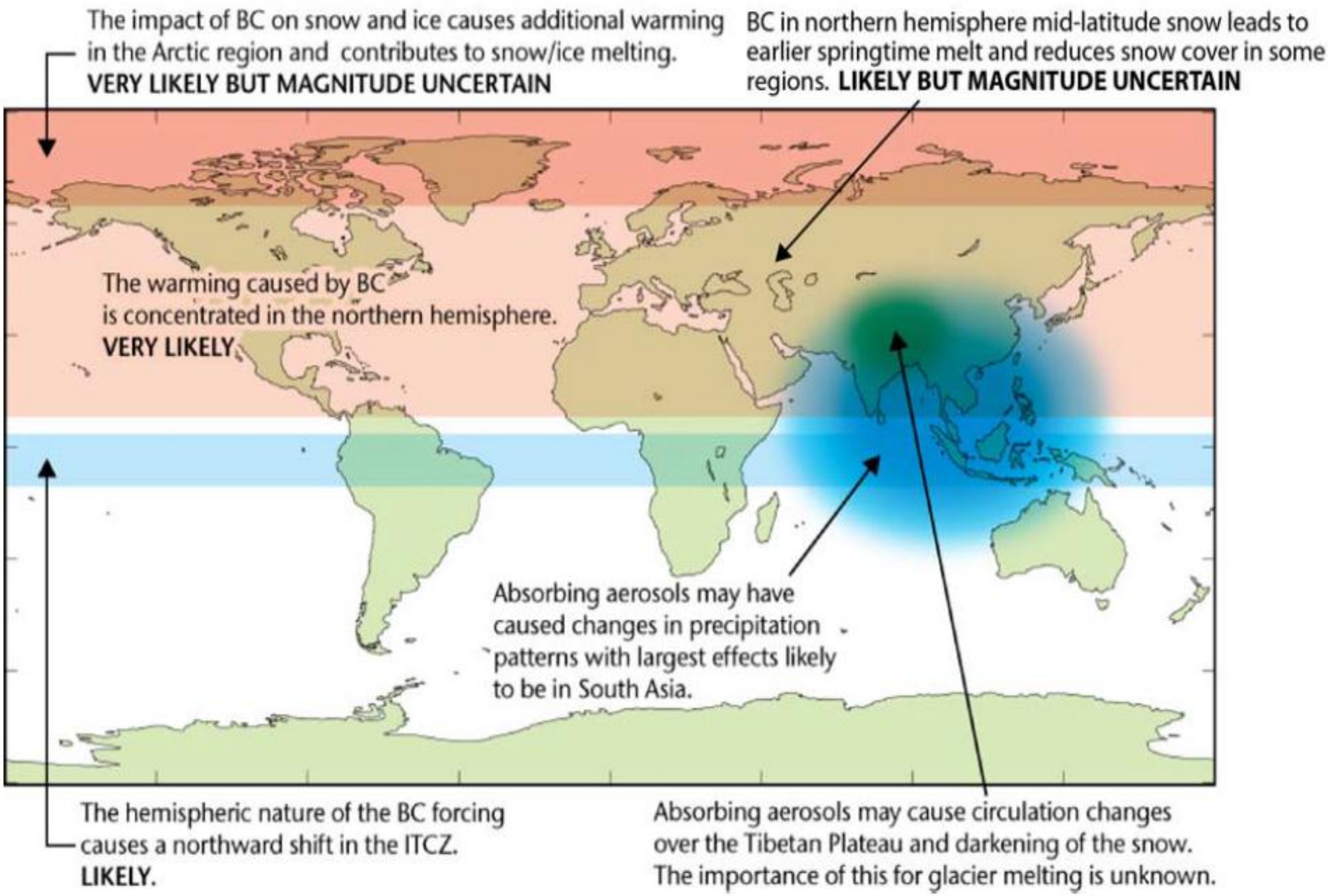
Annual Mean 2001 to 2010



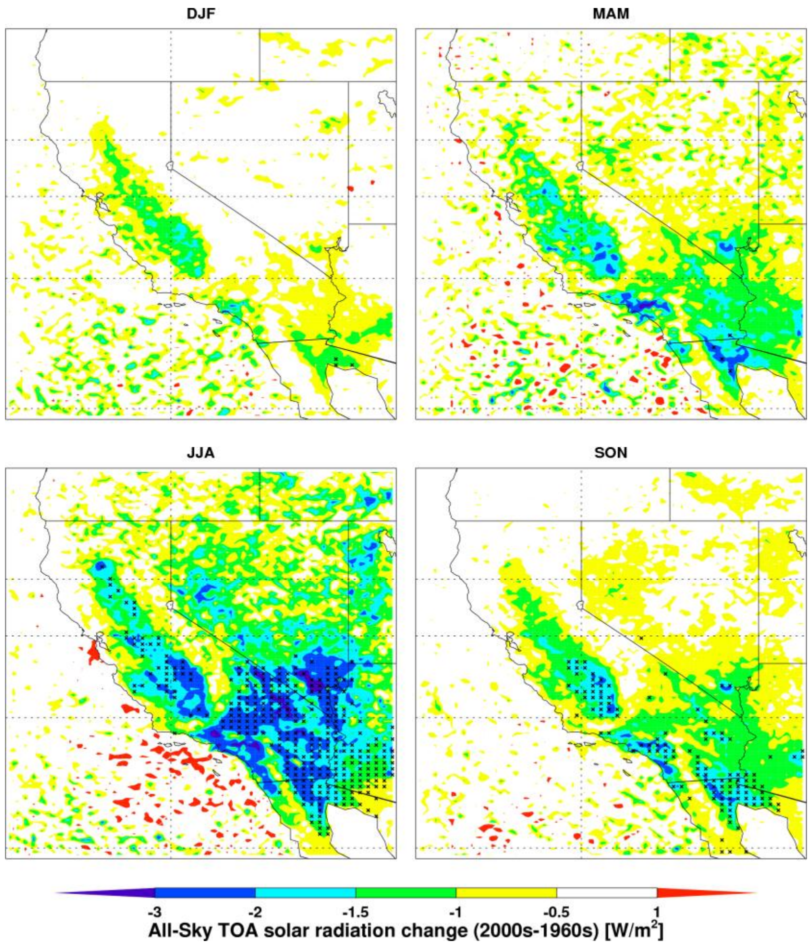
Ramanathan et al, 2013: CARB 08-323

Climate effects of black carbon emissions

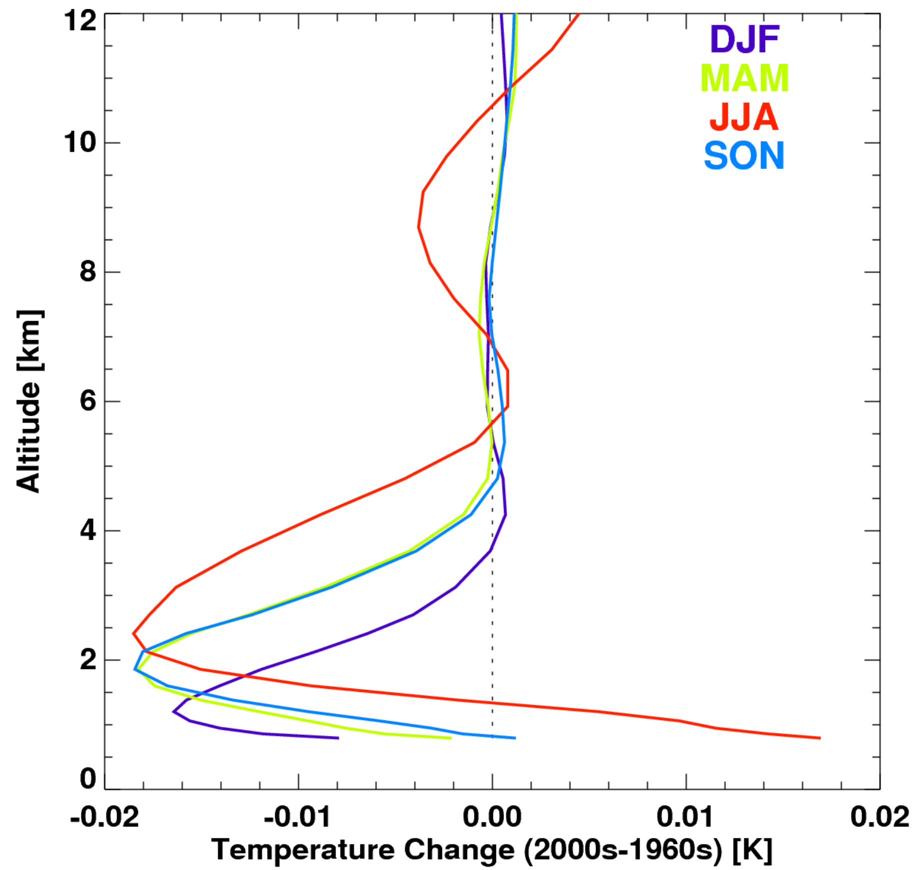
Bond et al, 2013



Impact of BC reduction on Regional Climate



Source: Zhao et al, 2013



- **Changes in TOA solar radiation in the last 40 years attributed to BC decrease.**
- **Changes that are statistically significant at the 90% confidence level are stippled.**
- **The simulated atmospheric cooling and surface warming are shown on the right panel(not significant at the 90% level).**

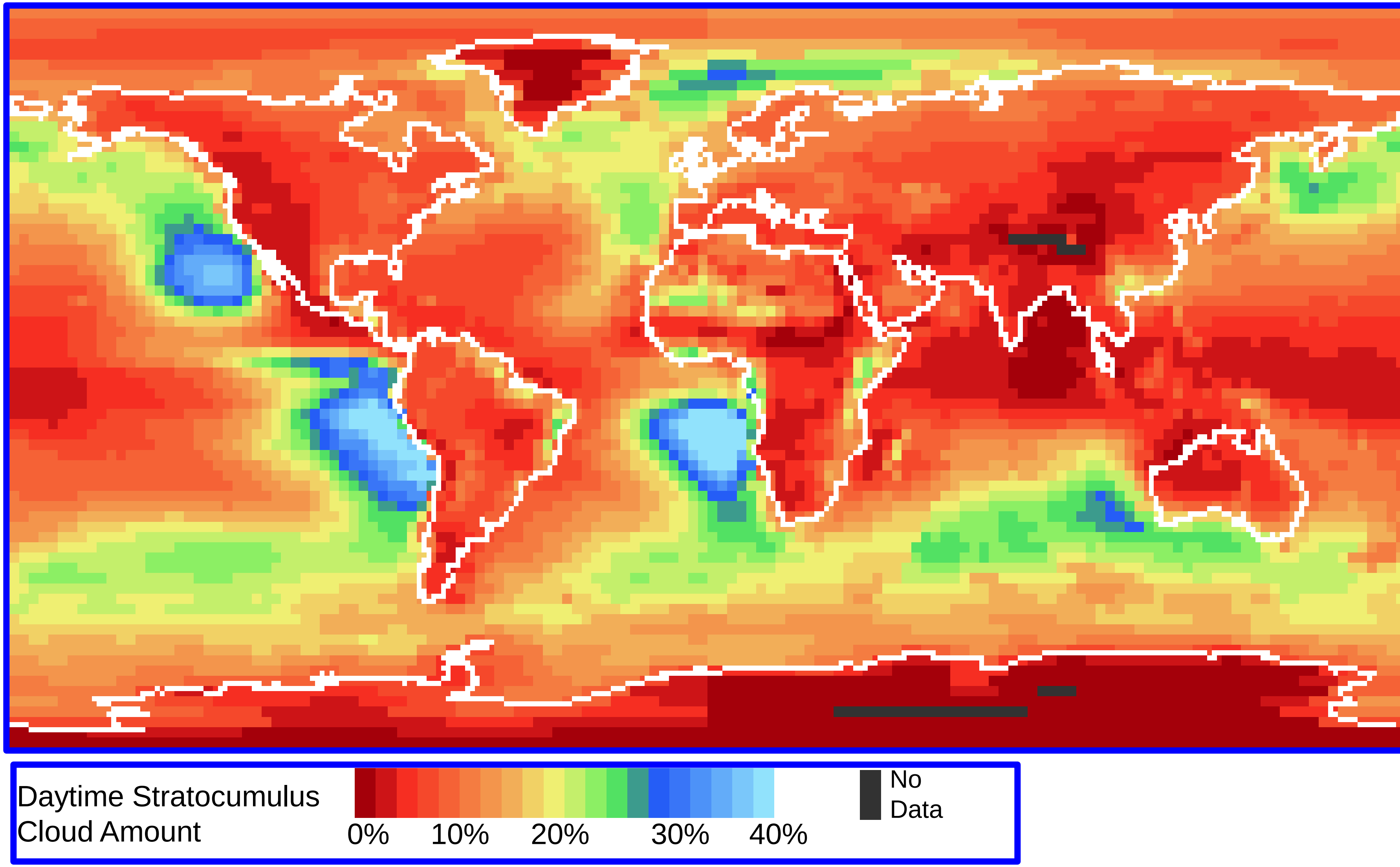
Ramanathan et al: CARB 08-323

Part II: Changes in Cloud Properties due to BC-Cloud Interactions

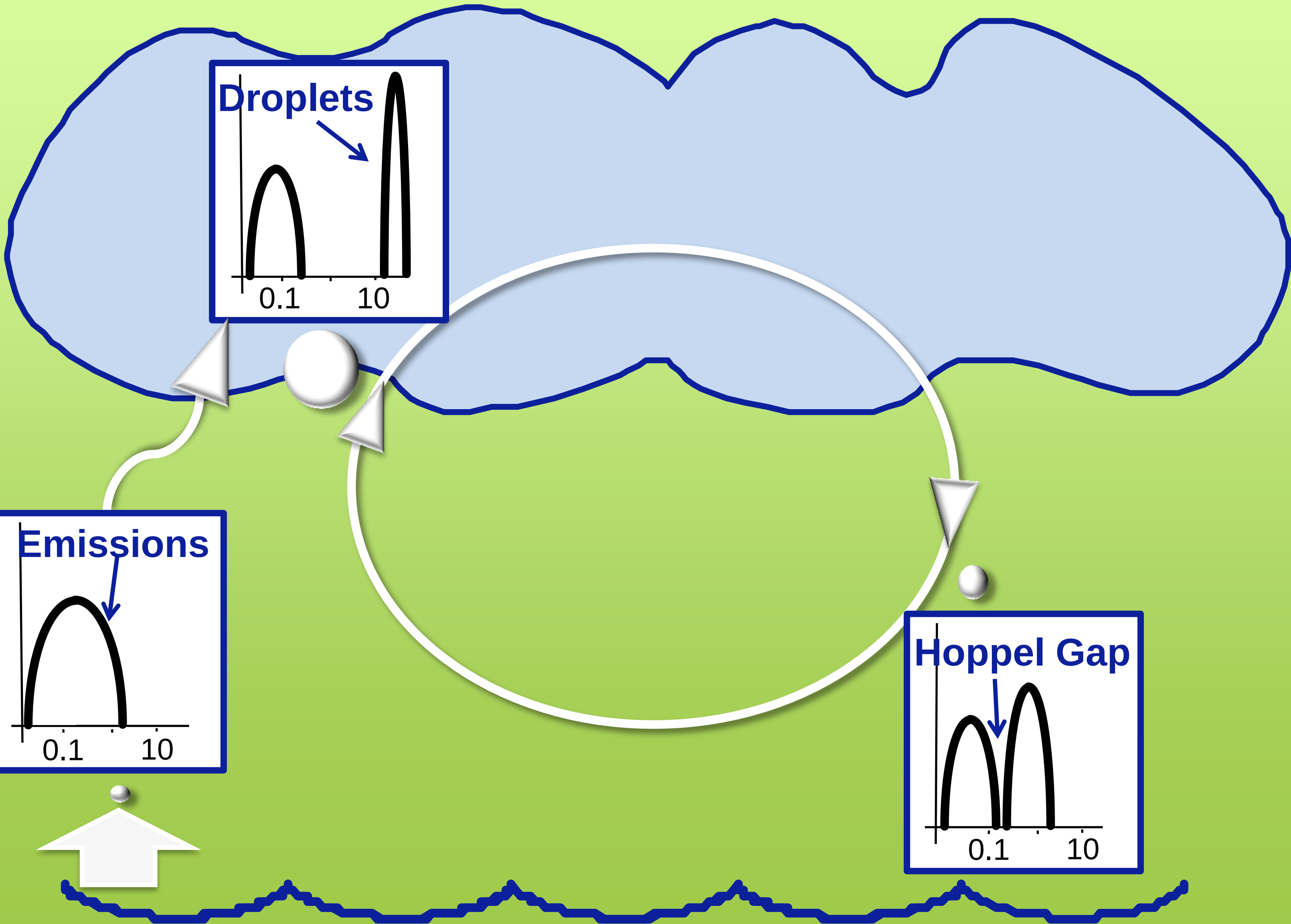
CARB Contract 09-337, PI Lynn Russell

- The importance of aerosol-cloud interactions in climate
- Conflicting GCM results on role of BC in clouds
- **Our results explain this discrepancy**
- **For California: There is a "Cloud Offset" to BC warming, but it is small**
- The largest uncertainty is the size and composition of absorbing particles

Where Do Low Clouds Occur?



How Aerosols Interact with Clouds



Atmospheric Environment Vol. 8, pp. 1251–1256. Pergamon Press 1974. Printed in Great Britain.

POLLUTION AND THE PLANETARY ALBEDO

S. TWOMEY

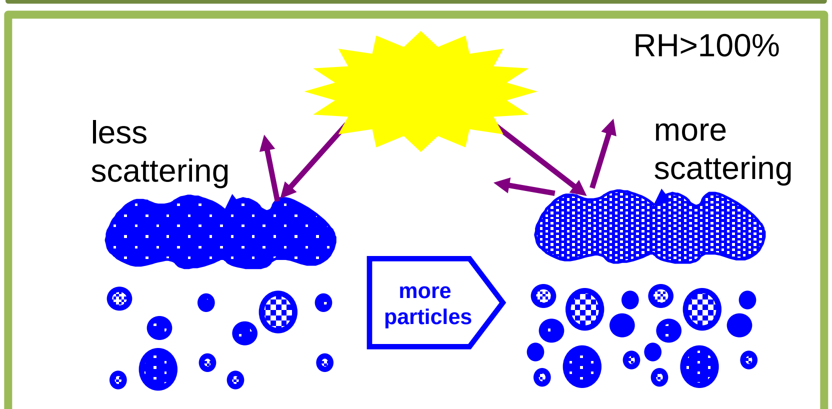
Institute of Atmospheric Physics, The University of Arizona, Tucson, Arizona 85721, U.S.A.

(*First received* 27 *February* 1974 *and in final form* 17 *May* 1974)

Abstract—Addition of cloud nuclei by pollution can lead to an increase in the solar radiation reflected by clouds. The reflection of solar energy by clouds already may have been increased by the addition of man-made cloud nuclei. The albedo of a cloud is proportional to optical thickness for thin clouds, but changes more slowly with increasing thickness. The optical thickness is increased when the number of cloud nuclei is increased. Although the changes are small, the long-term effect on climate can be profound.

Cloud albedo effect:

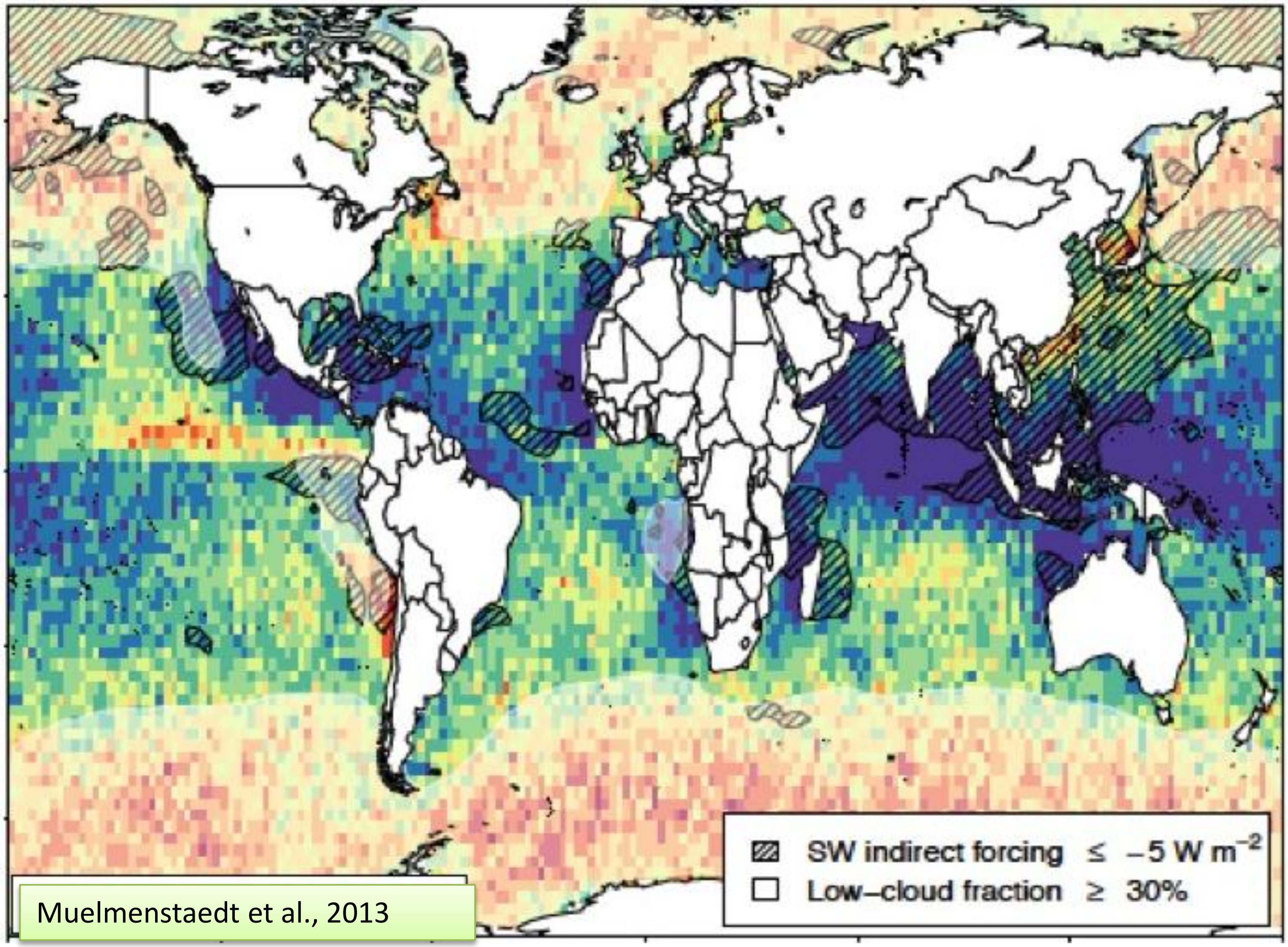
More droplets → increased reflectance



$$\frac{dA}{dN_d} = \frac{A(1-A)}{3N_d}\left(1 + \frac{\cdots}{d\ln N_d} + 5\frac{\cdots}{d\ln N_d}\right)$$

$$\frac{\Delta A}{A(1-A)} = \frac{1}{3}\Delta(\ln N_d)$$

Aerosol-Cloud Albedo Effects Can Cause Large Regional Cooling



Muelmenstaedt et al., 2013

Conflicting GCM Results on Role of BC in Cloud Modification

Jacobsen 2010

- Found that reduced BC increased cloud drops, enhancing BC warming
  - Drops increased by 14%
  - Warming reduced 15-17%

Chen et al. 2010

- Found that reduced BC decreased cloud drops, offsetting BC warming
  - Drops decreased 5.9%
  - Warming increased 0.1 W/m^2

Why do these simulations disagree on the role of BC in climate?

Our Results Explain This Discrepancy

Aerosol Cloud Model shows

- Jacobson “FS” scenario is correct if BC particles are
  - Smaller than 80 nm
  - Not mixed with salts
- Chen “HF” scenario is correct if BC particles are
  - Larger than 80 nm
  - Mixed with salts

For California sources

- Existing measurements indicate that BC-containing particles are often
  - Larger than 80 nm
  - Because they are mixed with salts and other organics
- But more measurements are needed to reduce these uncertainties

Bahadur et al., 2012, J. Geophys. Res.

For California: There is a "Cloud Offset" to BC warming, but it is likely small

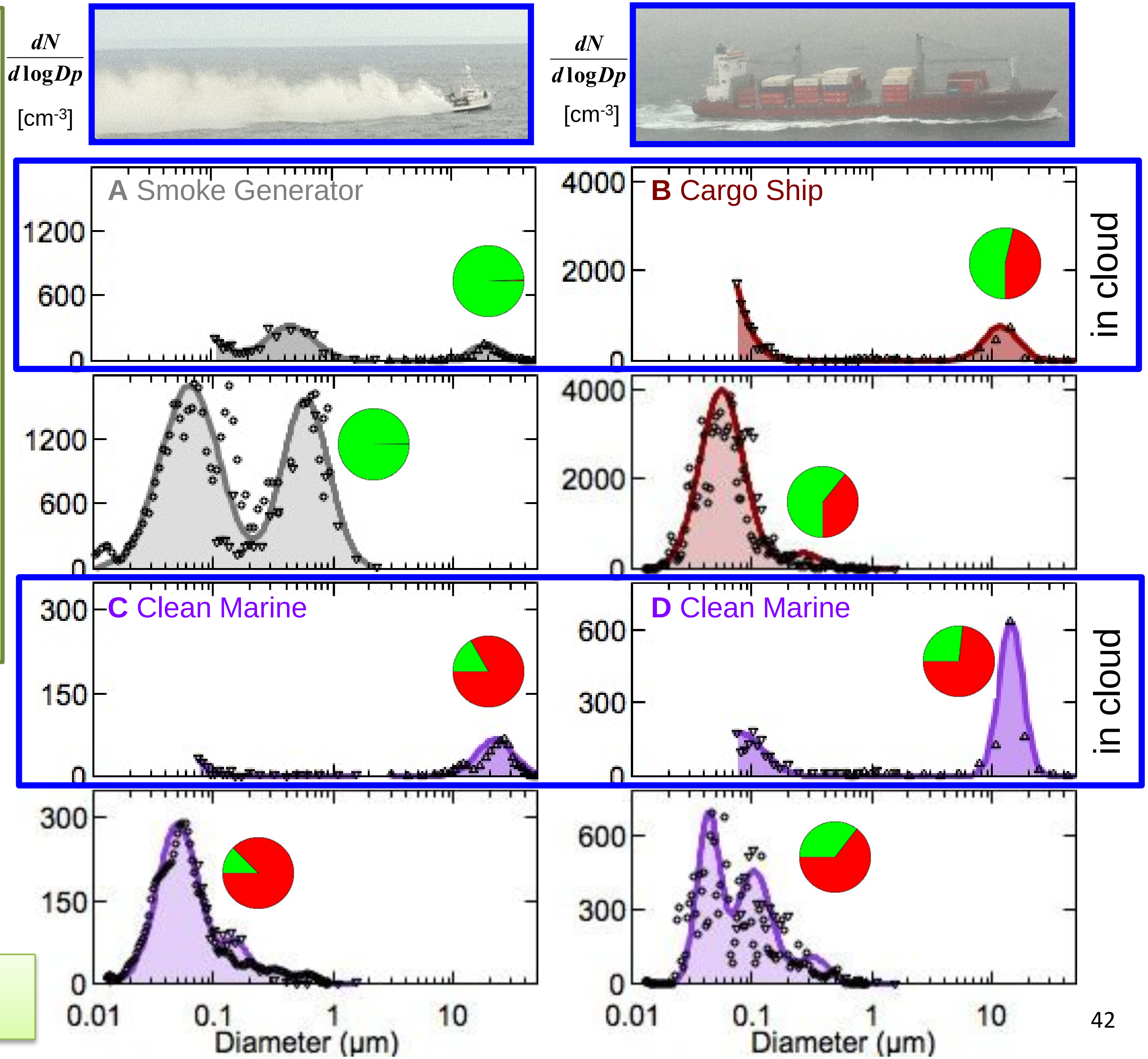
- Reduction of BC has still resulted in net cooling, as observations have shown
- Further reductions in both BC and Brown Carbon will also provide net cooling

Bahadur et al., 2011, Atmos. Environ.

The Largest Uncertainty is the Size and Composition of Absorbing Particles

- In order to reduce this uncertainty, measurements are needed to characterize
  - The size distribution of BC-containing particles
  - The role of Brown Carbon in absorbing particles
- Key sources in California are
  - Diesel and off-road vehicles
  - Residential and agricultural burning

How can we measure the role of BC in clouds?

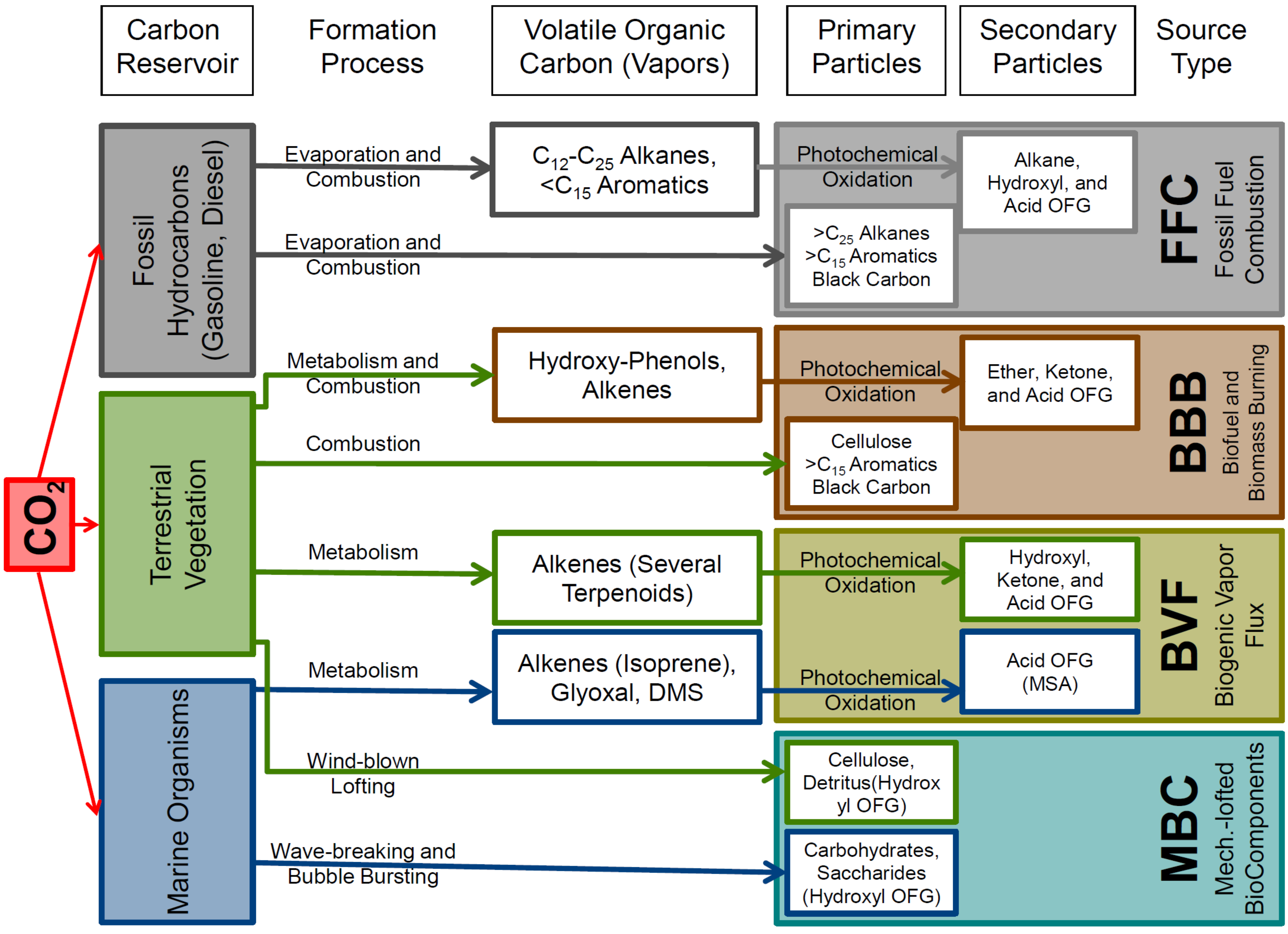


Sulfate
Organic

Russell et al., 2013, Bull. Am. Met. Soc.

How Can We Identify the Role of Brown Carbon in Clouds?

- **Brown Carbon** is identified with three California sources
  - **Residential Burning** (*e.g.* Foothills)
  - **Agricultural Burning** (*e.g.* Central Valley)
  - **Secondary Photochemical or Fog formation** (*e.g.* SoCAB)
- How do we quantify the organic mass from these sources?



Carbon Reservoir
Formation Process
Volatile Organic Carbon (Vapors)
Primary Particles
Secondary Particles
Source Type
Fossil Hydrocarbons (Gasoline, Diesel)
Evaporation and Combustion
C_{12}-C_{25} Alkanes, <C_{15} Aromatics
Photochemical Oxidation
Alkane, Hydroxyl, and Acid OFG
Evaporation and Combustion
>C_{25} Alkanes >C_{15} Aromatics Black Carbon
FFC
Fossil Fuel Combustion
CO_2
Terrestrial Vegetation
Metabolism and Combustion
Hydroxy-Phenols, Alkenes
Photochemical Oxidation
Ether, Ketone, and Acid OFG
Combustion
Cellulose >C_{15} Aromatics Black Carbon
BBB
Biofuel and Biomass Burning
Metabolism
Alkenes (Several Terpenoids)
Photochemical Oxidation
Hydroxyl, Ketone, and Acid OFG
Marine Organisms
Metabolism
Alkenes (Isoprene), Glyoxal, DMS
Photochemical Oxidation
Acid OFG (MSA)
BVF
Biogenic Vapor Flux
Wind-blown Lofting
Cellulose, Detritus(Hydroxyl OFG)
Wave-breaking and Bubble Bursting
Carbohydrates, Saccharides (Hydroxyl OFG)
MBC
Mech.-lofted BioComponents

Part III: Implications for Global Climate Change Mitigation and Future Work

Ramanathan et al, 2013: CARB 08-323

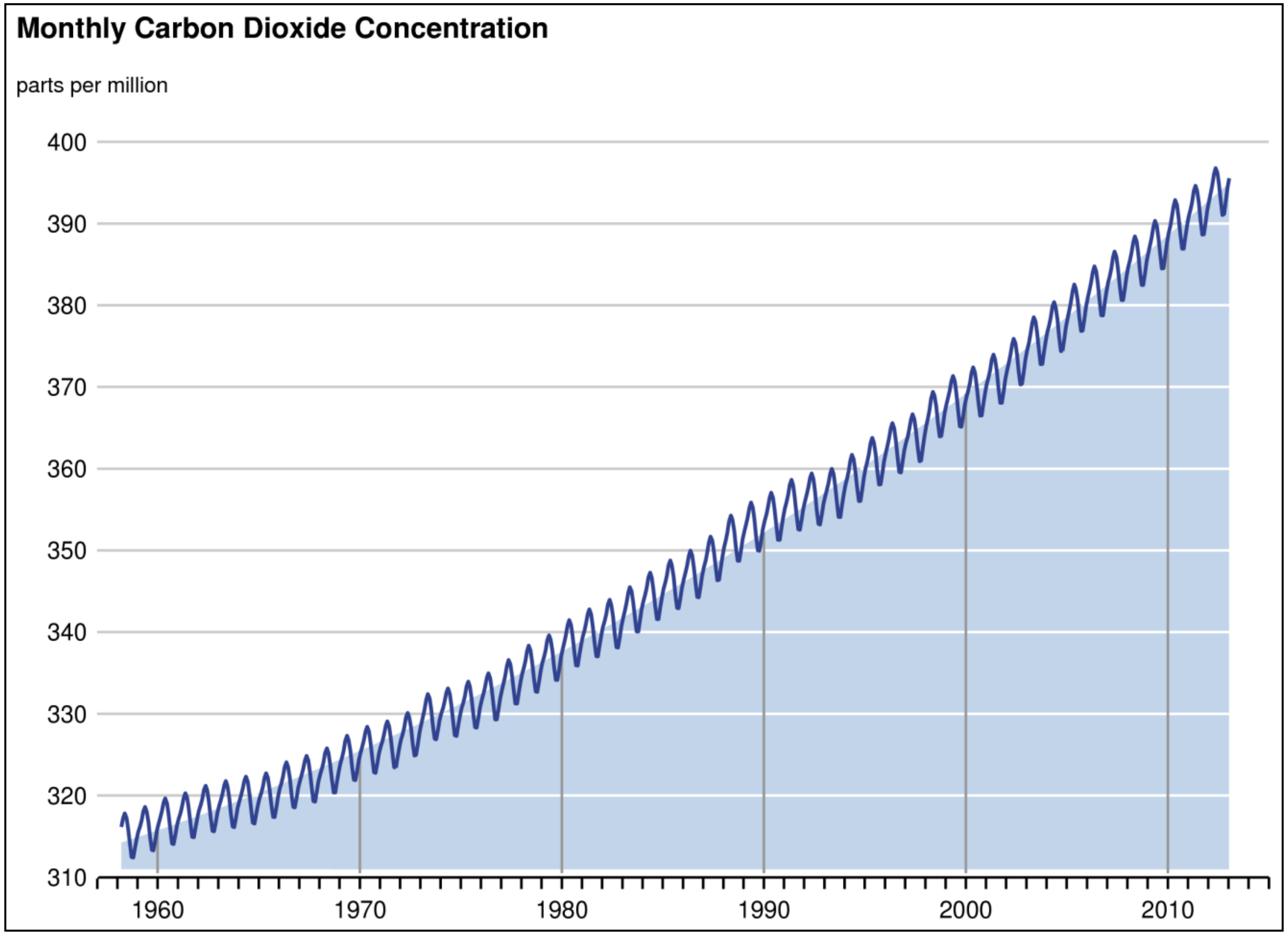
Summary from Part 1:

- **For the annual mean, the current top-of-atmosphere (TOA) direct forcing of BC+OC varies from about 0.2 Wm^{-2} over Northern California (NCA) to as large as 1.9 Wm^{-2} over Southern California (SCA)**
- **In the 1980s when BC concentrations were higher by about 100%, the TOA forcing for BC+OC could have been as large as 0.4 to 3.8 Wm^{-2}**
- **The direct warming effect of brown carbon, ignored in most models, offsets about 60% to 90% of the direct cooling effects of other organic carbon aerosols**

Carbon Dioxide is the #1 Climate Warmer and is increasing still unabatedly

The KEELING CURVE,

Scripps Institution of Oceanography, University of California, San Diego



The forcing has three components

BOND ET AL.: BLACK CARBON IN THE CLIMATE SYSTEM

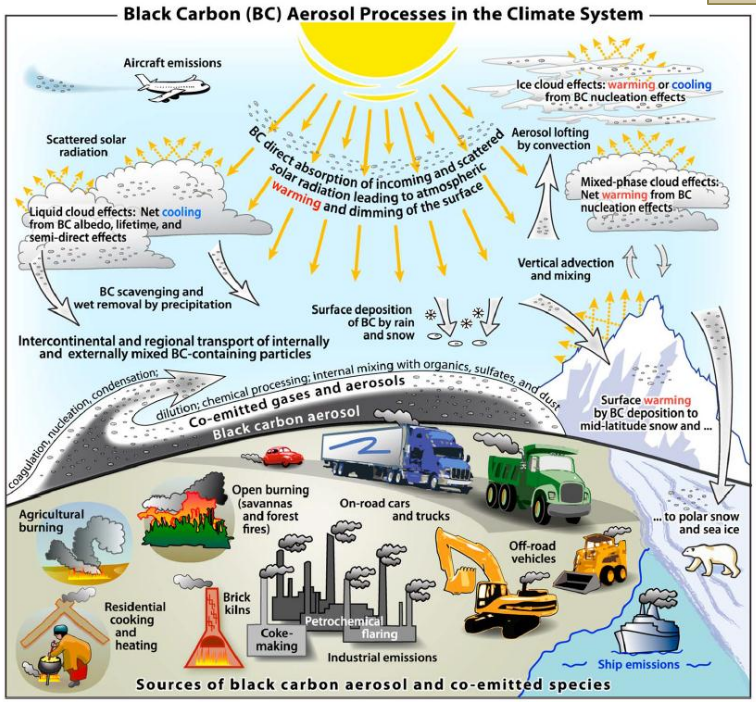


Figure 1. Schematic overview of the primary black-carbon emission sources and the processes that control the distribution of black carbon in the atmosphere and determine its role in the climate system.

1. **Direct Forcing**
2. **Forcing from Aerosol-Cloud Interactions (low, middle and high clouds)**
3. **BC deposition on snow and ice surfaces**

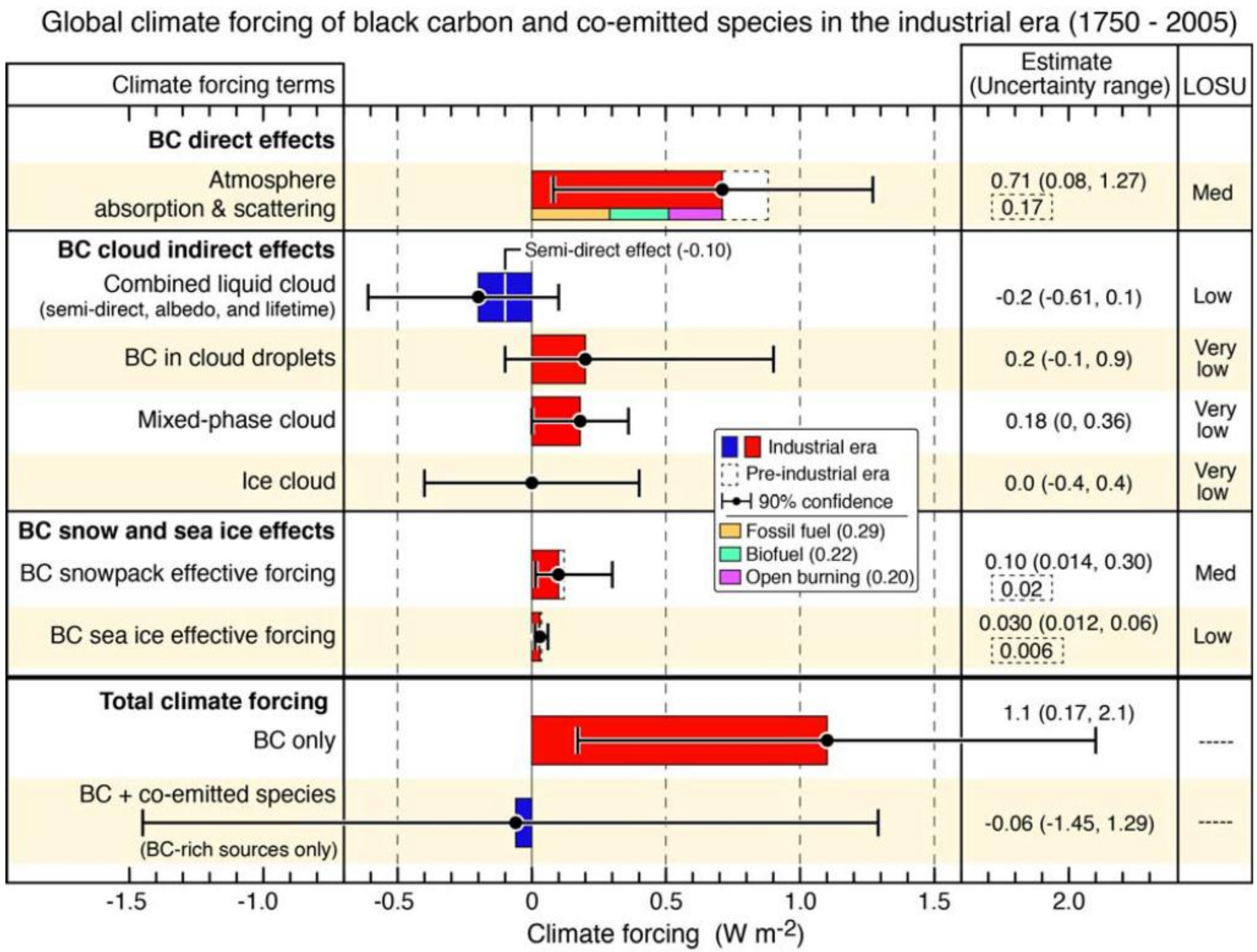
We adopt 3 studies that account for all three components and the co-emitted species including organic carbon:

Jacobson, 2010; WMO-UNEP, 2011; Bond et al, 2013

All three studies conclude the direct effect is the largest component; and the sum of the three is positive for diesel source of black carbon

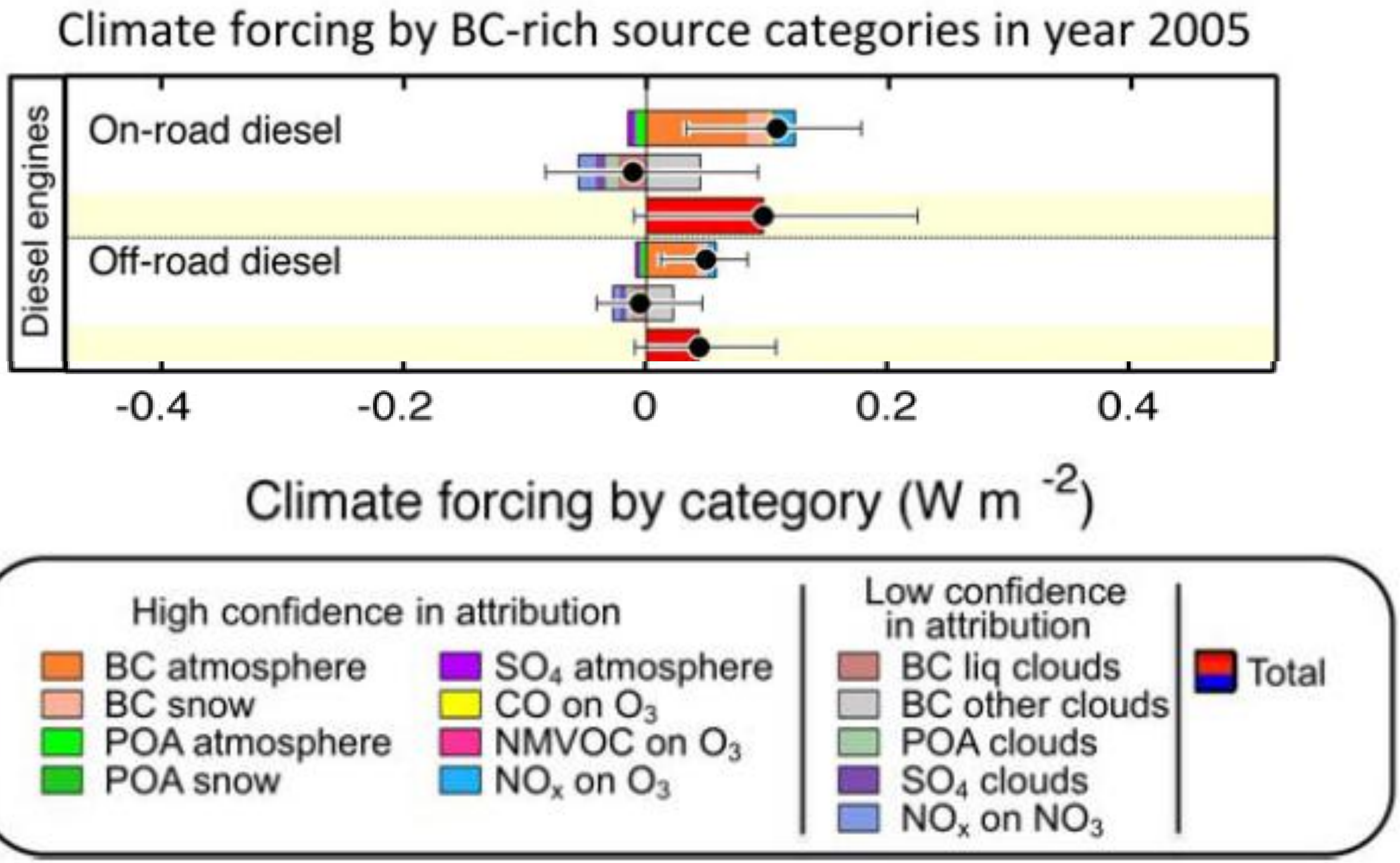
Summary of BC Forcing:
Direct forcing is the largest contributor; BC-Cloud effects has positive forcing

Source: Bond et al, 2013



Diesel Emissions of BC and co-emitted species have net positive forcing; BC-Cloud effects have negligible effects

Source: Bond et al, 2013



Integrated Assessment of Black Carbon and Tropospheric Ozone

Chair: Drew Shindell (National Aeronautics and Space Administration Goddard Institute for Space Studies, USA).

Vice-chairs: Veerabhadran Ramanathan (Scripps Institution of Oceanography, USA), Frank Raes, (Joint Research Centre, European Commission, Italy), Luis Cifuentes (The Catholic University of Chile, Chile) and N. T. Kim Oanh (Asian Institute of Technology, Thailand).

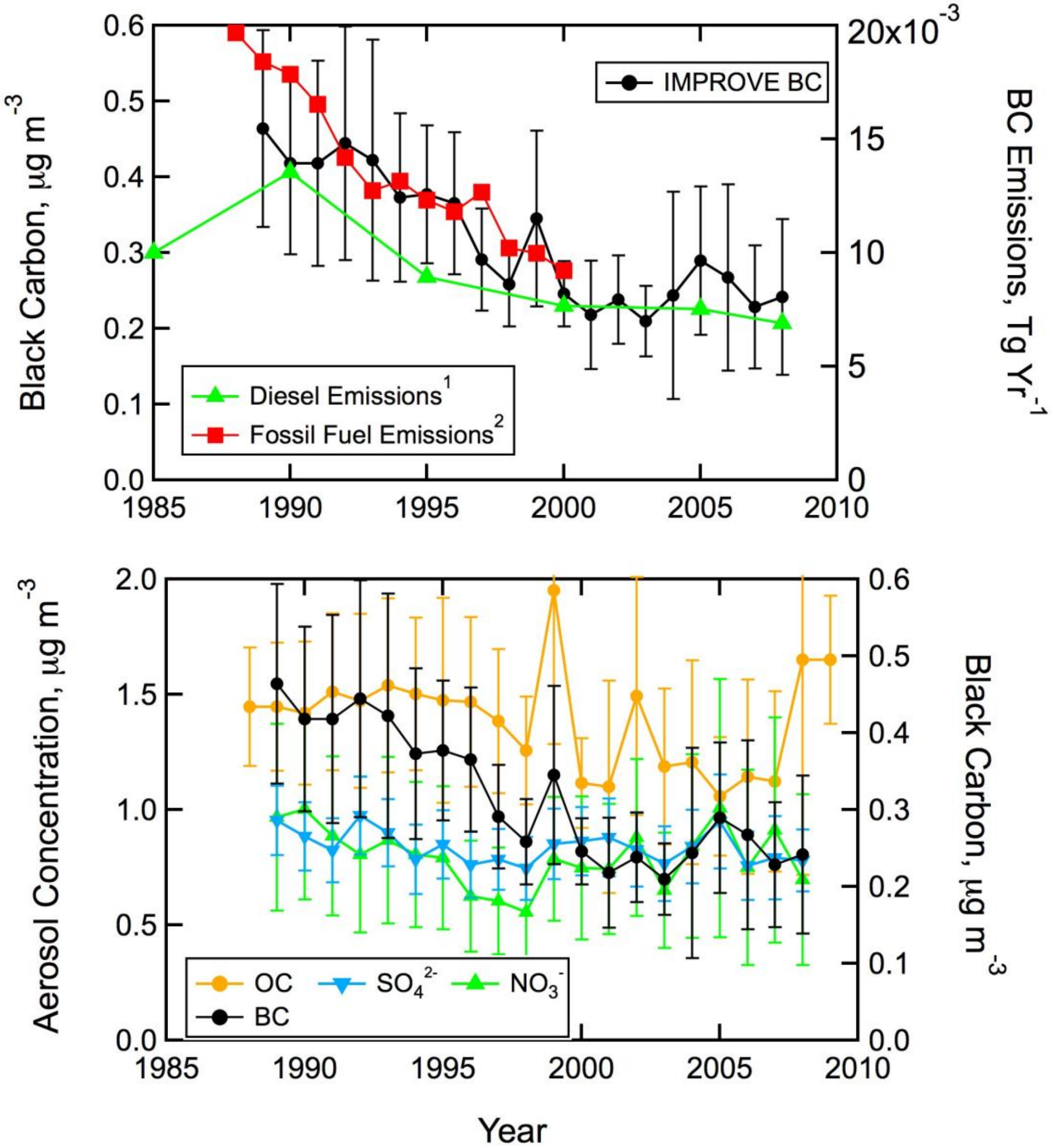
Diesel transport has the lowest OC/EC ratio

Table 2.1 Anthropogenic and natural emissions for the year 2005 used in this assessment (Mt/yr)

	BC	OC	$PM_{2.5}$	SO_2	NO_x[a]	CH_4	NMVOC
Anthropogenic							
Large-scale combustion	0.10	0.15	8.1	71.6	34.1	0.36	1.2
Industrial processes	0.43	0.66	4.5	12.7	2.4	0	8.0
Residential-commercial combustion	2.7	9.6	17.8	5.8	5.0	8.8	37.9
Transport	1.6	1.4	3.4	15.9	71.5	2.3	38.5
Fossil-fuel extraction and distribution	0.28	0.06	0.51	2.4	1.4	101	36.4
Solvents	N/A	N/A	N/A	N/A	N/A	N/A	23.4
Waste/landfill	0.1	0.75	1.3	0.06	0.12	49.8	1.1
Agriculture[c]	0.31	1.2	3.4	0.16	0.26	126	4.0
Total anthropogenic	5.5	13.8	39.0	109	115	288	150
Natural[d]	3-3.7	33-38	6000[e]	28-31	54-60	210	470-549[f]
Global total	8.5-9.2	47-52	6039	137-140	169-175	498	620-699

California BC and OC Concentration Data Confirm The Emissions Ratio Data

Source: Bahadur et al, 2010



BC Trends are not accompanied by comparable trends in OC or Other Species

Ramanathan et al, 2013: CARB 08-323

Global Climate Change Mitigation Estimates

Basis: Jacobson, 2010 study for Global Warming Potentials

- **Choosing a conservative 100-year time horizon**
- **Making another conservative estimate of adopting emission reductions in just mobile-diesel sources, and earlier emission factors (which were low by about 70%)**

1. **We estimate that the reduction in diesel BC emissions from 1989 to 2008, is equivalent to reducing CO_2 emissions by 21 million metric tons annually**

   Using all transportation sources and updated emission factors

2. **The reduction in diesel BC emissions from 1989 to 2008, is equivalent to reducing CO_2 emissions by 50 million metric tons annually**

Ramanathan et al, 2013: CARB 08-323

A Perspective on the Efficacy of California's Diesel BC Reductions

California's CO_2 emissions as of 2009 was 393 MMT/Yr

Reductions in BC concentrations witnessed in California between 1989 and 2008 is equivalent to mitigating 5% to 13% of California's CO_2 emissions. This Climate benefit may date back to the 1960s and is currently ongoing

However, simultaneous mitigation of CO_2 emissions from fossil fuels is essential to limit global warming below 2^oC during this century.

Ramanathan et al: CARB 08-323

Overall Findings of the Ramanathan et al, 2013 CARB 08-323 Report

- Statewide BC has been reduced by as much as 50% since the 1980s, mostly due to emission reductions from diesel engines
- This negative trend extends further back, with the decrease being 72% over the 1960-2000 time period and is continuing to the present
- Brown Carbon adds significant amount to BC heating The direct warming effect of brown carbon, ignored in most models, offsets about 60% to 90% of the direct cooling effects of other organic carbon aerosols

Overall Findings of the Ramanathan et al, 2013 CARB 08-323 Report (Cont.)

- The large negative trend in BC direct radiative forcing and the lack of corresponding negative trends in OC, confirm that diesel related BC emission reduction would lead to global cooling
- Bottom-up emission models, including regional models, underestimate the heating of the atmosphere by BC and Brown Carbon by a factor of about 3
- BC emission and concentration reductions observed in California since the 1980s, as a result of air quality programs, are equivalent to reducing CO_2 emissions by 21 to 50 million metric tons annually

Recommended Future Work

- Reduce uncertainty in aerosol-cloud offsets:
  - Quantify **size of source and ambient BC** particles
  - Measure directly **contribution of BC to clouds**
- Quantify major **Brown Carbon** sources in key regions of California:
  - **Residential Burning** (e.g. Foothills)
  - **Agricultural Burring** (e.g. Central Valley)
  - **Secondary Photochemical or fog Formation** (e.g. SoCAB)

- **In view of the combined warming effects of brown carbon and black carbon, evaluate the role of increasing frequency of forest fires on regional and global climate**

My Personal Commentary

(and not to be attributed to the Ramanathan et al, CARB 08-323 report)

California's successful policies for reducing BC and its support of Science to evaluate regional climate impacts should serve as a Knowledge to Action example for the World

If California's efforts in reducing black carbon from diesel can be replicated globally, we can slow down the projected global warming for the coming decades by about 15 percent*, in addition to protecting people's lives

**based on estimates using the Ramanathan and Xu, PNAS, 2010 study*

THANK YOU

CARB FOR FUNDING THE STUDY

Dr. Nehzat Motallebi of CARB for assistance and advice with CARB data

Thanks to R. Bahadur for coordinating this study

Thanks to co-authors R. Bahadur, K. Prather & A. Cazorla,
T. Kirchstetter, O. Hadley, R. Leung & C. Zhao