

# Assessing Climate Benefits of Carbonaceous Aerosol Emission Reductions

Denise L. Mauzerall

Woodrow Wilson School of Public and International Affairs  
and Department of Civil and Environmental Engineering  
Princeton University



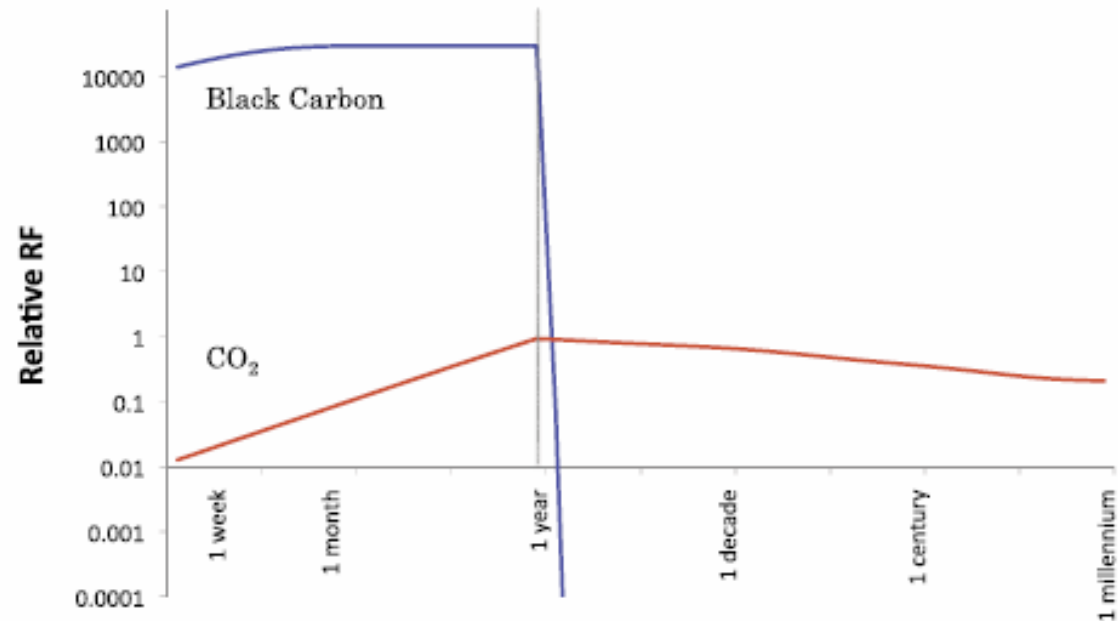
Addressing BC and Ozone as SLCF  
EPA Workshop  
Chapel Hill, NC  
March 3, 2010

# Assessing the climatic benefits of black carbon mitigation

- In the Copenhagen Accord, national governments have recognized that to avoid “dangerous anthropogenic interference with the climate system” the increase in global average temperature should be below 2°C.
- Limiting emissions of air pollutants with large radiative forcing (RF) will likely be necessary to achieve this goal, if it’s attainable at all.
- **Goals:**
  1. Reconcile various estimates of RF of carbonaceous aerosols and determine how large a contribution they make to the Earth's radiative balance today.
  2. Estimate the benefits of reducing emissions of carbonaceous aerosols from contained combustion in terms of years gained to reduce CO<sub>2</sub> emissions.

[**Kopp and Mauzerall**, PNAS, under review]

# Relative Radiative Forcing of Black Carbon and CO<sub>2</sub>



**Figure 2.1:** Relative direct radiative forcing of one ton of black carbonaceous aerosol (blue) emitted over the course of one year, compared to the radiative forcing of one ton of CO<sub>2</sub> (red) emitted over the same period of time. Both axes are logarithmic. Although the radiative forcing of BC is about 20 to 60 thousand times stronger while the BC is being emitted, its effect plunges to zero shortly after the end of emission. The effects of CO<sub>2</sub>, in contrast, linger for millennia.

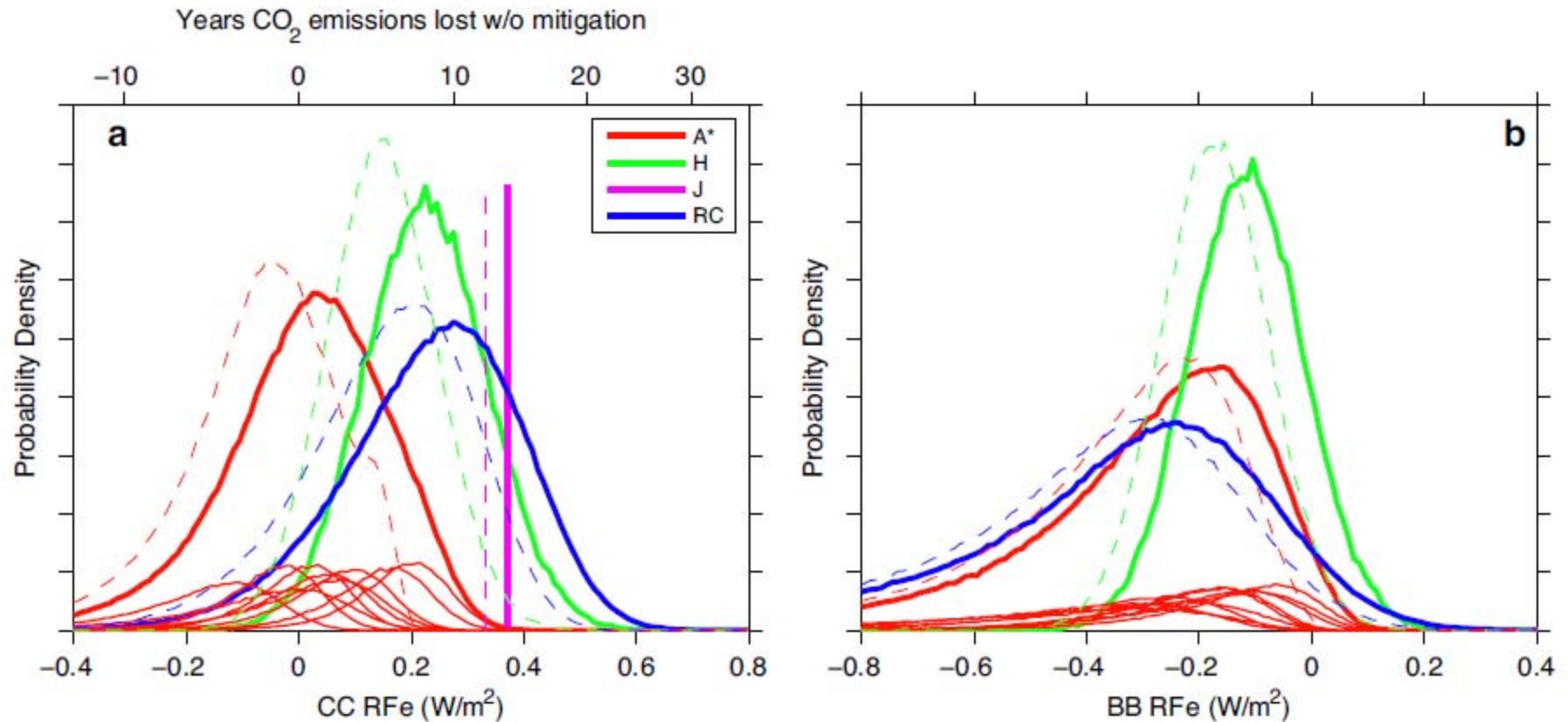
[Woodrow Wilson School of Public and International Affairs, workshop report, 2009

Available at: <http://www.princeton.edu/~mauzeral/WWS591e> ]

# Radiative Forcing Estimates of Carbonaceous Aerosols

- Consider four estimates:
  - 1) AEROCOM intercomparison study, *Schulz et al.*, 2006, (A)
  - 2) *Hansen et al.*, 2005, (H)
  - 3) *Jacobson* , 2002, 2004, 2005, (J)
  - 4) *Ramanathan & Carmichael*, 2008 (RC)
  
- Add approximations for omitted effects, then normalize estimates using a common estimate of global emissions of carbonaceous aerosols (*Bond et al.*, 2004).
  - AEROCOM – add estimate of indirect cloud albedo effect and global snow albedo RF from *Hansen et al.*, 2007 and *Flanner et al.* 2007. Increase RF in models which do not include internal mixing
  - *Hansen et al.* – no change. Apply efficacies to A\* and RC.
  - *Jacobson* – transform temperature change into global RF by comparing to warming produced by doubling CO<sub>2</sub>.
  - *Ramanathan & Carmichael* – add snow albedo RF from *Hansen et al.*, 2007 and *Flanner et al.* 2007.

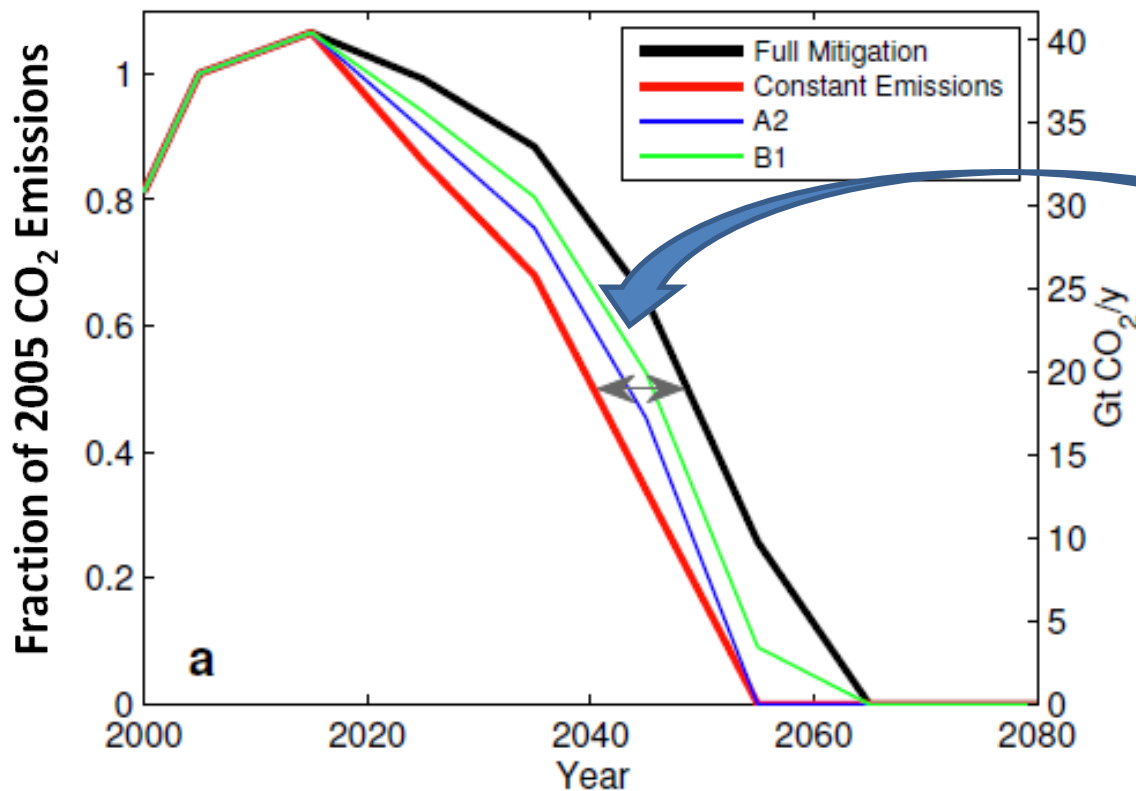
# Comparison of the effective RF of carbonaceous aerosols from Contained Combustion (CC) and Biomass Burning (BB)



Solid lines include snow albedo effect, dashed lines do not.

Obtain “best estimate” of RF from carbonaceous aerosols from CC = 0.22 Wm<sup>-2</sup>

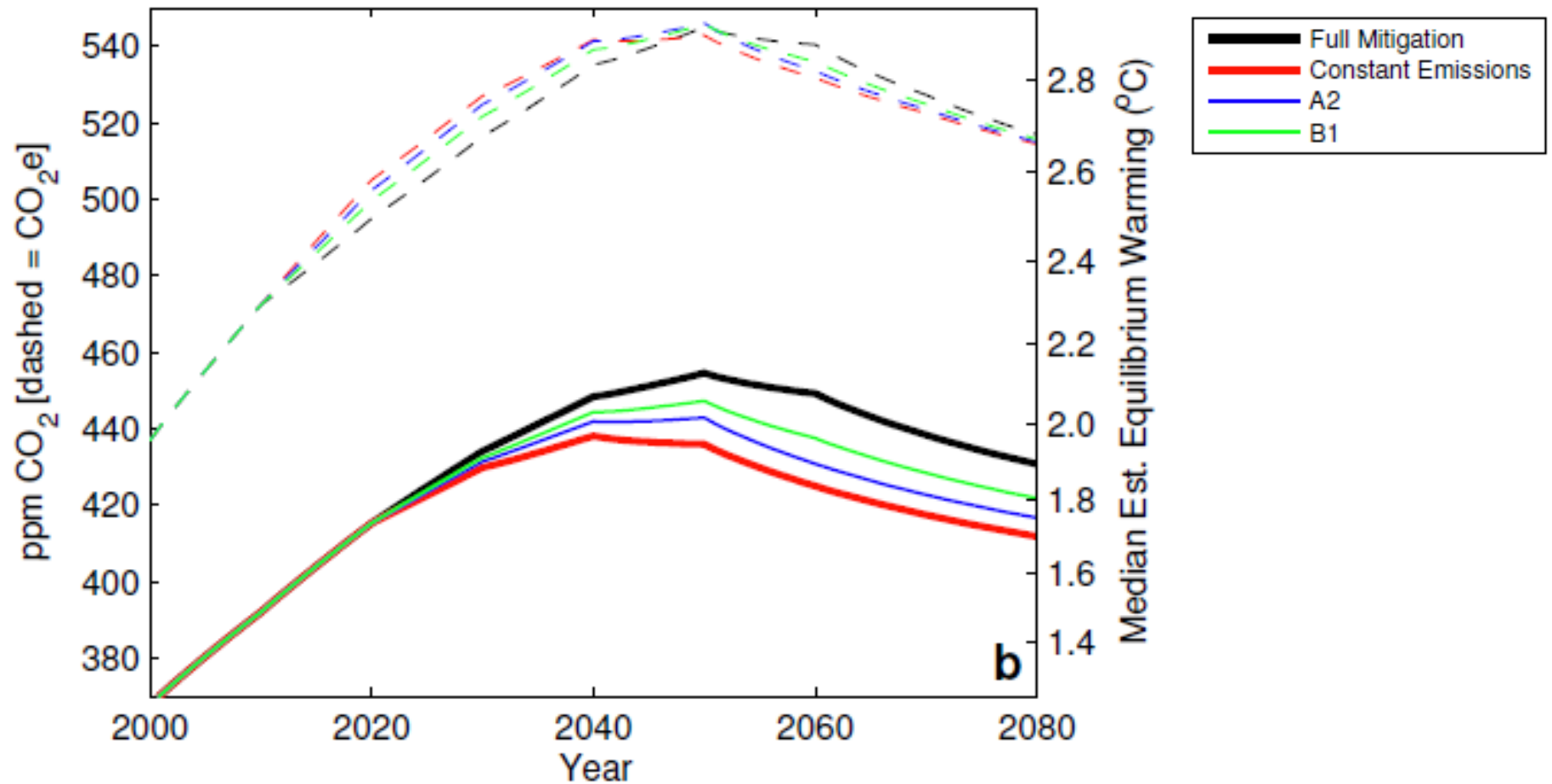
For a 500 ppm CO<sub>2</sub>e (3.1 W m<sup>-2</sup>) *effective* RF target in 2100 and using our “best estimate” of RF (0.22 0.22Wm<sup>-2</sup>) from carbonaceous aerosols, we estimate that failing to reduce carbonaceous aerosol emissions from contained combustion would require CO<sub>2</sub> emission cuts about 8 years earlier than would be necessary with full mitigation of these emissions.



CO<sub>2</sub> must be reduced to 50% of 2005 emission levels 8-years (1-15 years) earlier if carbonaceous aerosol emissions from CC continue at a constant 1996 rate versus if they are fully mitigated.

# CO<sub>2</sub>eq concentrations and resulting warming resulting from four CC mitigation strategies

(assuming climate sensitivity of 3°C from CO<sub>2</sub> doubling)

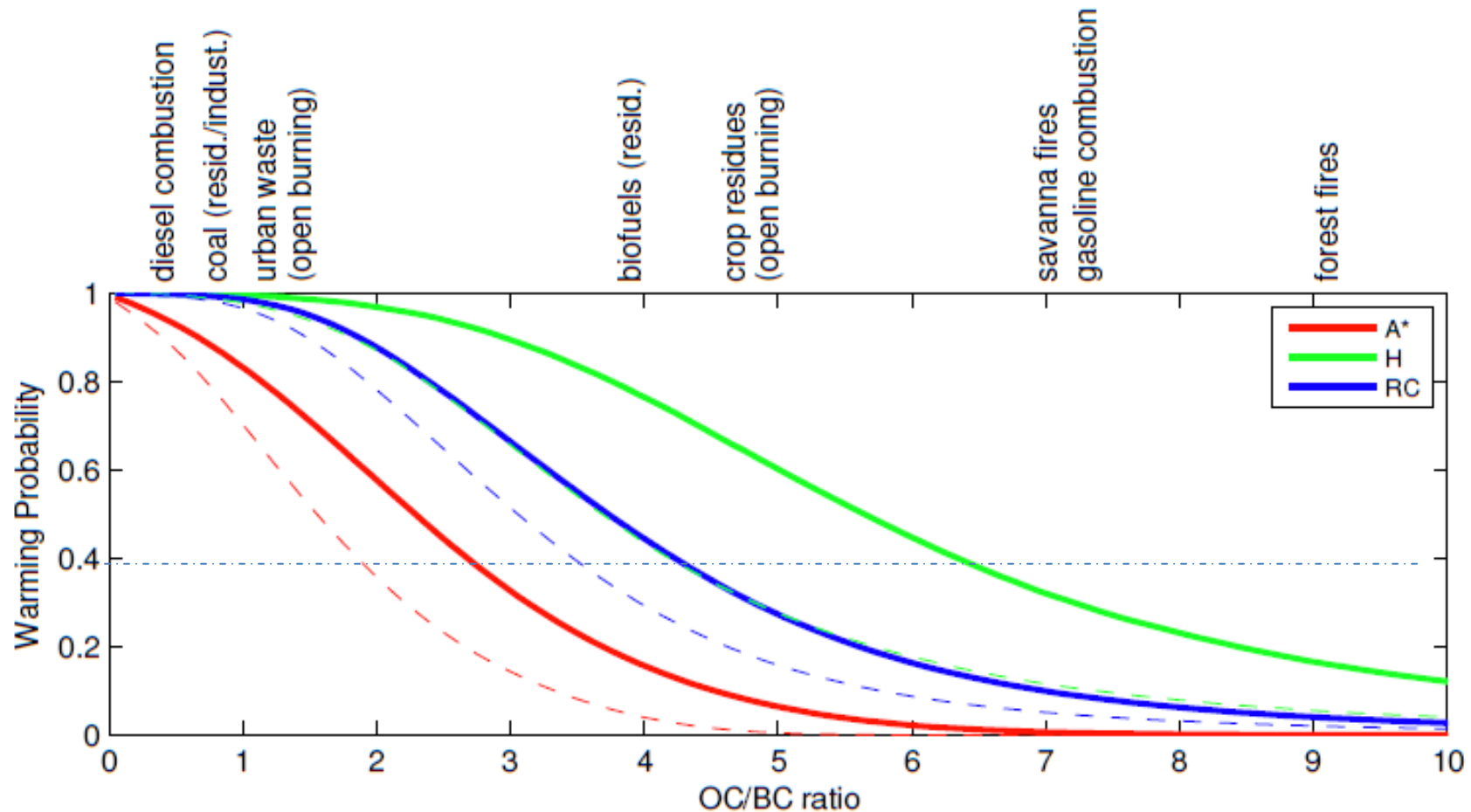


Solid lines: CO<sub>2</sub> concentrations

Dashed lines: CO<sub>2</sub>eq conc. and associated warming

# Relative Warming Probability based on OC/BC ratio of Various Combustion Sources (Bond et al., 2004) Using three estimates of RF

(Solid lines include and dashed lines exclude snow albedo effect)



**Fig. 3.** Probability distribution of the OC/BC threshold above which emissions are no longer net warming, assuming an average geographic and altitudinal distribution for the emitted particles. Typical OC/BC values of different combustion sources (3) are marked. Solid lines incorporate the snow albedo effect, assuming that it is caused by CC and BB in proportion to their BC emissions, while dashed lines exclude the snow albedo effect. Average OC/BC ratios are from (3). For example, residential biofuels have a typical OC/BC ratio of 3.9; based on H, assuming an average geographic and altitudinal distribution, and including the snow albedo effect, there is a 78% chance they produce carbonaceous aerosols with a net warming effect.

# Climatic benefits of black carbon mitigation

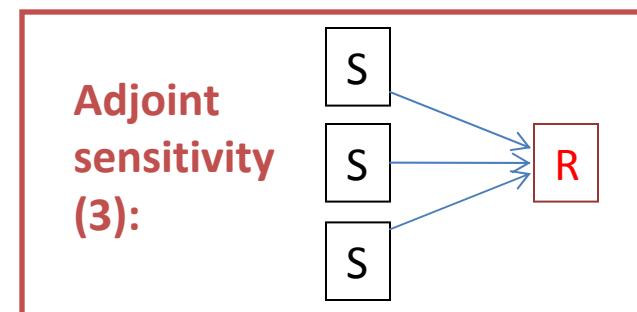
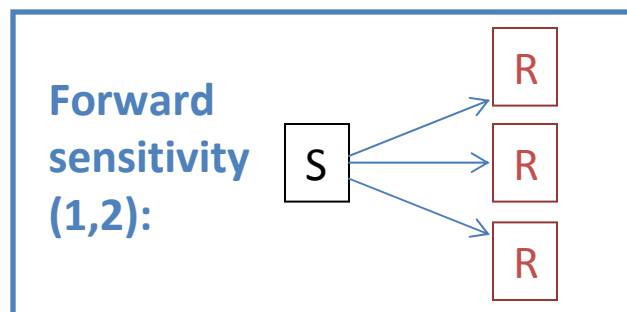
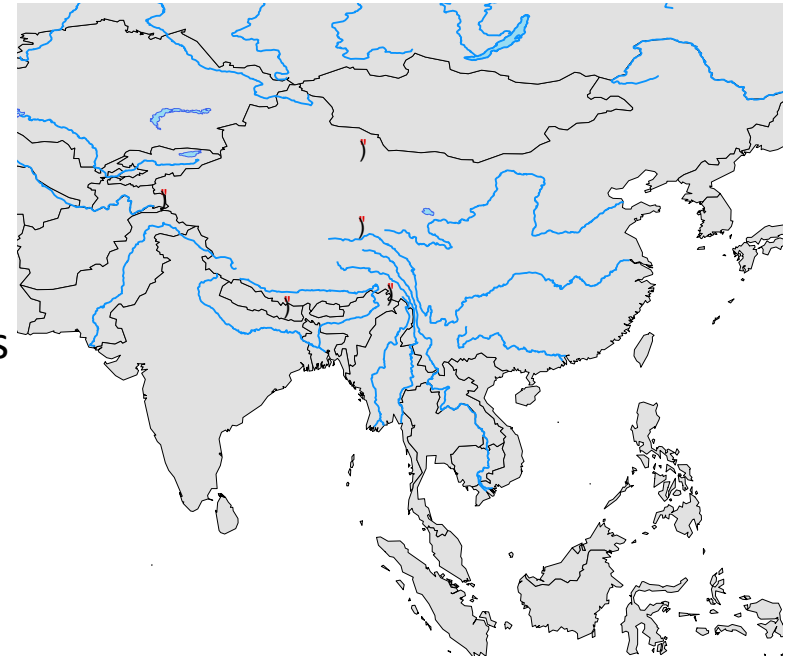
- Based on existing studies, we find that failing to reduce carbonaceous aerosol emissions from CC requires a greater reduction in CO<sub>2</sub> emissions in order to meet the same RF or temperature target.
- Our results suggest that reaching a 500ppm CO<sub>2</sub>eq RF target in the absence of carbonaceous aerosol emission reductions requires that global CO<sub>2</sub> emissions be cut to half their 2005 levels about 8±7 years earlier than with aggressive carbonaceous aerosol reductions.
- As the largest and only growing sources of carbonaceous aerosols are in the developing world, this is an opportunity for cooperative global action.

# Where does the BC that impacts sensitive regions come from? How can we target mitigation efforts?

## Methods to characterize source contributions:

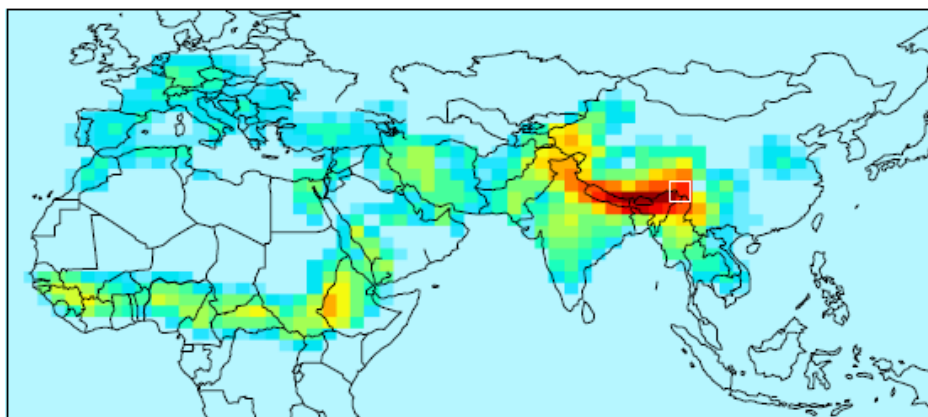
1. **Brute force**: perturb emissions from specific regions/sources and see the effect globally
2. **Tagged regions**: track emissions from tagged regions and see the effect of each tagged region globally
3. **Adjoint method**: identify contributions of source regions to concentrations at RECEPTOR and see globally where emissions came from

Glaciers sites for adjoint calculations in Himalayas and Tibetan Plateau

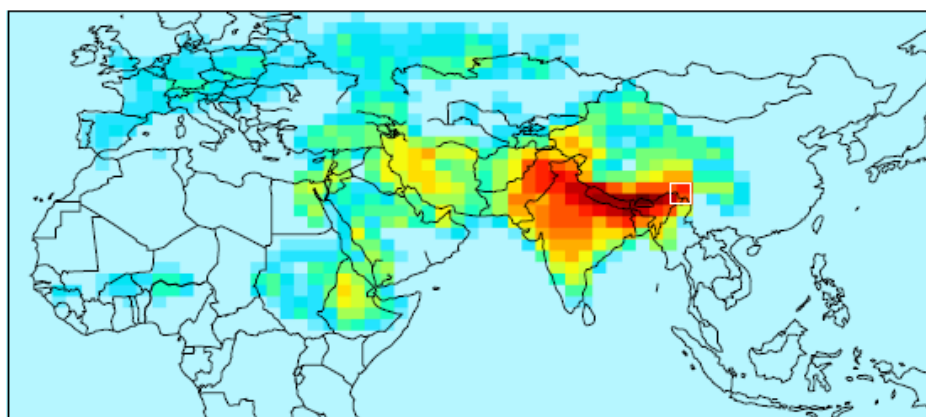


# Adjoint sensitivity: Seasonal BC emission contributions to Zuoqiupu glacier (south-eastern Tibetan Plateau)

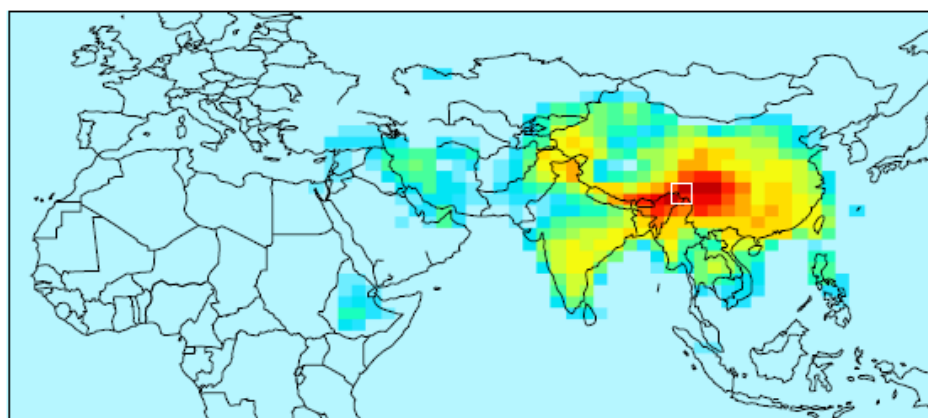
January (dry season)



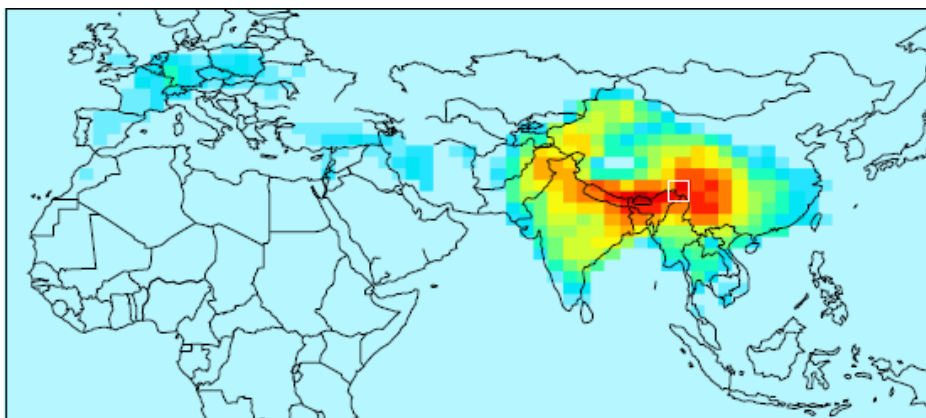
April (pre-monsoon)



July (monsoon)



October (post-monsoon)



1.0e-02 4.7e-01 2.2e+01 1.1e+03 5.0e+04 kg

Origin of total BC that has been transported (and deposited) to the glacier region in the white square over a two-week period.

[Kopacz et al., in prep]

# Black Carbon WWS Workshop Summary

- BC is not like GHGs
- 2°C target is very difficult without tackling BC
- BC has strong regional effects
- BC has costly impacts on human health

## BC Science

## BC in the U.S.

- Target transportation sector
- Diesel retrofits cost effective for health reasons
- Improve fuel efficiency
- Locate super-emitters
- Reduce off-road vehicle emissions
- Fuel switching

- Developing nations: Major growing contributors
- Developing nations are more vulnerable to climate and health effects
- Focus on transport fleet (new vehicles and retrofits) and stoves

## BC Abroad

## International Policy

- Promote Awareness - Need IPCC Special Report on BC
- Hot-Spot treaties
- Global Technical Standards
- Multilateral funds
- No trading of BC with GHG

[Woodrow Wilson School of Public and International Affairs, workshop report, 2009]

# Linking Changes in Aerosol Emissions from China to Global Public Health and Radiative Forcing

- Evaluate impacts of emissions of aerosols and their precursors (SO<sub>2</sub>, organic carbon and black carbon) from China on global air quality for
  - Present (year 2000) and
  - Future (three 2030 scenarios).
- Estimate impacts of these pollutant loads on global
  - Premature mortalities; and
  - Radiative forcing.

**E. Saikawa, V. Naik, L. W. Horowitz, J. Liu, D. L. Mauzerall.**

Present and potential future contributions of sulfate, black and organic carbon aerosols from China to global air quality, premature mortality and radiative forcing, *Atmospheric Environment*, 2009.

# Methodology

- Utilize global chemical transport model **MOZART v2.4** with MACCM3 meteorology.  
For each scenario, run two simulations:
  - With China's emissions
  - Without China's emissions
  - Calculate change in concentrations due to emissions from China
- Utilize the **GFDL Radiative Transfer Model** to calculate resulting changes in direct TOA radiative forcing due to each aerosol species.
- **Emissions**
  - 2000: IIASA CLE Scenario (Cofala et al., 2005; Dentener et al., 2005)
  - 2030 BAU: IPCC A2 Scenario - Business as usual
  - 2030 CLE: IIASA Full implementation of current air quality legislation by 2030
  - 2030 MFR: IIASA Maximum feasible emission reduction using technology existing today regardless of cost
- Calculate effect of China's emissions on:
  - Global premature mortality;
  - Radiative forcing.

# Emission Scenarios

Unit: Tg/yr

	2000 BASE	2030 BAU	2030 CLE	2030 MFR
<b>China</b>				
SO <sub>2</sub>	27 (27%)	40 (21%)	28 (26%)	6.1 (24%)
SO <sub>4</sub> <sup>2-</sup>	0.56 (27%)	0.83 (21%)	0.57 (26%)	0.13 (24%)
OC	4.7 (16%)	7.8 (17%)	3.5 (14%)	2.4 (17%)
BC	0.70 (16%)	2.7 (17%)	1.2 (14%)	0.83 (17%)
<b>Global total</b>				
SO <sub>2</sub>	102	191	105	25
SO <sub>4</sub> <sup>2-</sup>	2.2	4.0	2.3	0.66
OC	29	47	24	14
BC	4.3	16	8.5	4.8

**2000 BASE = IIASA CLE for 2000.**

**2030 BAU = Business as usual emission growth, IPCC A2 scenario**

**2030 CLE = Full implementation of current air quality legislation by 2030**

**2030 MFR = Maximum feasible reduction using technology existing today regardless of cost**

## Results -

### Effect of sulfate, OC and BC aerosols originating from China on *annual premature mortality* in each region

	2000 BASE	2030 BAU	2030 CLE	2030 MFR
North America	320	580	400	120
South America	10	20	10	0
Europe	230	320	220	60
E. Soviet Union	200	310	190	70
Africa	250	660	440	140
South Asia	830	2000	1200	430
China	470 000	720 000	500 000	240 000
S. East Asia	10 000	20 000	13 000	5 000
Australia	0	0	0	0
Korea & Japan	11 000	13 000	10 000	4 000
Total	500 000	760 000	520 000	250 000

Vast majority of premature mortalities occur within China.

However, substantial numbers occur within other parts of Asia and occur on other continents.

## Results – Radiative Forcing (RF) from Sulfate, OC and BC from China

	2000 BASE	2030 BAU	2030 CLE	2030 MFR
SO <sub>4</sub> <sup>2-</sup>	-108	-154	-109	-33
OC	-7	-11	-5	-4
BC	42	70	32	21
Net	-74	-97	-83	-15

Unit: mWm<sup>-2</sup>

China's aerosol emissions currently create net **NEGATIVE** radiative forcing, offsetting global warming, but at large costs to health.

However, the negative forcing will decrease in the future as SO<sub>2</sub> emissions decrease and BC emissions rise.

**Reductions in BC emissions provide opportunity to reduce positive RF with simultaneous health benefits.**