Black Carbon and the Regional Climate of California

A Multi-Institutional CARB Funded Project

CARB Board Meeting

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Univ of California at San Diego: V. Ramanathan, R. Bahadur, Y. Xu &P. S. Praveen (SIO); K. Prather and A. Cazorla (Chemistry)

Univ of California at Berkeley: T. Kirchstetter & O. Hadley (Lawrence Berkley Labs); R. Cohen (UC Berkeley).

Pacific Northwest National Laboratory: R. Leung and Dr. Zhao Chun (PNNL)

CARB Contract Manager: N. Motallebi

Major Topics

- Black Carbon Trends in California: Detection and Attribution

- Brown Carbon (BrC) Identification:

  Organic Aerosols that absorb solar radiation are called BrC.
  IPCC-models treat Organics as scattering, i.e, cooling aerosols

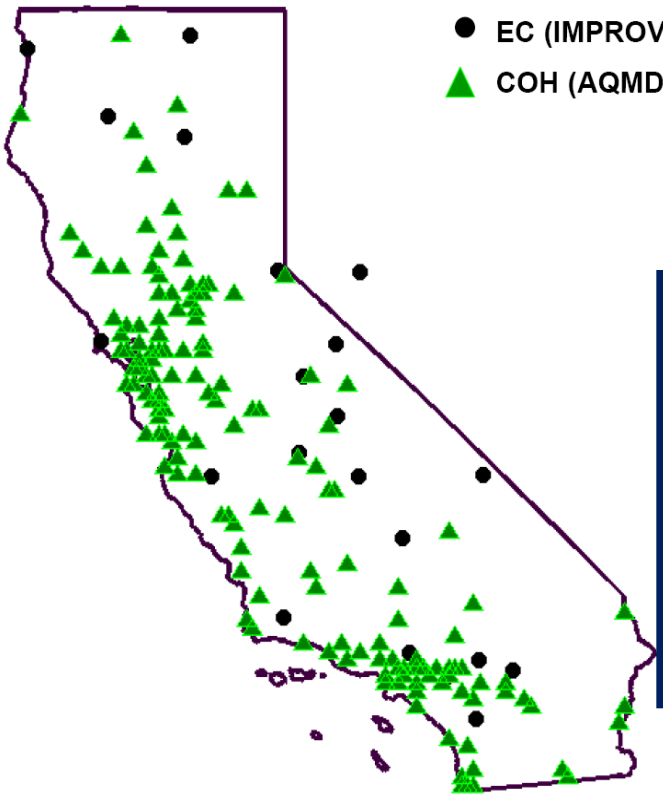
- Source Identification

- Radiative Forcing by Black and Organic Carbon Aerosols

- Mitigation of BC Radiative Forcing by California *(The forcing numbers are preliminary; will be finalized in few months)*

- Simulations by a Regional Model

Black Carbon Trends in California: Detection and Attribution



EC (IMPROVE) → ***'Remote sites'***

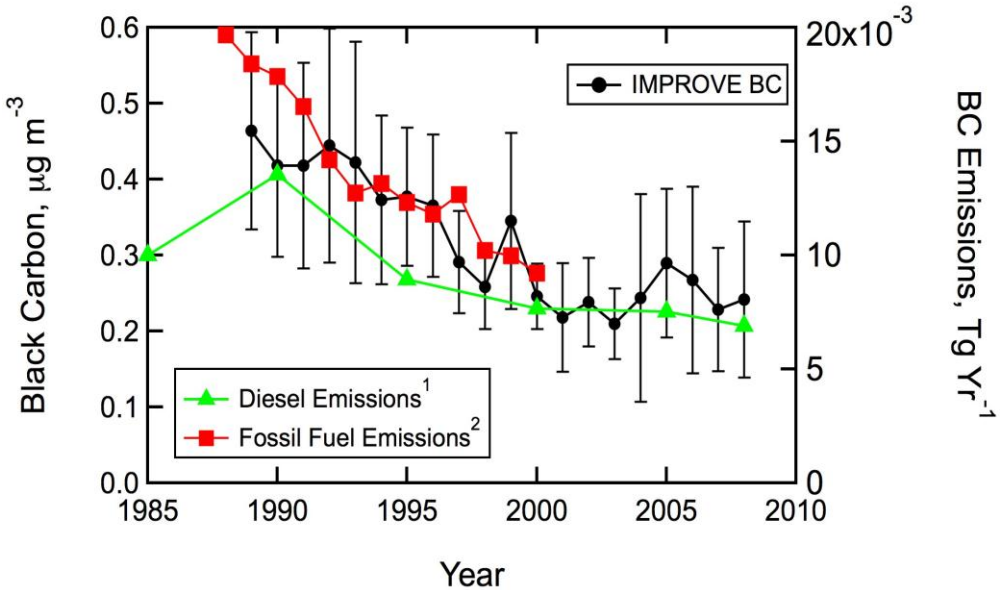
COH (AQMD) → ***Mostly Urban sites***

Both Urban and Rural sites show consistent declining trends

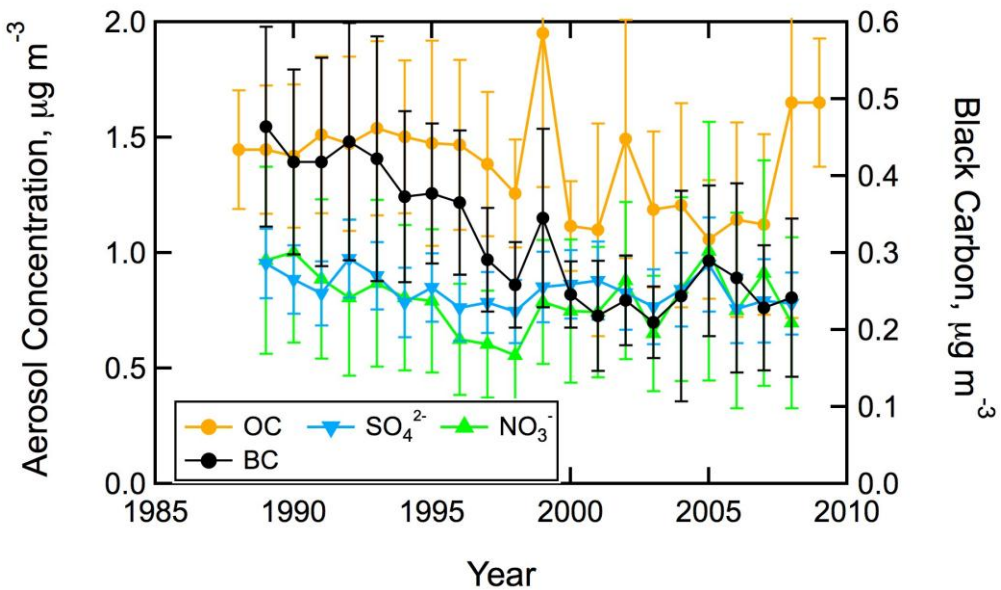
The decline is state-wide

The primary source for the decline is reduction in BC from diesel emissions

BC Trends in California: All IMPROVE Sites



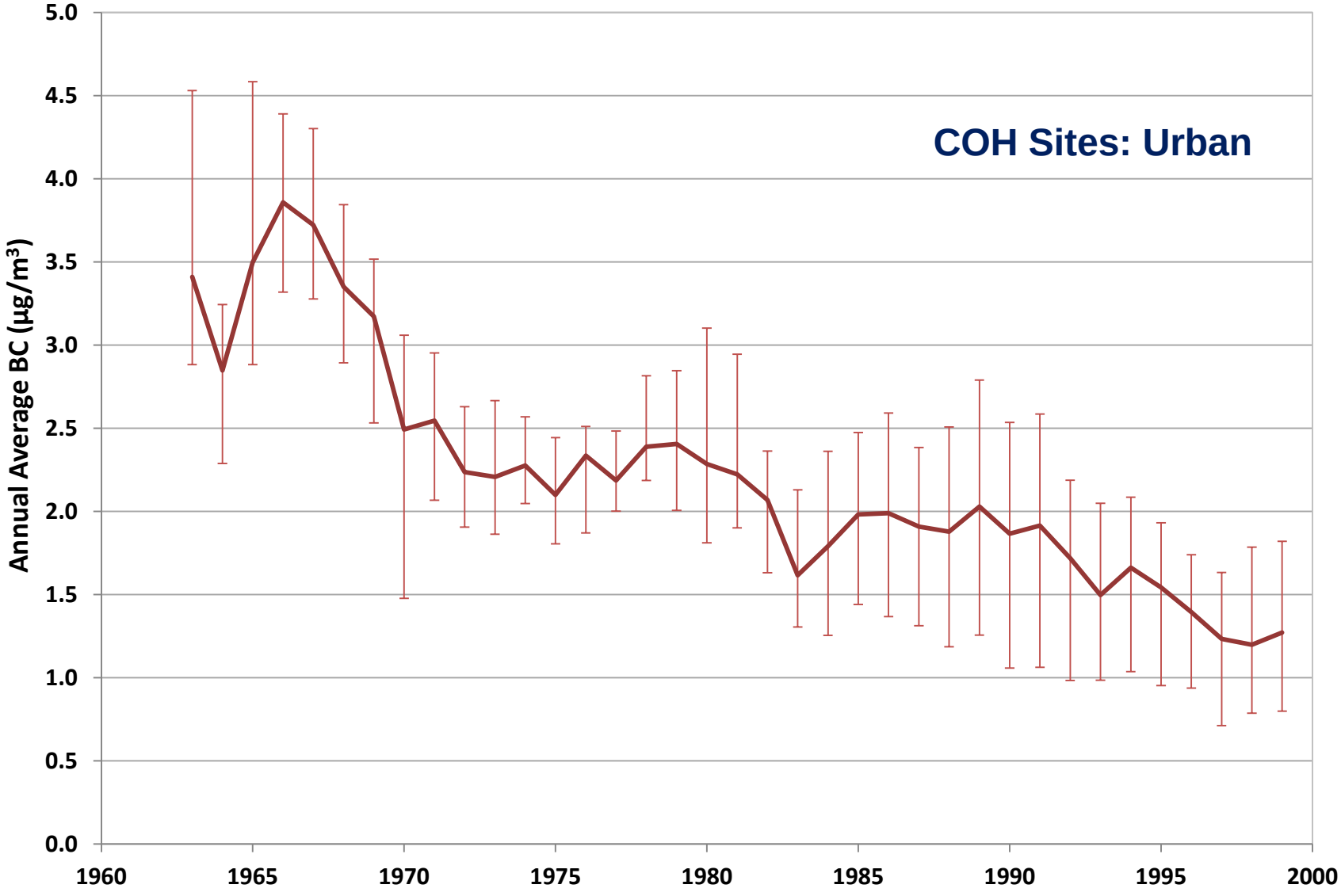
BC Trends are consistent with diesel BC emission trends.



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

Bahadur et al, 2010

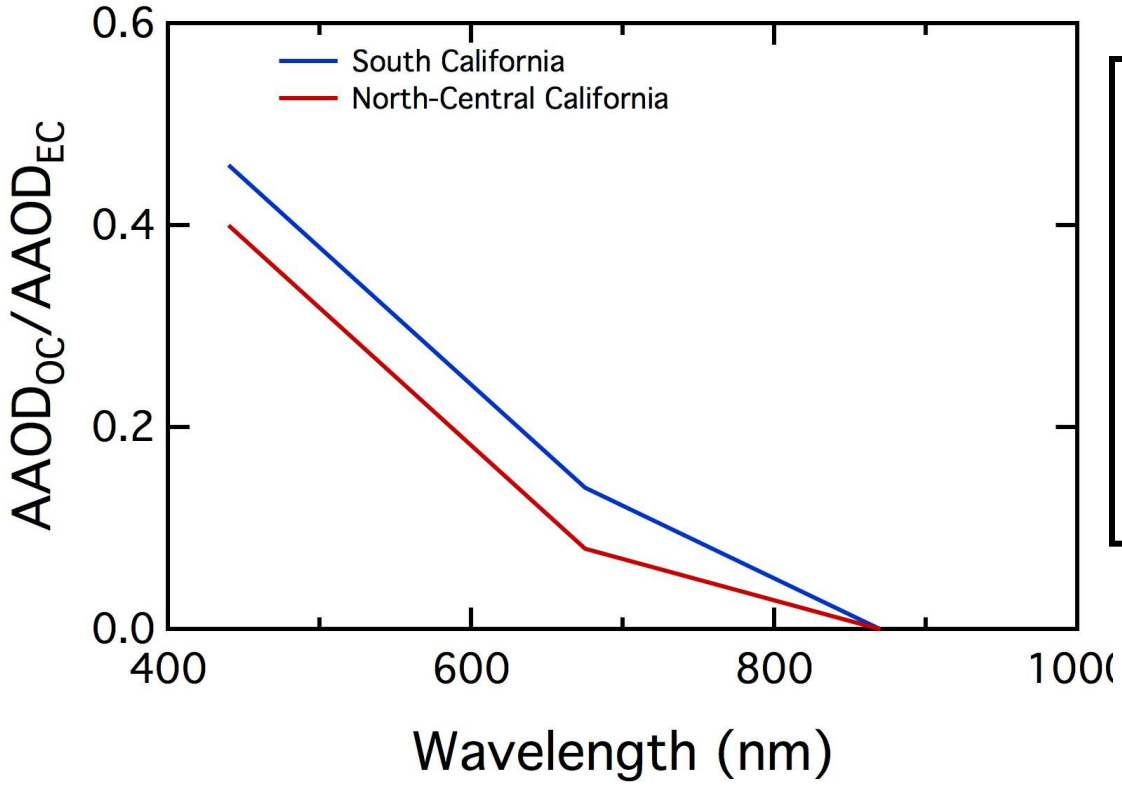
Declining Black Carbon Concentrations in Urban California



Ref: Kirchstetter et al, 2012

Brown Carbon:
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

Ref: Bahadur et al. *PNAS* **(in review, 2012)**

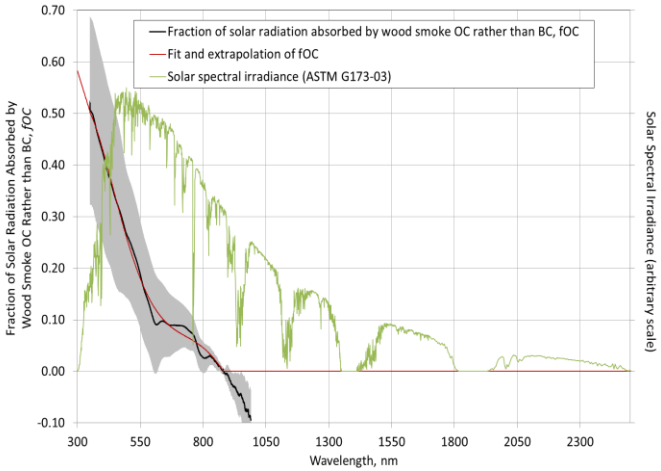
Fraction of solar radiation absorbed by OC in residential wood smoke PM (black line = 115 sample avg) and solar spectrum at the earth's surface (green line).

Brown Carbon: Significant solar absorption by Organics

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

- **Independent in-situ data of 115 wood smoke samples confirms the Brown Carbon (BrC) absorption inferred from the NASA-Ground based network.**

- **The in-situ data also confirms that BrC absorption is taking place at wavelengths where sunlight is near its peak intensity**

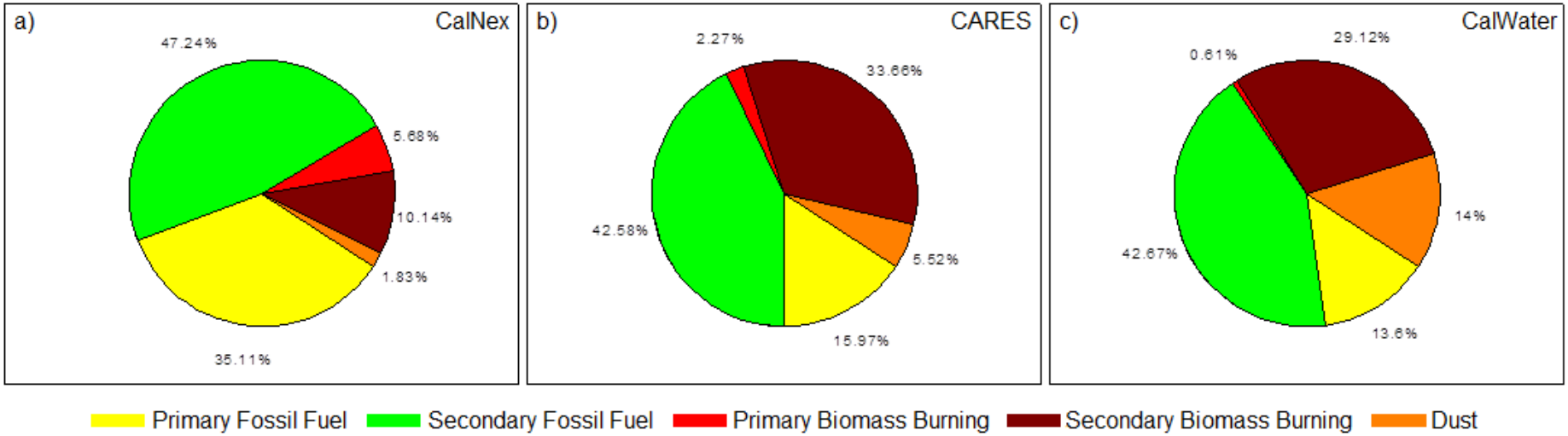


Fraction of solar radiation absorbed by OC in residential wood smoke PM (black line = 115 sample avg) and solar spectrum at the earth's surface (green line).

Kirchstetter & Thatcher, ACPD, 2012

Source Identification: ATOMFS

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



S. California dominated by fossil fuels ← — → **N. CA: Biomass plays larger role**

Ref: Cazorla and Prather

Observationally Constrained Forcing

Data sets:

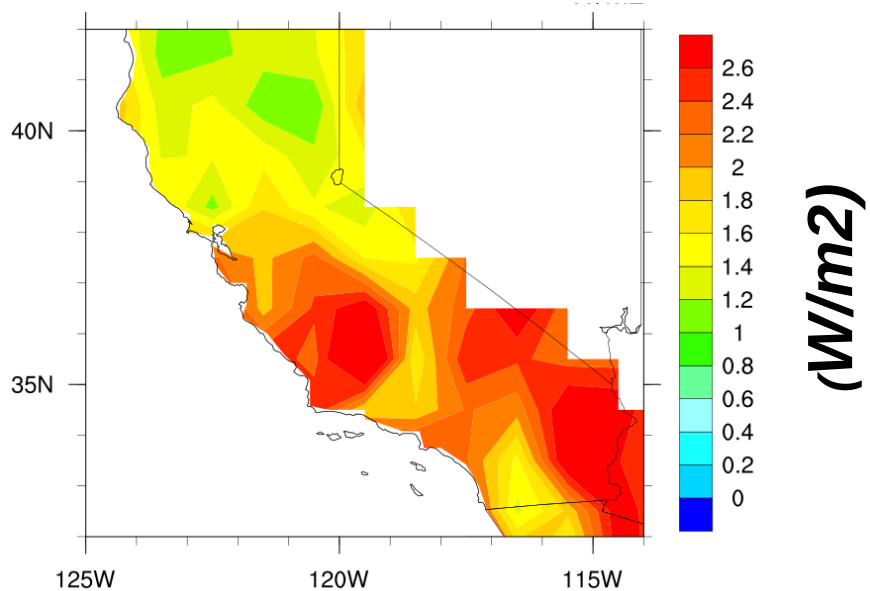
- **Satellite Aerosol Optical Data (MISR)**
- **Gives the total Scattering+ Absorbing effect of aerosols in the column**
- **NASA-Ground Network: AERONET:**
- **Gives the absorbing component(BC; BrC; Dust) in the column**

DEFINITION OF FORCING

- **BC absorbs solar radiation. This adds solar energy to the atmosphere-surface System**
- **This added energy is referred to as Forcing**
- **The unit is: Watts per Square Meter of surface area; the symbol is: WM^{-2}**
- **We next show the energy added to the atmosphere**
- **Then we show the vertically integrated energy added to the surface-atmosphere System**

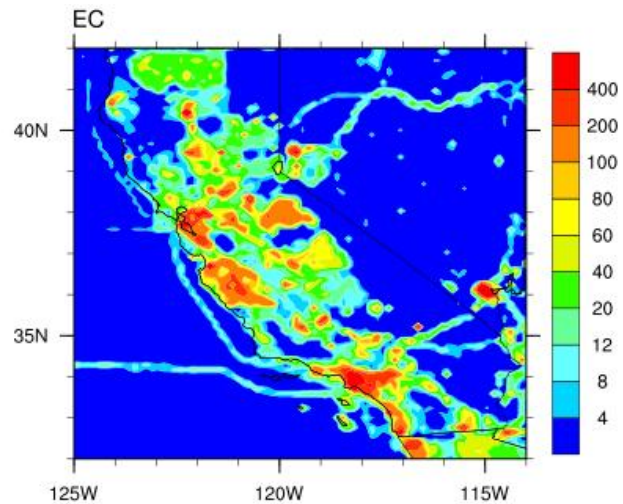
Carbonaceous Aerosol (BC+OC) Atmospheric Forcing Annual Mean 2001 to 2010

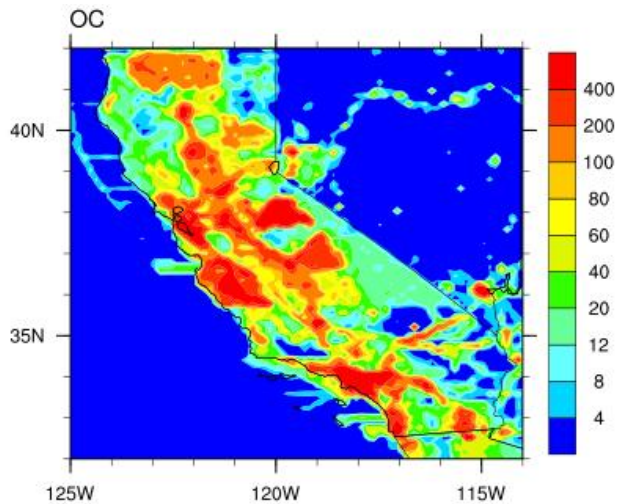
Atm. Forcing



Heating of the atmosphere By BC and BrC

Much larger in S. California; in part due to Diesel BC; less clouds

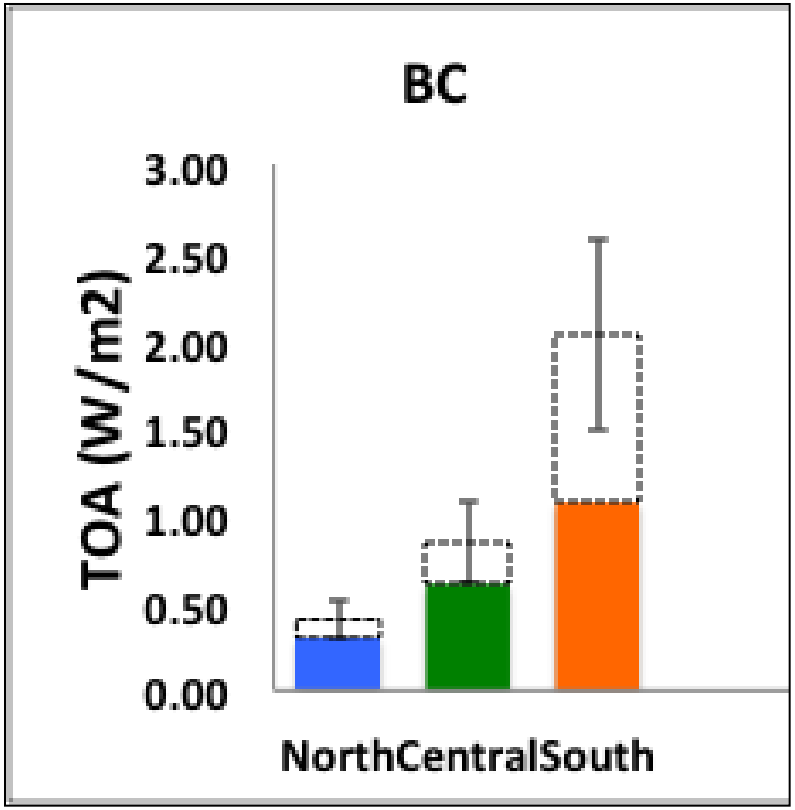




Emission(kg/km2/yr) ARCTA (baseline yr: 2006)

Black Carbon Forcing for California

Annual Mean 2001 to 2010



The dashed bar shows the range due to uncertainty in the ground network data; the error bar is the uncertainty due to satellite data

- **The warming effect can range from 0.4 Wm^{-2} over N California to as high as 2.5 Wm-2 over S. California.**

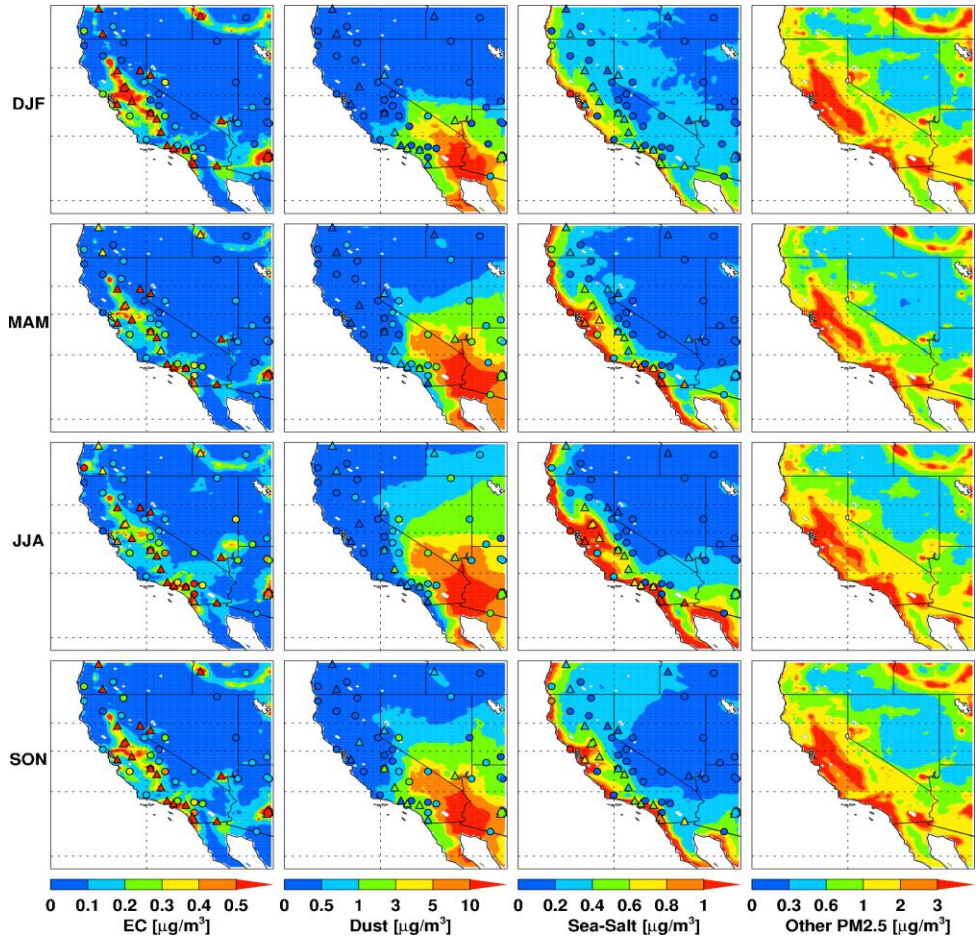
- **The Statewide average forcing can range from 0.5 Wm^{-2} to 1.4 Wm^{-2}**

- **A similar estimate for the 1980s will be double these forcing values**

- **The forcing numbers are preliminary; will be finalized in two months**

Regional Climate Change of BC trends: We need regional down-scaled models.

But model simulations of BC forcing have to agree with observed forcing



Ref: Leung et al, 2012

Major Findings

This study is the first of its kind to evaluate an observationally based regional scale BC forcing and its impact on regional climate

- **Statewide, BC has been reduced by as much as 50% since the 1980s**
- **Brown Carbon adds significant amount to BC heating**
- **The reduction in the State-averaged Direct forcing due to BC reduction can range from 0.5 to 1.4 Wm^{-2}; should also have reduced forcing outside CA.** The forcing numbers are preliminary; will be finalized in two months
- **The regional Climate Effects will be evaluated soon, including the semi-direct forcing**
- **California's successful policies for reducing BC and its support of Science to evaluate regional climate impacts should serve as a model for the climate and clean-air coalition: Knowledge to Action example for the World**