Climate Science and Major Sources

Tami C. Bond

University of Illinois at Urbana-Champaign

November 14, 2012

U.S. EPA Region 9 – Black Carbon Symposium

Q: What is black carbon?

A: A rather curious,
hot little particle…

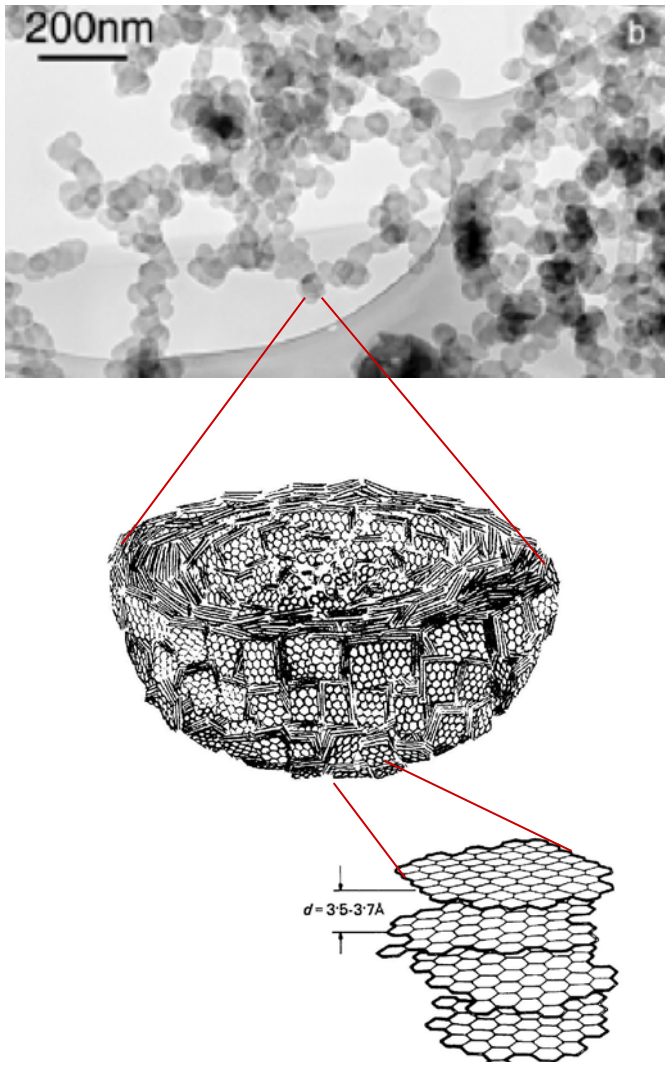
this candle is making
black carbon
right here

and this one is making
“organic” carbon…
no flame, no game!

Atmospheric black carbon is *very* distinctive

1. Aggregate of small spheres
2. Insoluble in water and organic solvents
3. Strongly absorbs visible light; little wavelength dependence(mass absorption cross-section > 5 m2/g at 550 nm)
4. Refractory *
   (Vaporization temperature near 4000 K)

Despite this unique combination,
BC has been rather hard to measure.



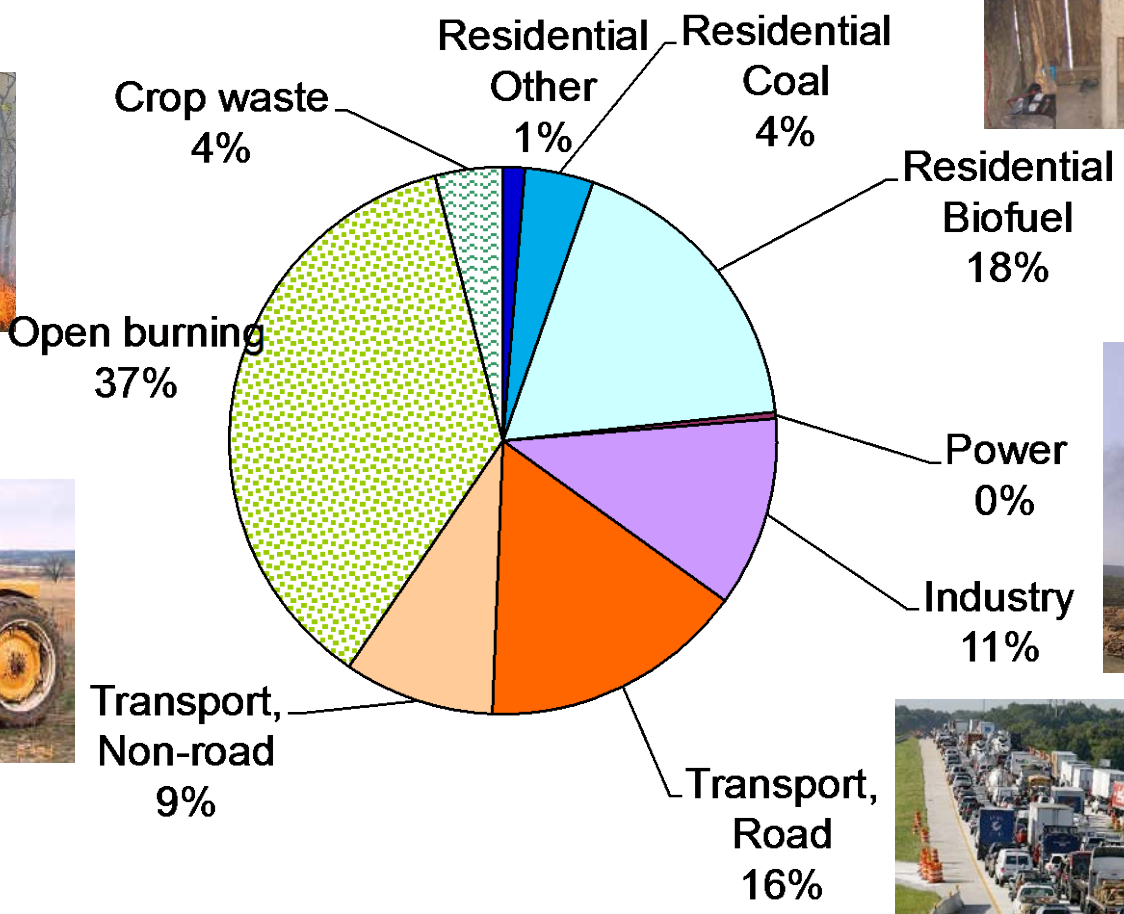
Figures: Li *et al.*, JGR, 2003
Heidenreich *et* al., *J. Appl. Crystallography* **1,** 1-19, 1968

Q: Where does black carbon come from?

A: A few major sources
that have
poorly mixed
combustion gases

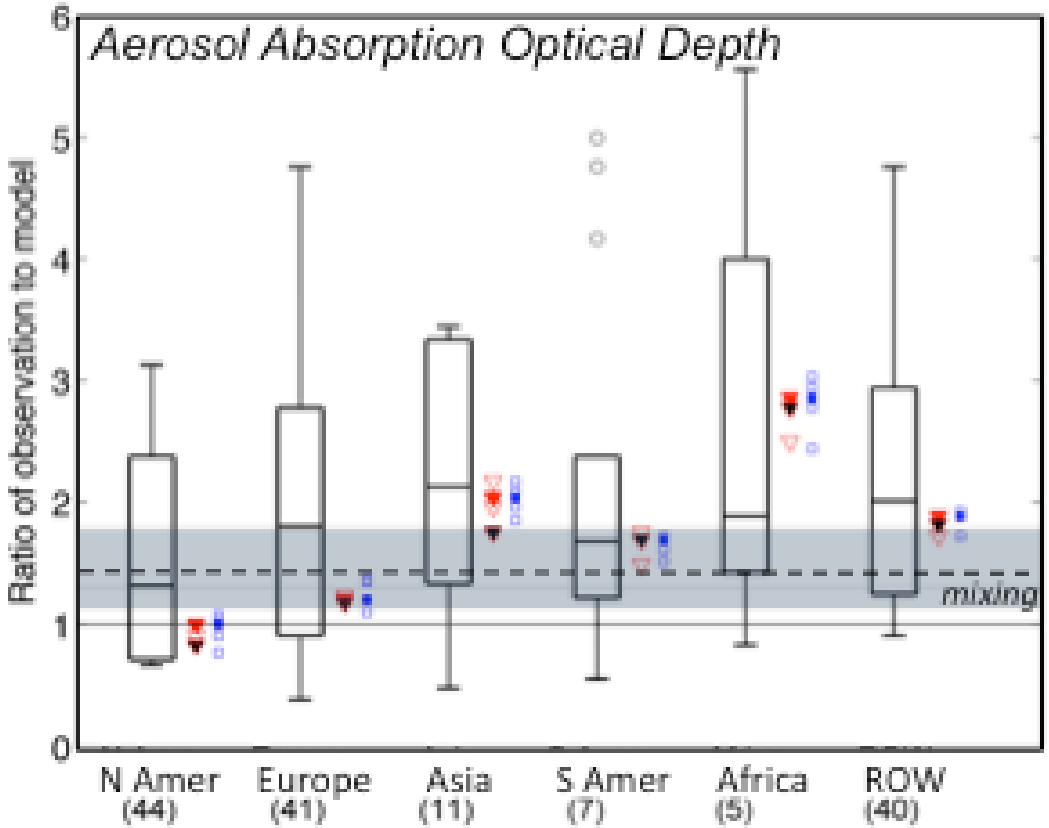
Major global sources: bottom-up estimate

~8000 tons/yr



Year 2000 estimates (Bond et al., GBC 2007 + van der Werf, 2006 + updates for IPCC AR5)

Emission estimates (or something else in the model) have big gaps



Values in parentheses are number of AERONET stations.
Much of the globe isn't covered

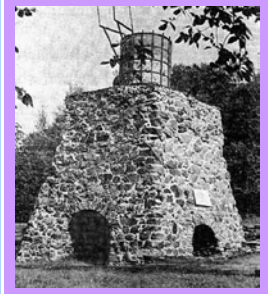
Data source: Koch *et al.*, 2009;
Figure: Bond et al., 2013 (submitted to JGR)

Dominant sources change as development occurs

development → & increasing → quality of life

Residential

People have to eat and stay warm…



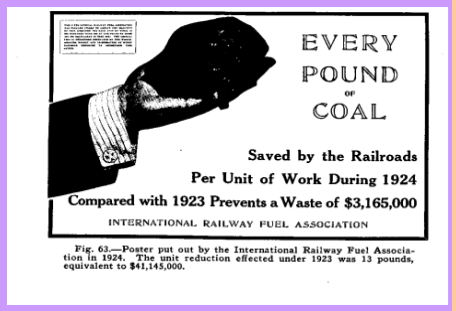


Fig. 63.—Poster put out by the International Railway Fuel Association in 1924. The unit reduction effected under 1923 was 13 pounds, equivalent to $41,145,000.

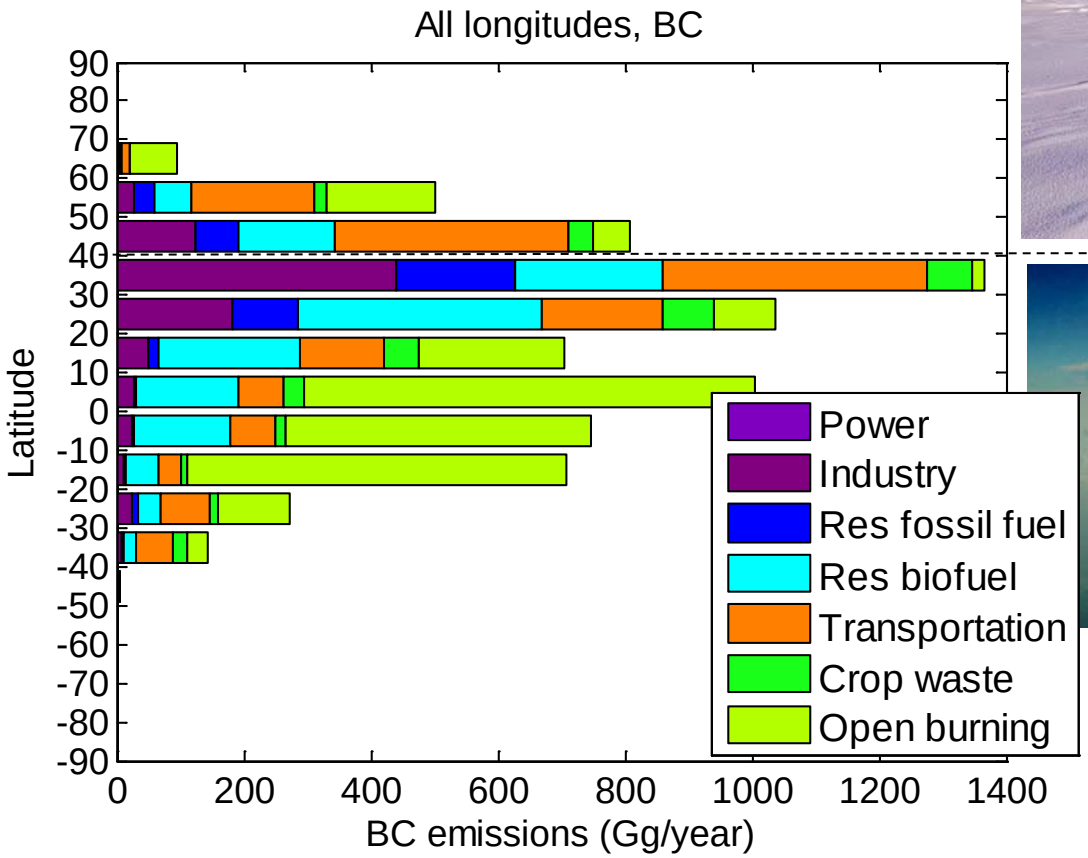
Industry

Next, people want jobs…

Transport

Happy, employed people want to buy things & go places!

Estimated location of global sources



North of 40°N
May travel directly to Arctic

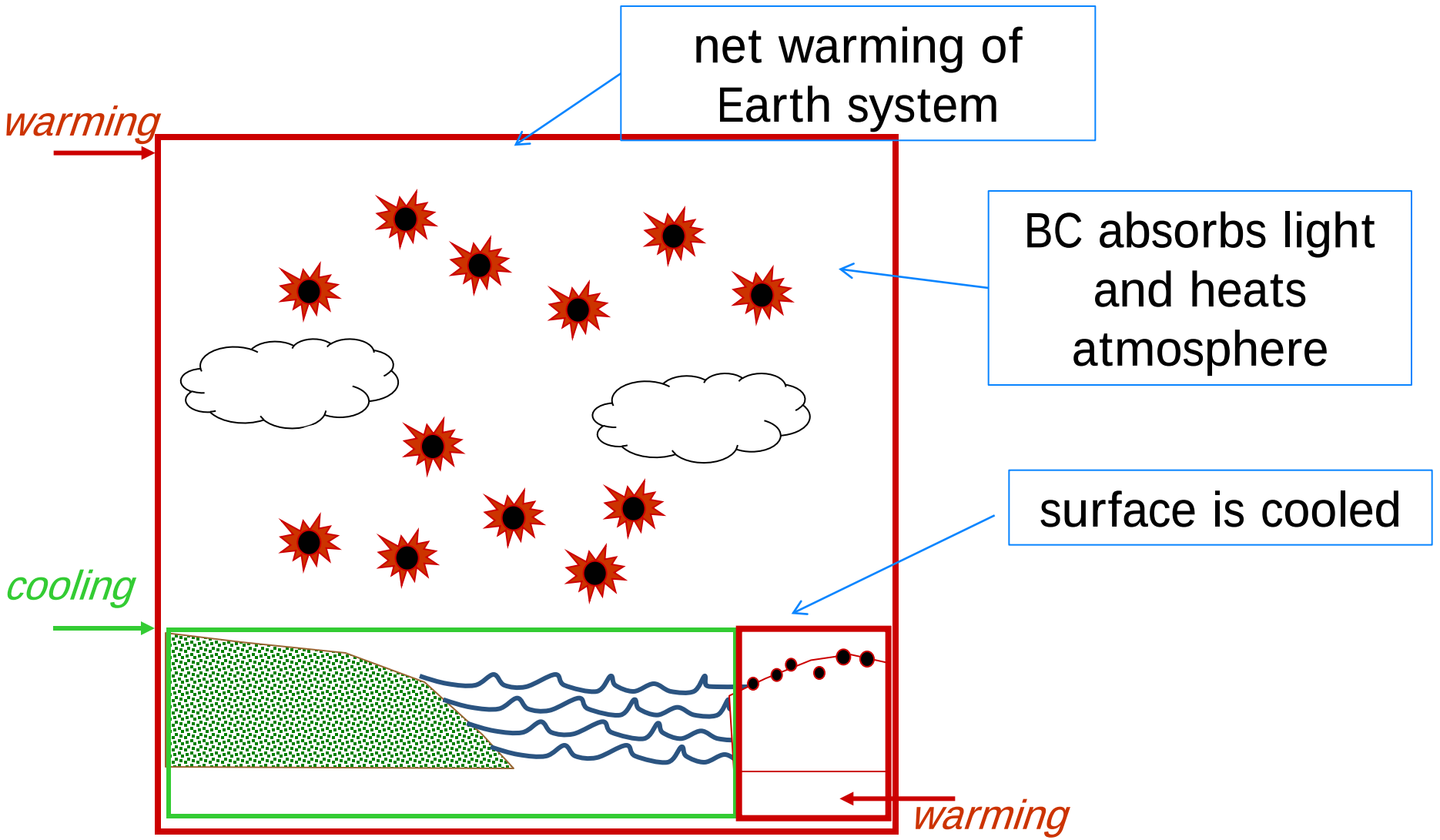
S of 40°N
Affects atmospheric warming

Photo credits: guardian.co.uk (above), V. Ramanathan (below)

Q: How does black carbon affect climate?

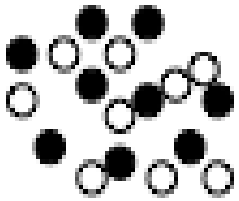
A: It redistributes
solar energy
and keeps more of it in the
Earth system

Direct forcing: change in radiative balance



Distribution of BC in particles affects absorption

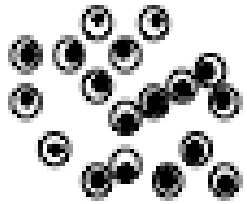
Externally mixed
Different species are in different particles



6-7.5 m^2/g

Least absorption
Unlike observations

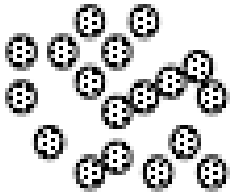
Internally mixed
Core-shell
Species are divided among particles



12 m^2/g

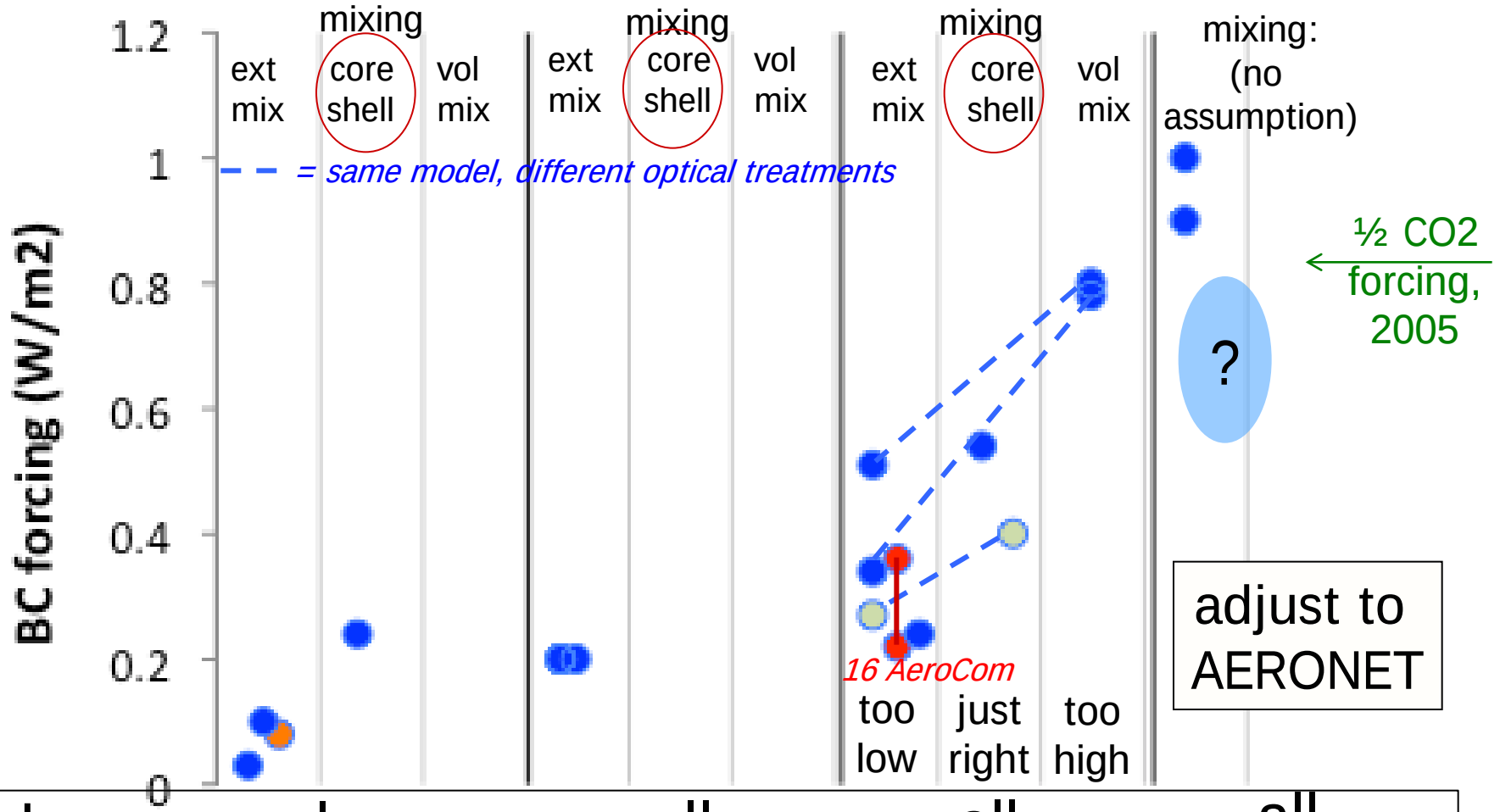
More absorption
Similar to observations

Internally mixed
Volume mixing
All species are divided equally among particles
Each particle is homogeneous inside



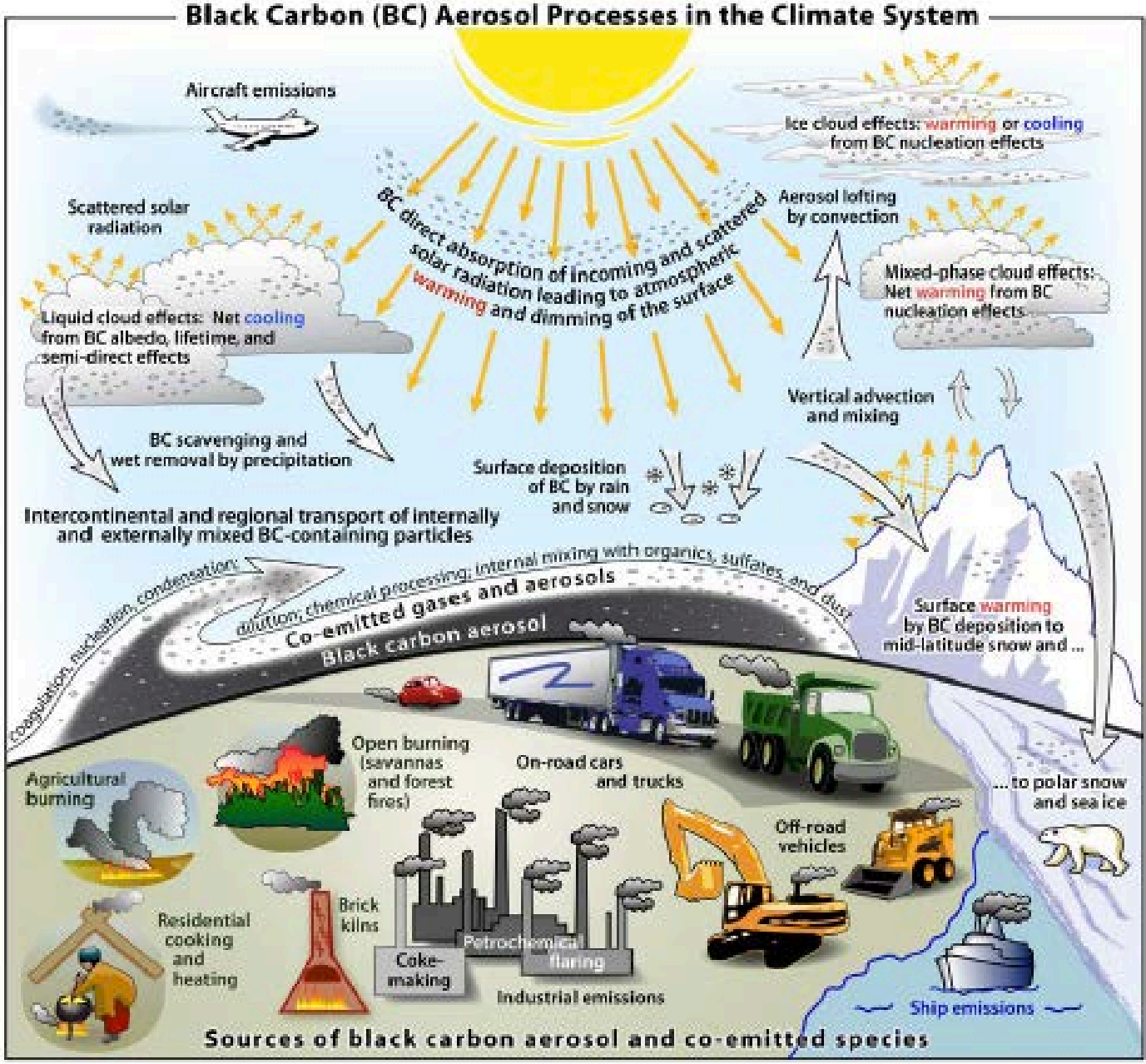
Most absorption
Physically unrealistic

Black carbon direct forcing values



Black carbon induces more changes than just direct forcing.

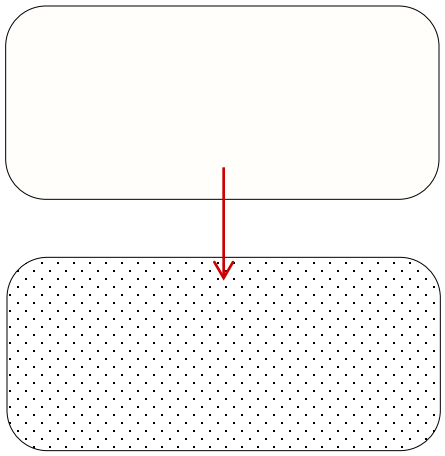
SNOW and CLOUDS are two other complex factors.



Bond et al., "Bounding the Role of Black Carbon in the Climate System Under review at JGR

BC deposited on snow has positive forcing

Think of BC as a very small rock.



BC reduces snow's reflectivity

Solid takes up heat; heat melts snow (or ice)

Exposed surface absorbs heat and melts remaining snow

Net result: Effect is greater than just direct forcing

Clouds are not simple, either

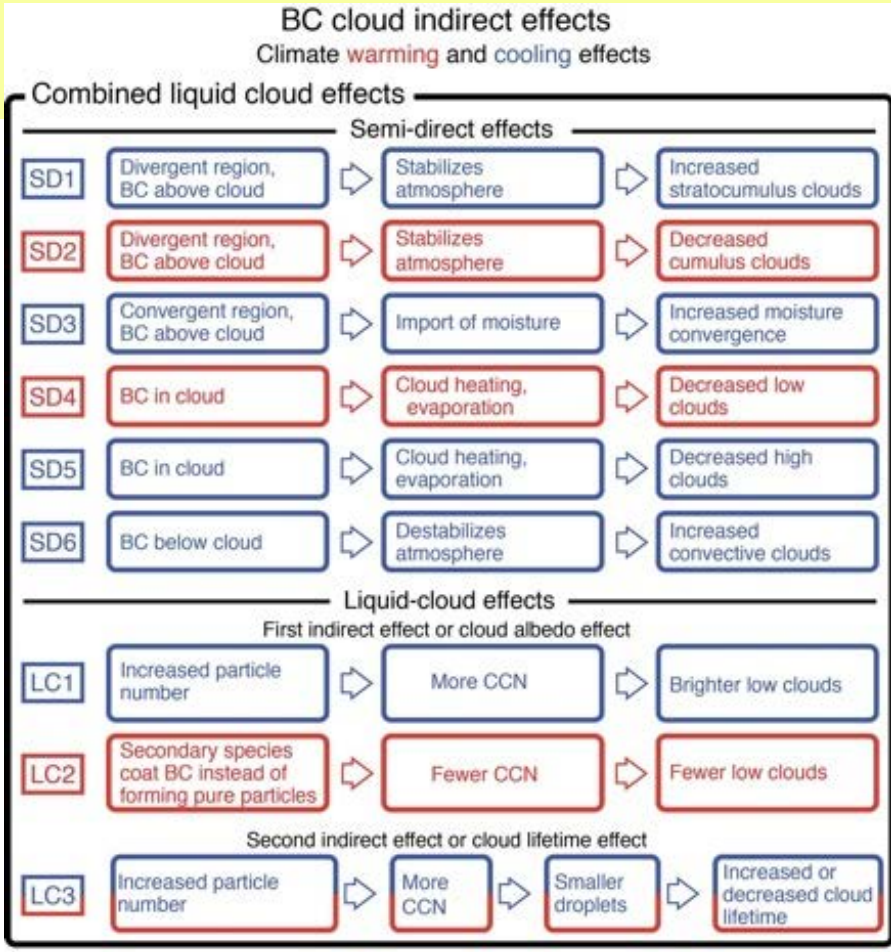
Semi-direct
(-)
but depends on BC location

Cloud absorption
(+)
(like burnoff but including BC in cloud droplets)

Liquid indirect
(-)
but small

Mixed (water-ice) clouds **(+)**

Ice clouds
+ / -



Bond et al., "Bounding BC"… Koch and Kaercher cloud chapter Under review at JGR

T.C. Bond

Q: Is black carbon important compared with carbon dioxide?

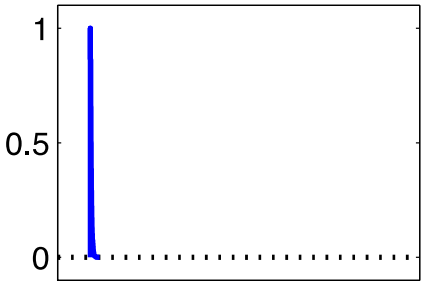
Carbon mass emitted as BC
is 0.1% of C mass emitted as CO_2

A. YES…

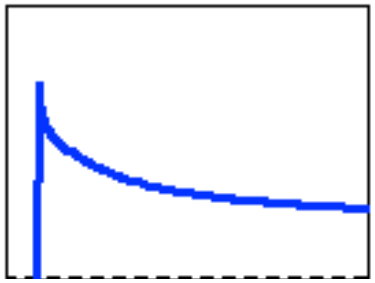
For a while

BC and CO_2 are quite different animals.

BC



CO_2



Lifetime

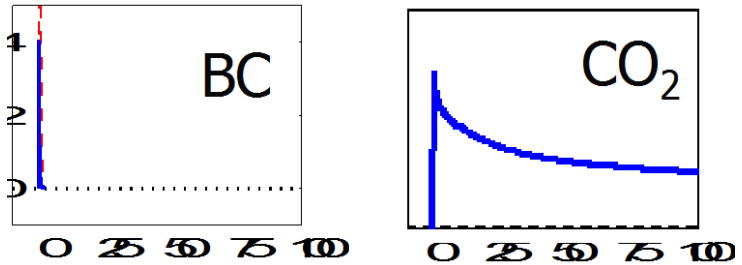
BC washes out of the atmosphere and CO2 doesn't.

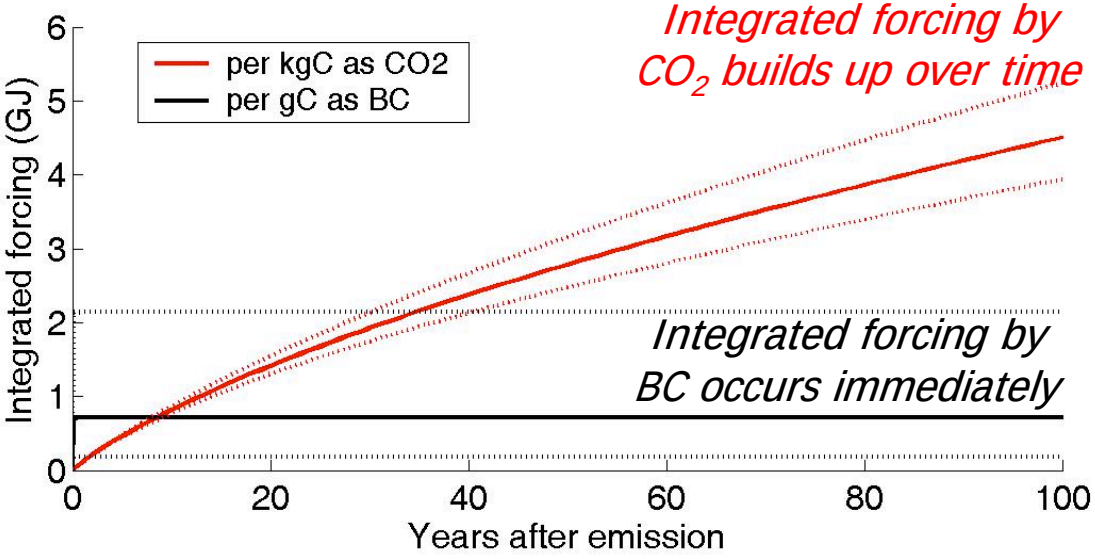
BUT: Compared to CO_2, BC absorbs **1,800,000** times as much light while it's in the atmosphere.

One gram of BC intercepts about as much light as 6-12 umbrellas

"Climate metrics" compare these different species.

One such metric is the Global Warming Potential





Bond & Sun, ES&T 39, 2005

GWP definition:
Forcing of 1 kg BC*
integrated over a certain time period
Divide by integrated forcing for CO_2

* or whatever; GWP can be defined for any species

GWP for BC:
about 740
with 100-year integration

Q: Can we mitigate BC sources and eliminate all that positive forcing?

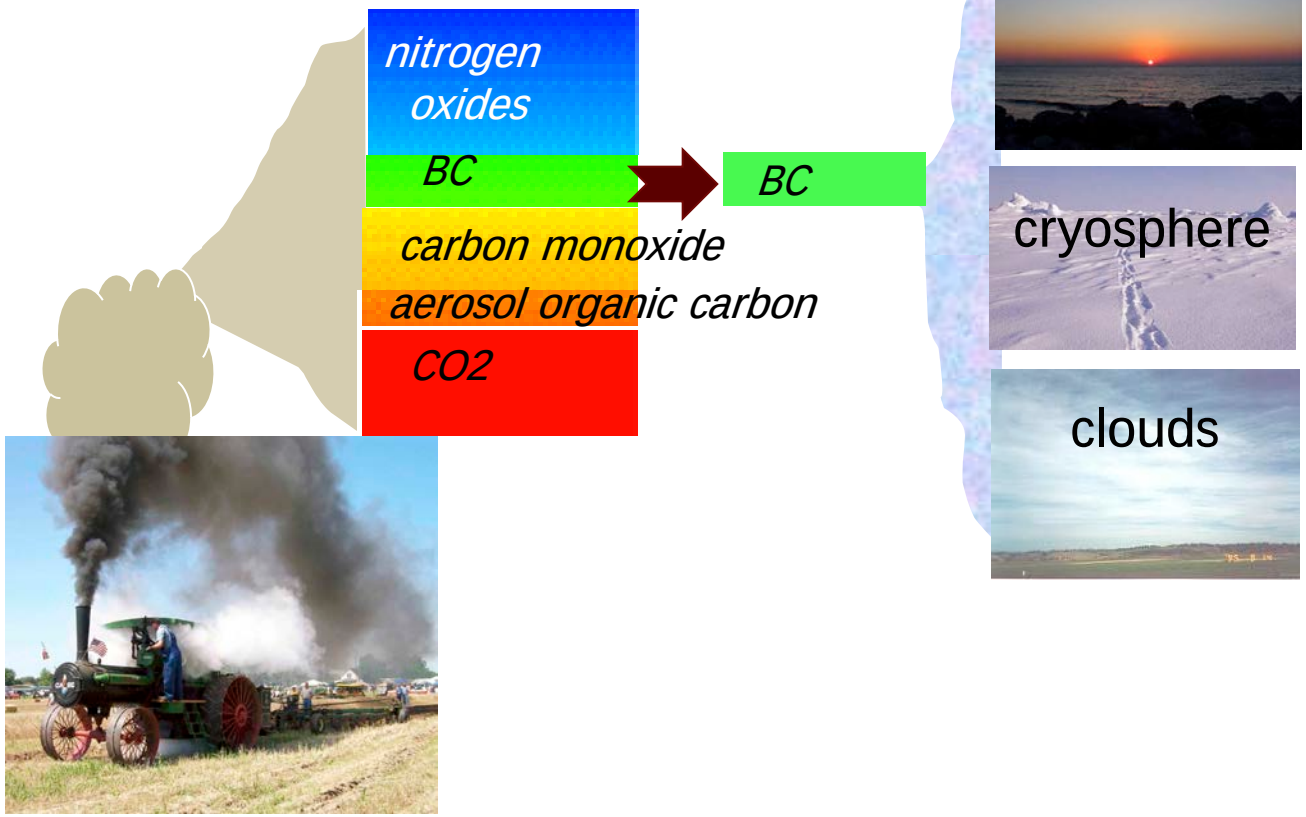
A. NO

Major issue: co-emitted species

Changing any source of black carbon also changes other emitted pollutants.

each source has multiple pollutants

each pollutant has multiple effects



Counteracting BC positive forcing…

1. Organic carbon

Most sources also emit OC

OC direct forcing is too small to negate BC...

But effect of OC *on clouds* can be large

Most relevant to: residential solid fuels, open biomass

2. NOx (maybe)

NOx has short-term warming (interactions with ozone)
but long-term cooling (interactions with methane)

Most relevant to: diesel engines

Summary: Take-home messages

1. Black carbon is an unusual particle with unusual climate effects (positive forcing) and a few major sources

diesel engines, residential solid-fuel, industry, open burning

2. Net forcing of BC – even after cloud complications– is positive with high likelihood

3. Mitigation strategies relying on BC reductions must be chosen carefully

greater confidence in direction of climate impact if co-emitted pollutants are low