



# Short lived climate forcers: Black carbon Science and geo-politics.....



**Anumita Roychowdhury**

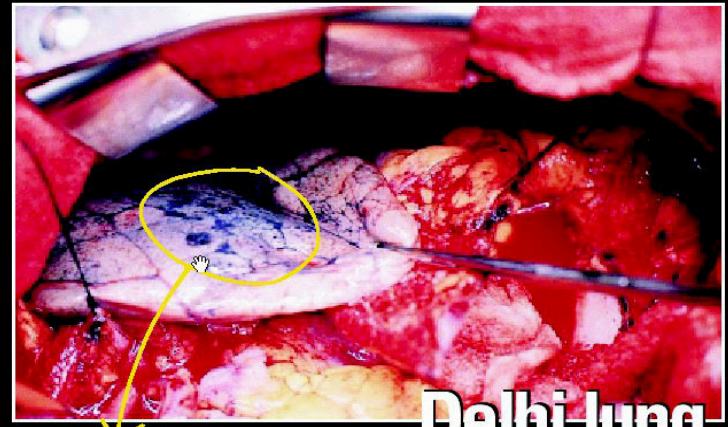
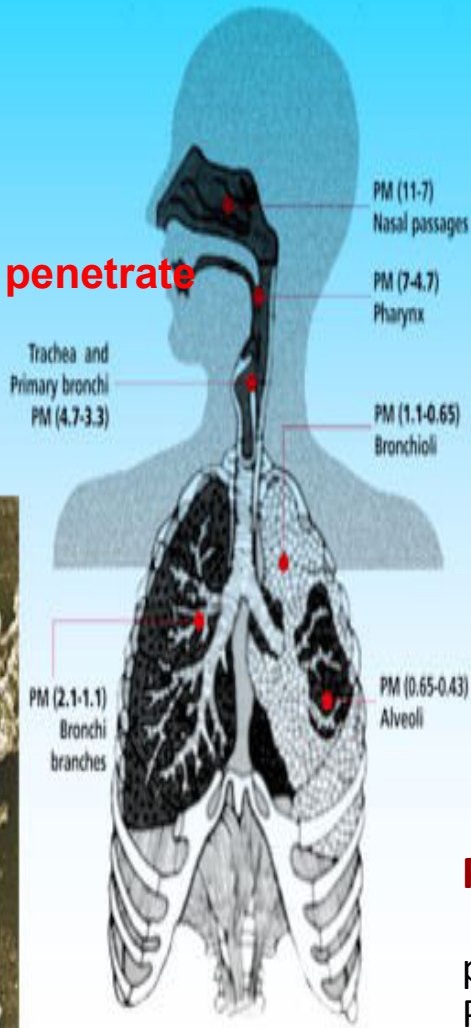
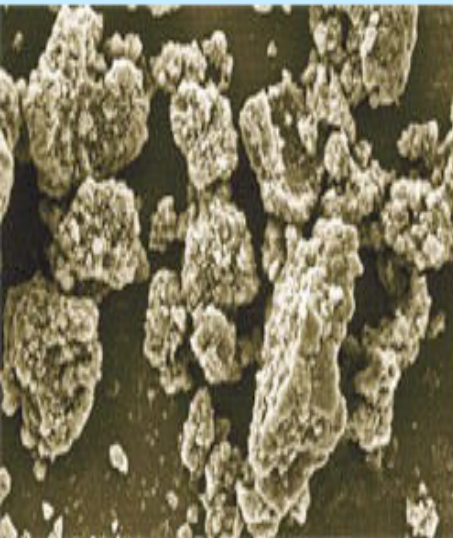
***South Asian Media  
Briefing Workshop on  
Climate Change, 2012***

**Centre for Science and  
Environment, November  
16-17, 2012, New Delhi**



# Air pollution story in India: How is this linked with climate change?

How far tiny particles penetrate our lungs



**Delhi lung**  
Capital punishment

Look at these black spots on the lung. The unfortunate owner lives in Delhi and has been breathing polluted air. Air full of carbon particles which accumulate in the lungs (black spots). What you can't see is a cocktail of gases and tiny particles, even smaller than carbon that get into our bodies. Actually, you are getting polluted.

Scary? But those cars are so sexy!

## Particulate matter: Special health worries:

Acute and chronic effects; Cause premature deaths. Studies show association of PM with mortality at much lower level (less than 50 microgramme per cum

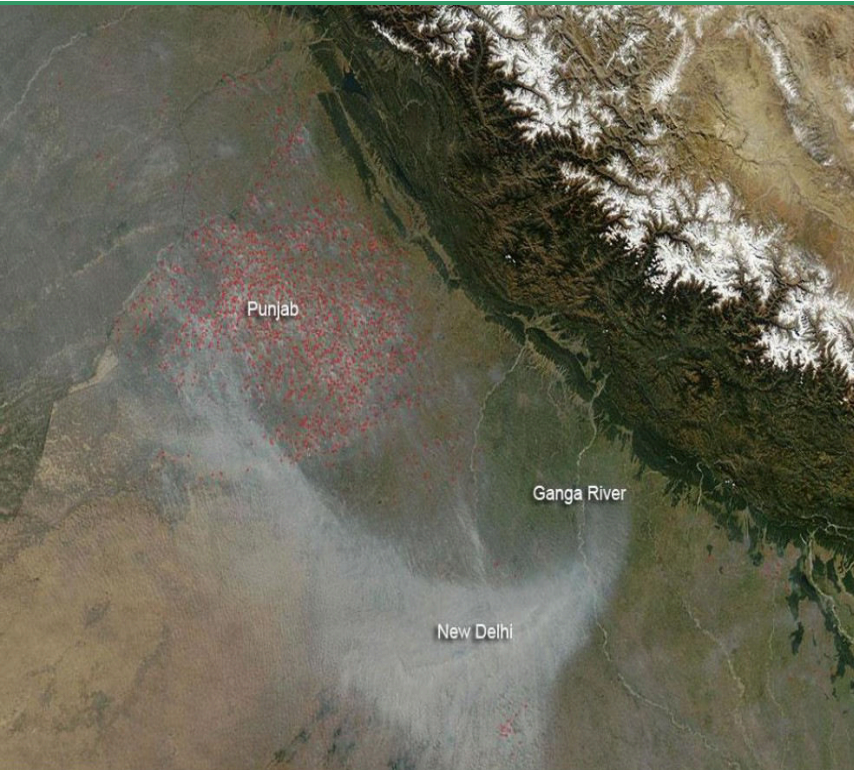
WHO says -- no safe level

Ultrafine particles 0.65 microns

Magnified 200,000 times

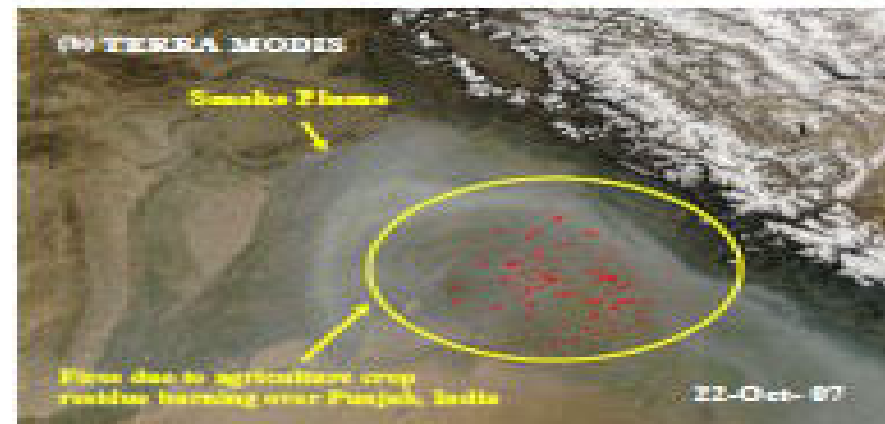
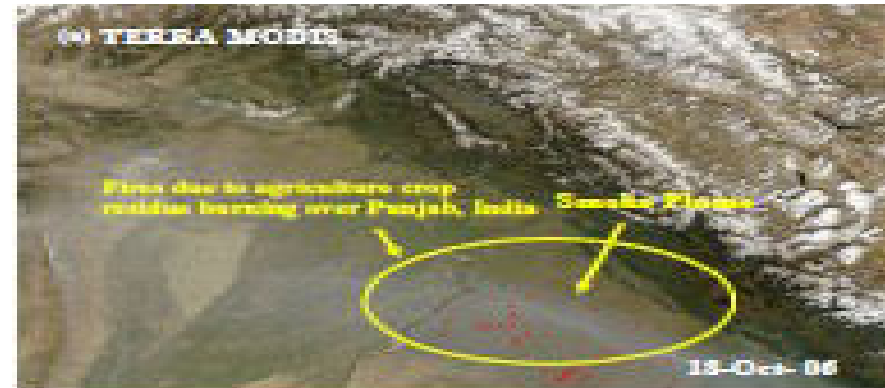


# Arial raids.....Smoke from Punjab hogged news this year



**October 2012:** This is NASA image of smoke plume from agricultural burning

**2007:** Study by National Remote Sensing Centre showed enhanced atmospheric pollution associated with agriculture crop residue burning in Punjab.







## Emerging science on the link between local air pollutants and warming....



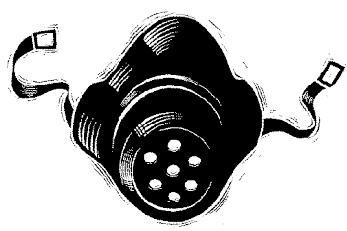
- **Local pollution can enhance warming ....**
  - HC + NO<sub>x</sub> lead to regional ozone but also to background **hemispheric ozone**
  - CO becomes CO<sub>2</sub> but consumes OH radicals along the way increasing **methane CH<sub>4</sub>**
  - Diesel PM increases PM<sub>10</sub> & PM<sub>2.5</sub> & ultrafine PM but also **black carbon**
  - **IPCC has listed several short lived pollutants that have warming impacts**
- **Warming gases can enhance local public health impacts as well...Eg**, each increase of 1 degree Celsius caused by carbon dioxide, can enhance PM and ozone build up. The resulting air pollution can lead thousands of additional deaths and many more cases of respiratory illness and asthma etc. (Mark Jacobson 2008)



## The challenge of 2 ° C .....



- The emerging science is saying that the **2°C** temperature rise target need us to cap CO<sub>2</sub>e at **450 ppm**. World already reaching 430 ppm -- still dangerous
- If annual emissions remain at today's level, greenhouse gas levels would be close to 550 ppm by 2050
- This would mean temperature increase of 3-5°C
- **Desperation: Slow down warming**
- **Spotlight on short term climate forcers to delay tipping the point .....**



- **The emerging science is saying .....Warming depends not only on the accumulated concentration of CO<sub>2</sub> but also on the intensity of emissions of short-lived pollutants with much higher warming potential.**
- They spike temperature peak in the short term.....
- **What are short term climate forcers.....**



## More potent than CO<sub>2</sub>.....

### Global warming potential of short lived gases



**A group of pollutants with short life span have much higher warming potential than CO<sub>2</sub>. Example --**

-- Atmospheric lifetime and GWP relative to CO<sub>2</sub> at different time horizon for various greenhouse gases (Global warming potential (GWP) for given time horizon)

	Lifetime Year)	20 year	100 years	500 years
Carbon dioxide (CO <sub>2</sub> )	100-500+	1	1	1
Methane	12	72	25	7.6
Nitrous oxide	114	289	298	15.3
CFC -12	100	11000	10 900	5200
HCFC-22	12	5160	1810	549

**Short lived climate forcers produce over their lifetime several times the radiative forcing of the same quantity of CO<sub>2</sub>.....**

**Black carbon is one of them.....**



- **The story of black carbon.....**





# What is black carbon?



- Black carbon is a solid particle emitted during incomplete combustion
- Black carbon is part of PM<sub>2.5</sub> that are emitted from combustion sources. These particles cause the most health damage
- **This is also a powerful climate forcer.** Black carbon absorb light and converts that energy to heat...
  - One kg of black carbon is estimated to be **460 times more potent than an equivalent amount of CO<sub>2</sub> over 100 year** time frame and **1600 times more potent over 20 years** time horizon.... (unofficial estimates of IPCC). BC has a life span of 3-8 days.....
- Focusing on small particles yields co-benefits for air quality and climate mitigation, says the emerging science



# Primary Emission Sources



## Particulate Matter

- Combustion processes (all)
- Dust generating activities (all)
- Secondary particulates --  
Reaction of ammonia and NO<sub>x</sub> in the atmosphere to form ammonium nitrate
- The oxidation of SO<sub>2</sub> or SO<sub>x</sub> in the atmosphere to form sulfate
- The condensation of gases into liquid droplets

## Black Carbon

- Low temperature combustion of carbonaceous fuels; Incomplete combustion....
- Examples: open fires, cook stoves, primitive industrial sources, and diesel engines



# How BC Warms the Climate?



- Black carbon absorbs radiative heat from the sun and warms everything around it (**direct effect**)
- Black carbon interacts with clouds and affects rainfall patterns (**indirect effect**)
- Black carbon falls onto snow and ice and changes the overall reflectivity of those surfaces, making them melt faster, which exposes the darker ground or water below them, causing even faster warming (**albedo effect**)



## Why strong interest in short lived climate forcers today?



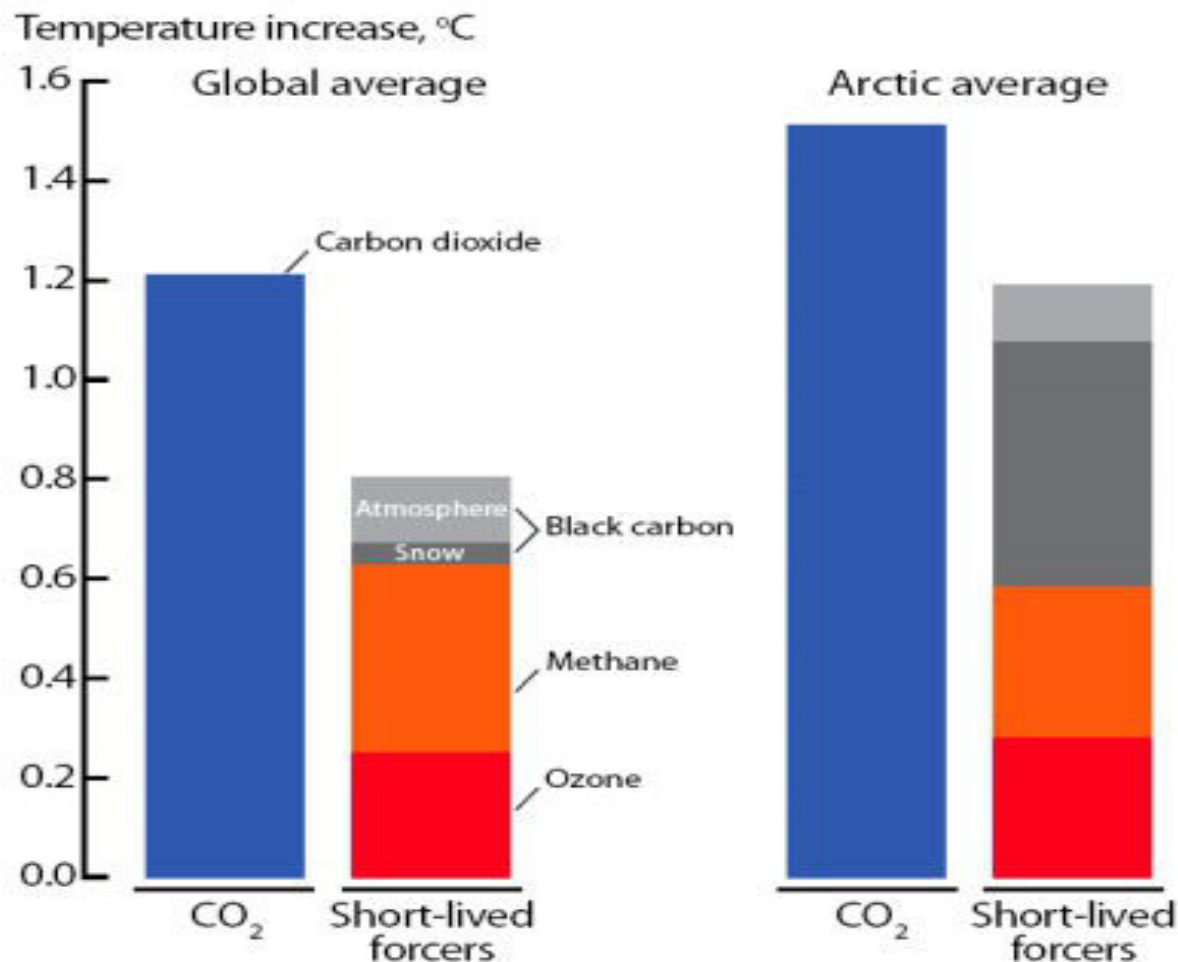
- **UNEP 2011**– Reducing SLCFs is likely to slow down the rate of global warming over the next two to four decades and delay the tipping point.....

While long lived CO<sub>2</sub> is steadily pushing up global temperature the short lived climate forcers accelerate short spikes.....

- *“Methane is like CO<sub>2</sub> on steroid and black carbon is CO<sub>2</sub> on crack, hundreds of times worse as they add to our double burden of health and climate catastrophe.”* – Kirk Smith, Health and Climate scientist



# Global versus Regional Impacts



Source: Laura McKelvey, EPA Office of Air Quality Planning and Standards, November 18, 2009

(Adapted from Reiersen and Wilson, 2009)





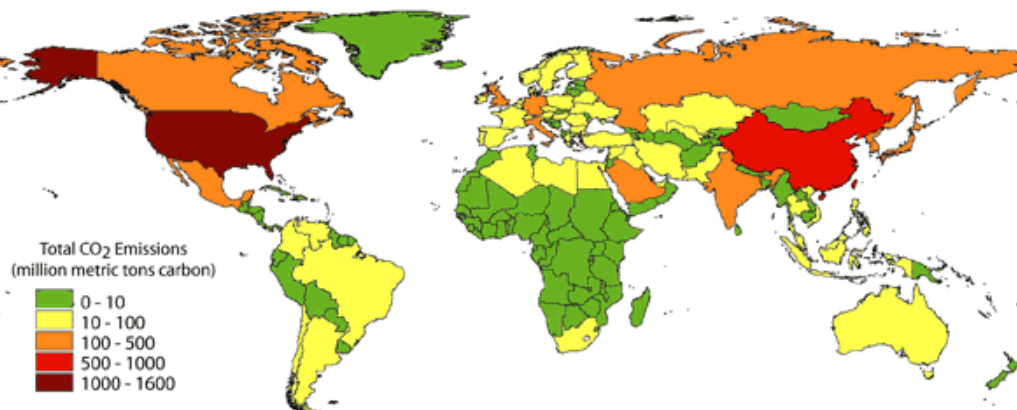
- Geo-politics of the new science....



# Global concentration of CO<sub>2</sub> vs Global concentration of PM<sub>2.5</sub>



Total CO<sub>2</sub> Greenhouse Gas Emissions in the Year 2000, by Country



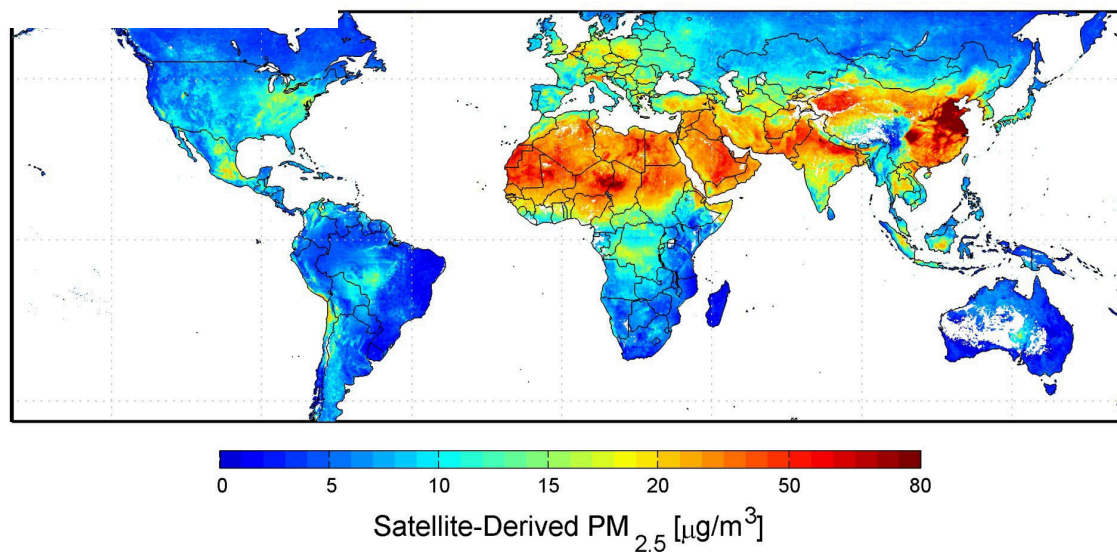
Data Source:  
Marland, G., T.A. Boden, and R. J. Andres. 2003. Global, Regional, and National Fossil Fuel CO<sub>2</sub> Emissions. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.



Maps produced by the Center for Sustainability and the Global Environment (SAGE)

## Global CO<sub>2</sub> Concentrations

## Global PM<sub>2.5</sub> Concentrations





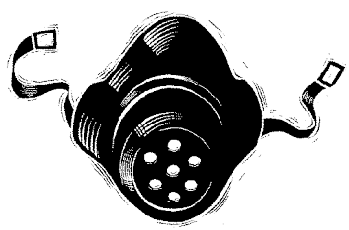
- How do we understand this science?



## **A throw back in time...** **Storm over Asian Brown Cloud (ABC).....**



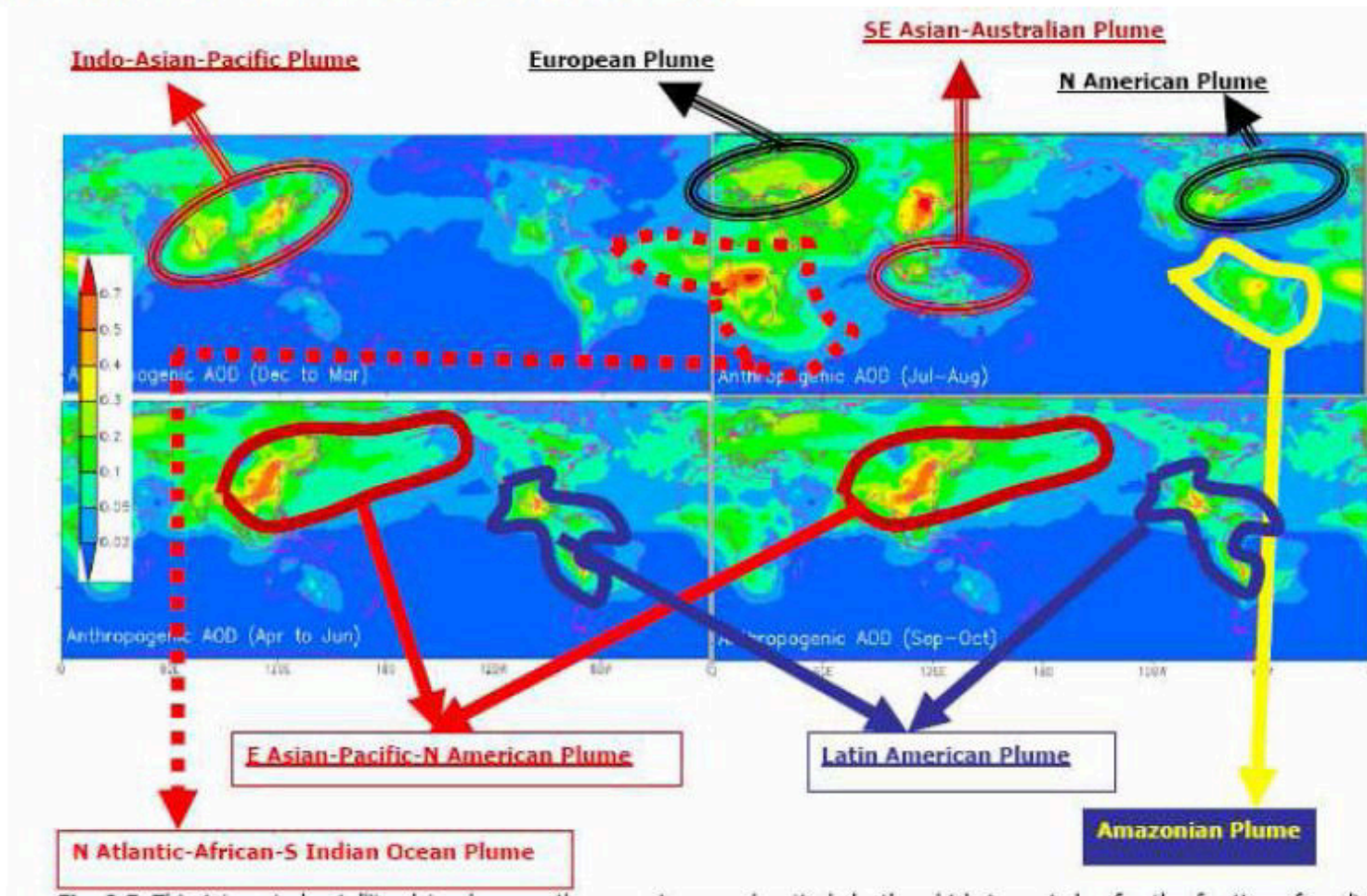
- **UNEP study on Asian Brown Cloud (2002)..... -- ---**  
Pollutants and aerosols from biomass burning and industrial emissions formed a three km thick brown layer over Asia ... disrupting rainfall and wind pattern....This can reduce solar radiation over the ocean, reduce evaporation and rainfall...
- **Raging controversy.... Strong reaction in India....** This is winter haze, effect of global cooling due to sulphate aerosols was not considered, etc....
- **Since then.....**



# The term Asian Brown Cloud replaced with Atmospheric Brown Cloud (ABC) More plumes traced.....



## SEASONAL MEAN ANTHROPOGENIC AODs

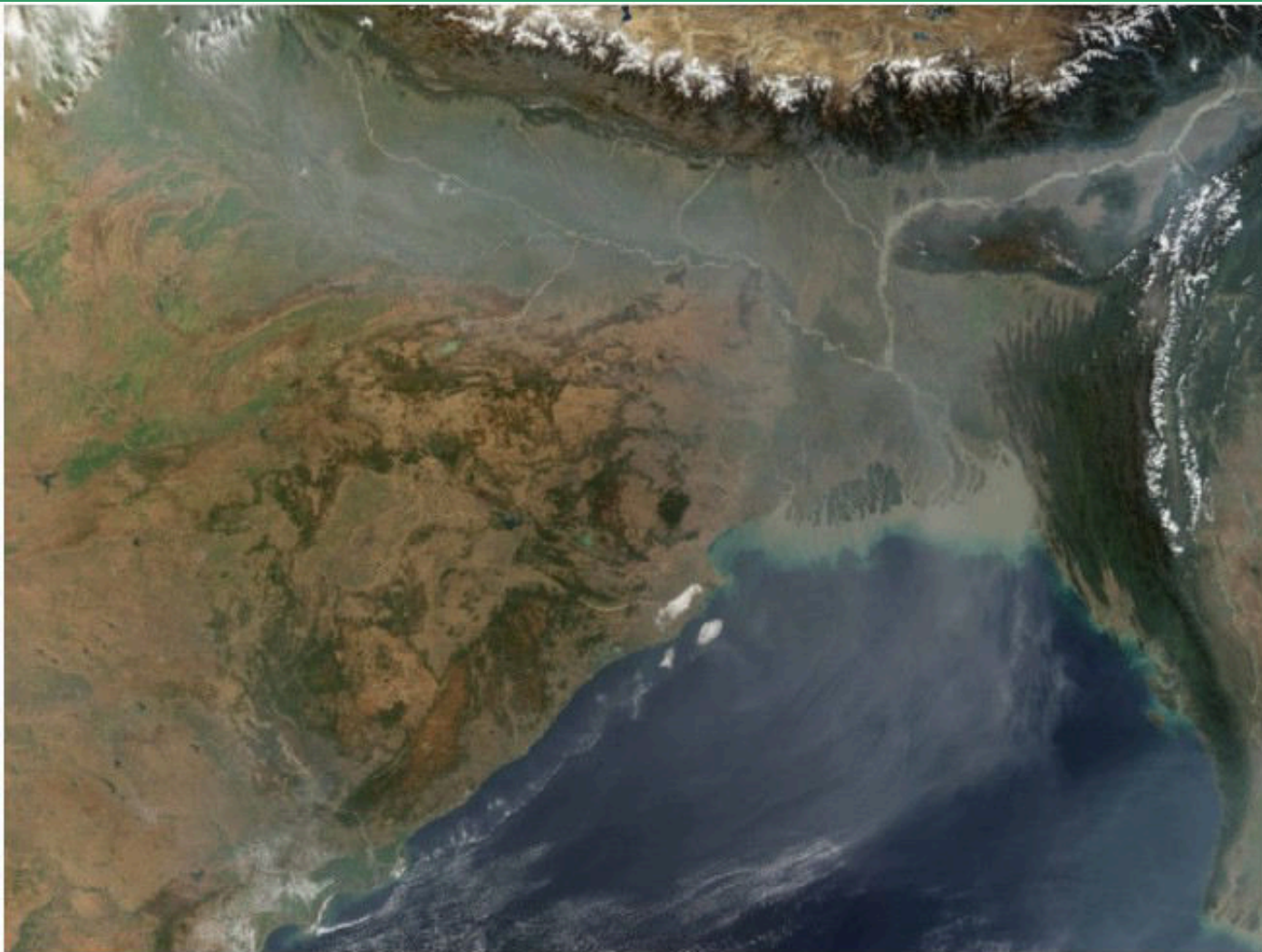


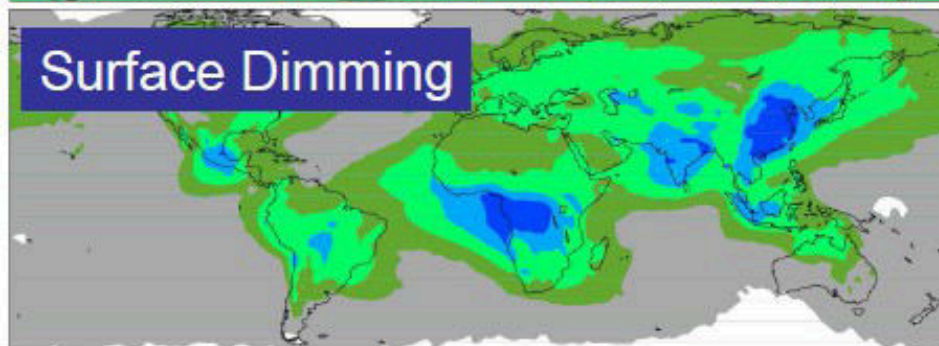
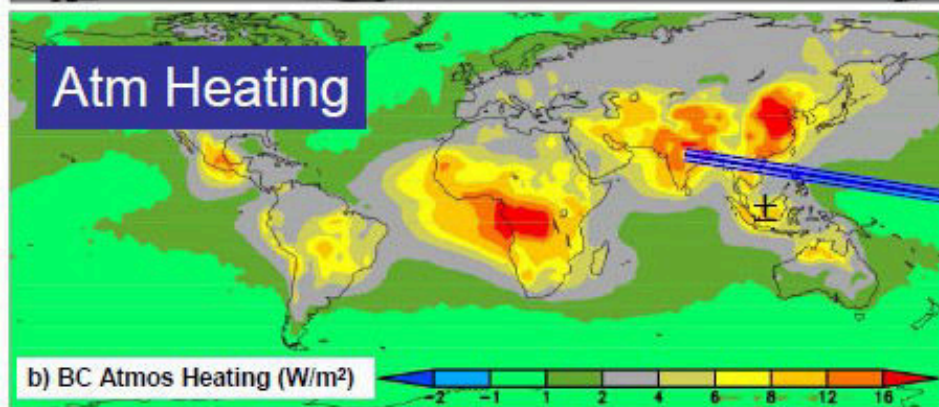
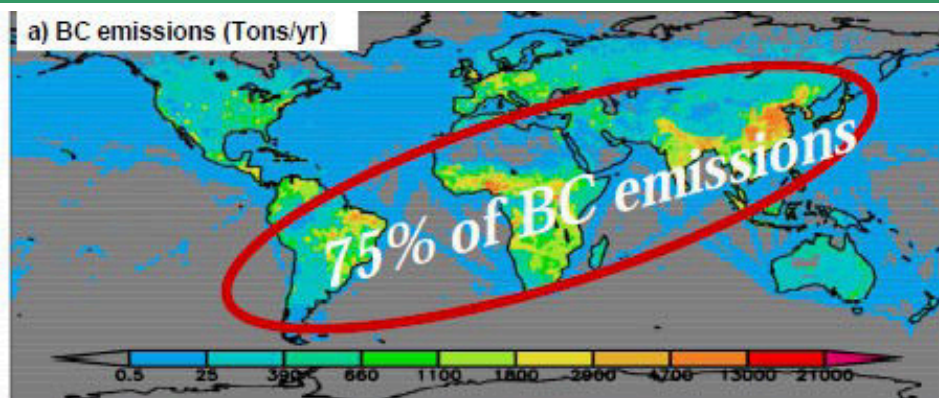




# More images of haze.....

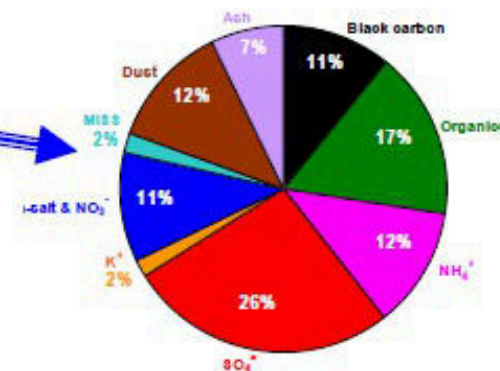
## NASA 2006, Haze over the Ganges Delta





## ABCs: Emission & Global Forcing

*Ramanathan and Carmichael, Nature\_Geoscience 2008*



Ramanathan et al, 2001

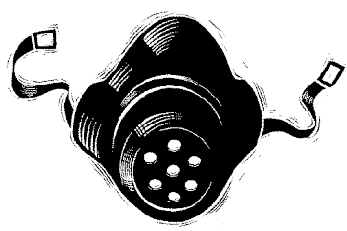


# Triggered Indian studies as well.....



- **Indian scientists have also started assessing the problem -- Physical Research Laboratory, Indian Institute of Science etc.....**
  - Large reduction of surface solar radiation due to dust – a lowering of atmospheric warming...
  - Studies in Indo Gangetic plain... Significantly high aerosol mass concentration, measurements of constituents of the mass and variability, study impact on climate concentrations during haze events, properties and sources of aerosols
  - Difference in natural and anthropogenic aerosols and their impact on radiative forcing... Impact of aerosols on rain
  - Aerosols reduce the heating of the earth's surface as they decrease the amount of solar energy reaching the surface by absorbing or scattering it...reduces evaporation...aerosol mass makes smaller droplets, less rain etc, etc.....

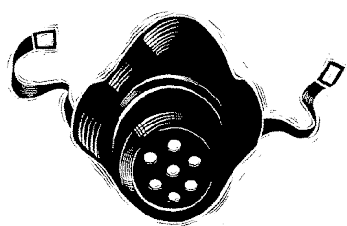




## Complex science.....



- **There are good and bad aerosols .....  
some warm while some cool**
- Some aerosols like sulphates also have cooling effect – The proportion of light scattered by aerosols to that absorbed determines their warming and cooling influence..
- **From public health perspective all are bad**

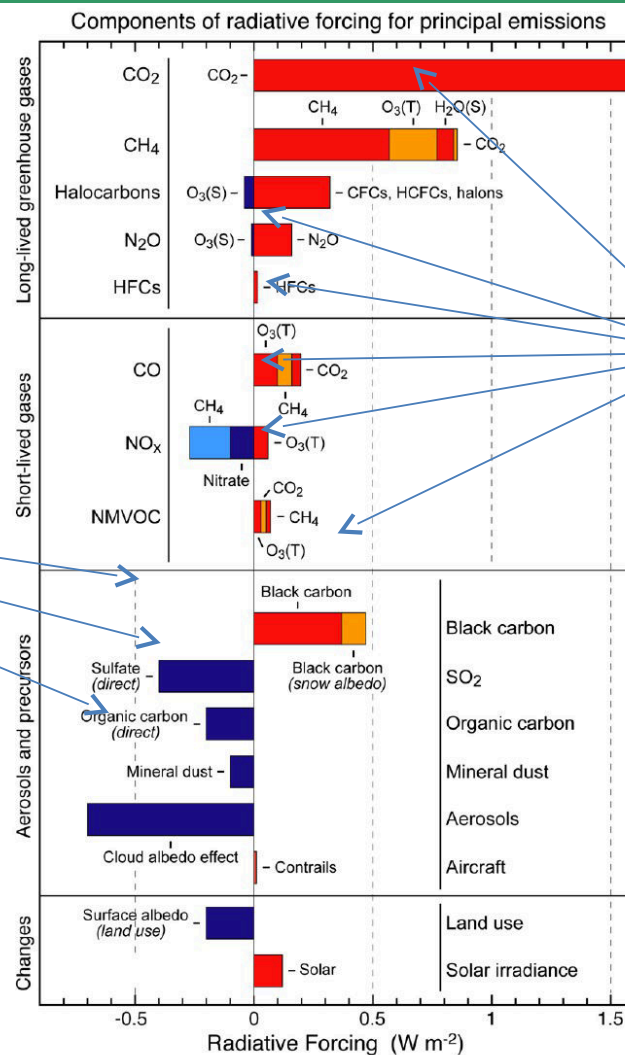


# Some cool and some warm..... Global Radiative Forcing Since the Industrial Revolution



Sulfate Aerosols  
Organic Carbon  
Clouds  
"Good" SLFs

Tropospheric  $O_3$   
Black Carbon  
Methane  
F-Gases  
"Bad" SLFs



**Figure 2.21.** Components of RF for emissions of principal gases, aerosols and aerosol precursors and other changes. Values represent RF in 2005 due to emissions and changes since 1750. The uncertainties are given in the footnotes to Table 2.13.





# Mix of cooling and warming PM varies in different sources of pollution



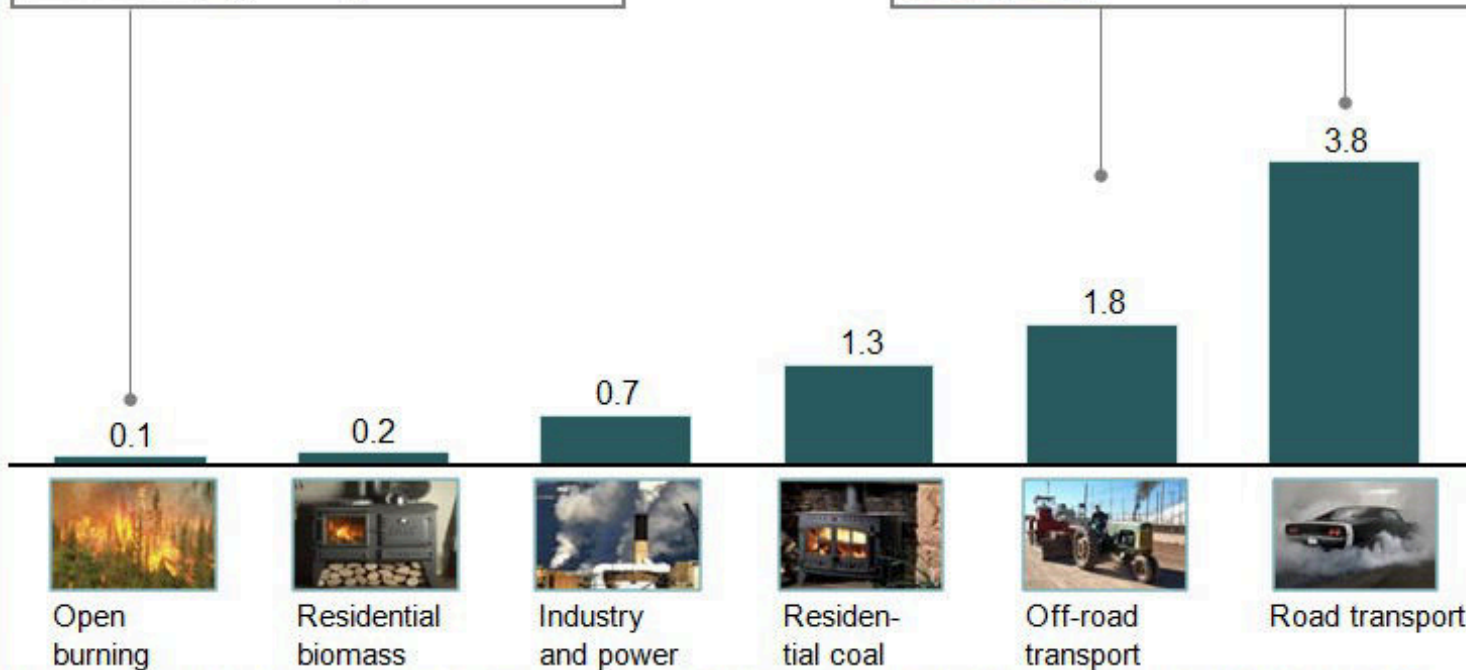
## Ratio of black carbon to organic carbon



Smoke from open burning of biomass or wildfires appears gray because of the high ratio of OC which scatters sunlight and therefore appears light colored

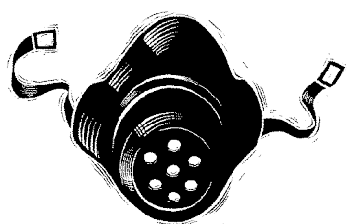


Soot from diesel combustion appears black because of its high content of black carbon, the light-absorbing component of aerosols

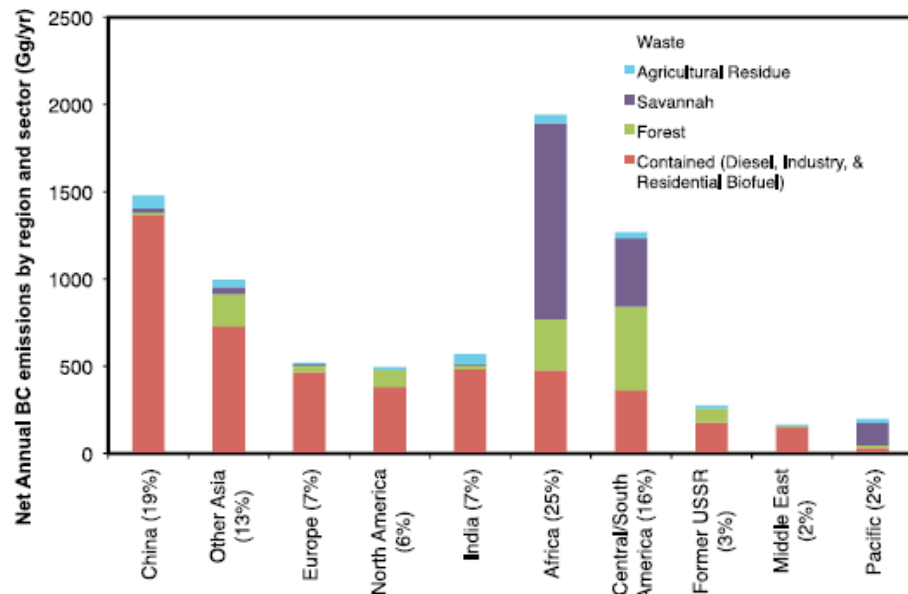


Note: All sources emit significant quantities of other pollutants that may warm or cool the climate, including CO<sub>2</sub> (warming), NO<sub>x</sub> (ozone and N<sub>2</sub>O warming, nitrate cooling), and SO<sub>2</sub> (sulfate cooling)

SOURCE: Non-CO<sub>2</sub> Climate Forcers Report (2010), Bond (2007), GAINS

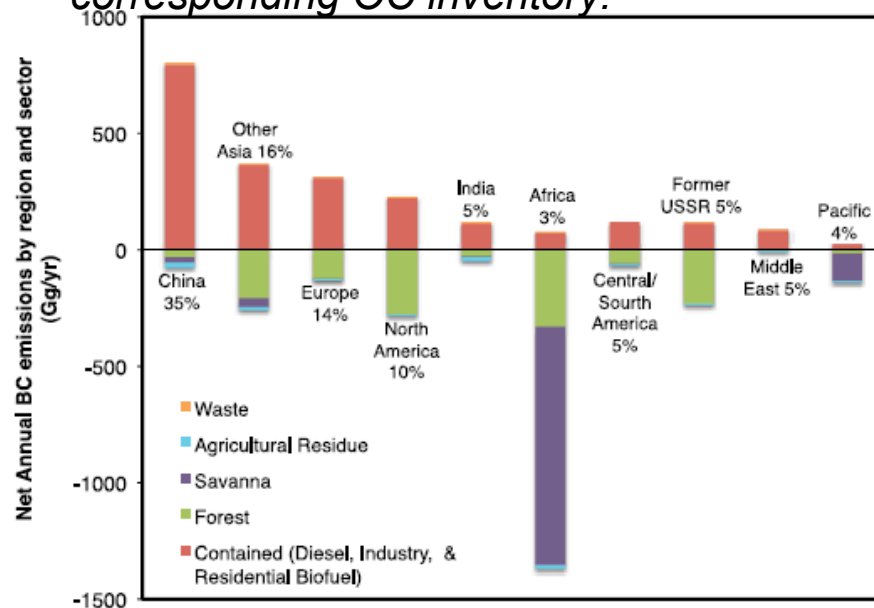


# This science influence the position of regions Quantum of aeorsols and their sources – region- wise.....



**Gross annual BC emission by region and sector: Region of North America excludes Mexico while Pacific region includes Japan. Efforts Emphasize Air Quality Co-Benefits**

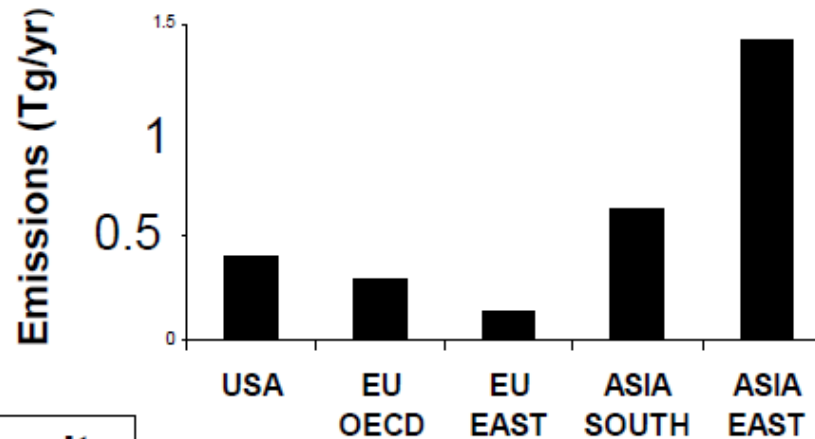
**Net annual BC inventory by region and sector: BC inventory is offset by corresponding OC inventory.**



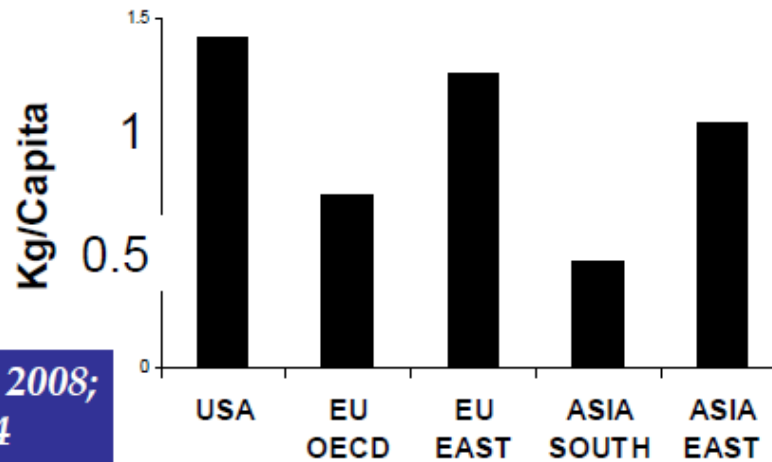


# Relative position

**BC emission**



**BC Emission/Capita**



*Ref: Ramanathan and Feng, 2008;  
Data source: Bond et al 2004*



- The big worry --- Effect on glaciers and snow.....accelerates melting...



## BC Impact on the Arctic

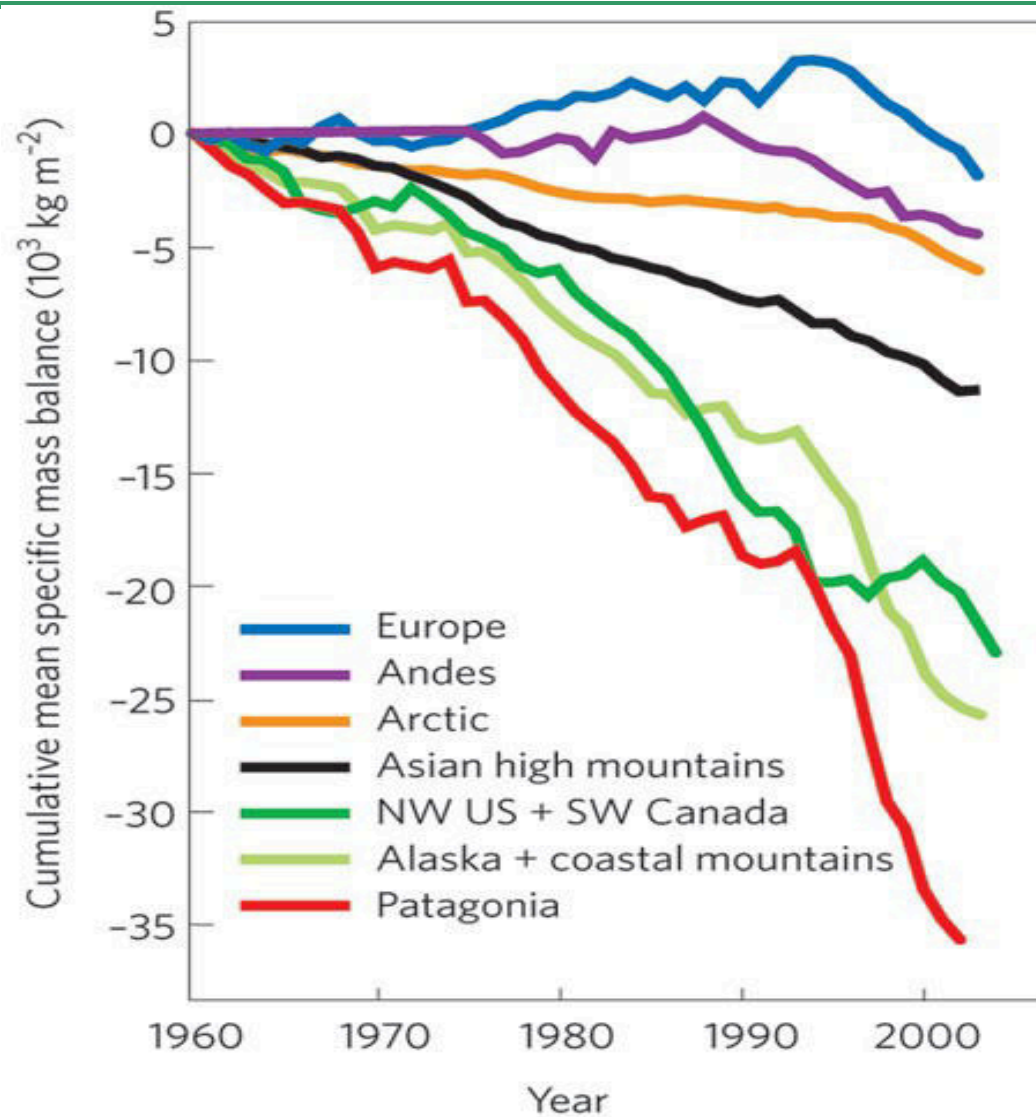


BC responsible for 50% or nearly  $1.0^{\circ}\text{C}$  of the  $1.9^{\circ}\text{C}$  temperature increase in the Arctic from 1890 to 2007 (Shindell, Faluvegi 2009)





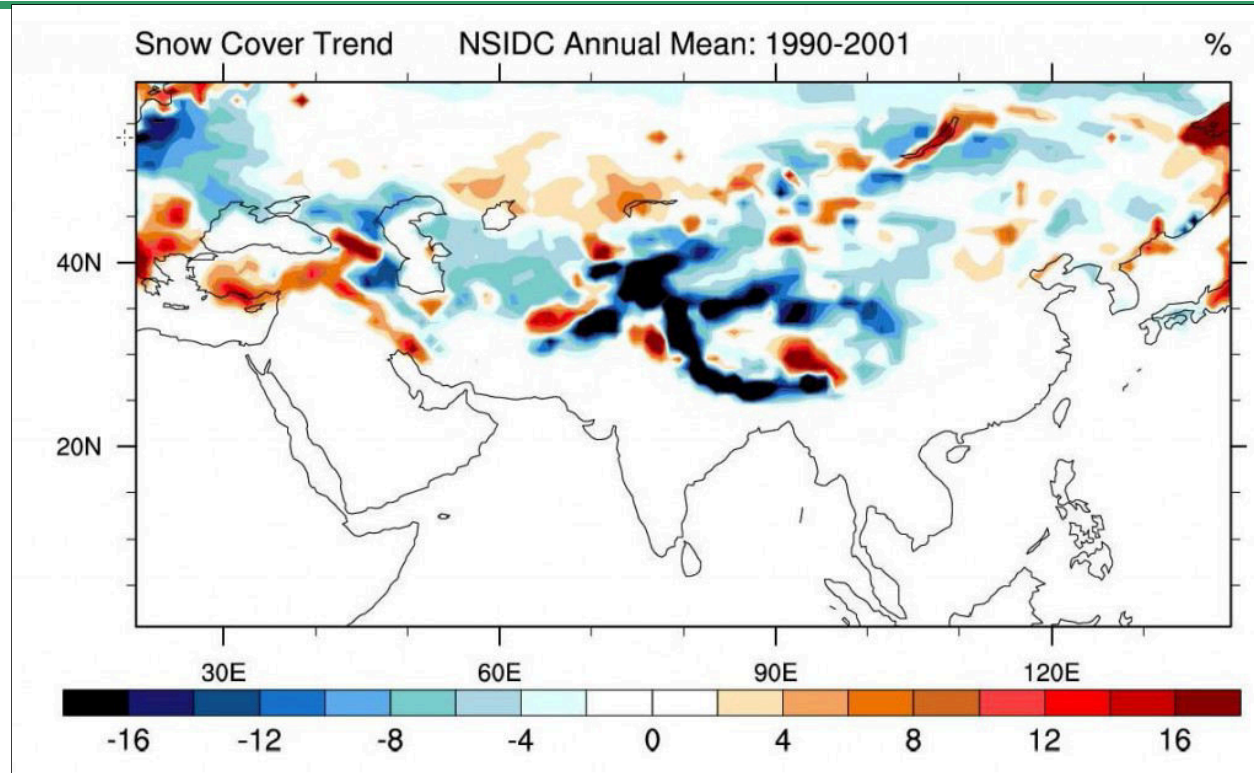
# Glaciers at Risk



Source:  
Nature Magazine  
March 10, 2010



# Himalayan Snow Cover Trend



The thick blue band across the Himalayas shows snow cover declining by at least 16 percent.

Source: Surabi Menon, LBL



# Soot and glacial melt

## Linking to Gangotri receding



The IPCC notes that the Himalayan glaciers, the source of water for billions of people in the region, are retreating faster than in any other part of the world and are in danger of disappearing by 2035.

(Cruz et al., 2007). Credit: NASA EROS Data Center,  
September 9, 2001

**Doubts....** Indian scientists have questioned the findings on the soot and the Himalayan glacial melt theory ... Claim soot's impact on tropical climate is complex... requires better assessment and measurements... (J Srinivasan et al....)

More studies underway...31.....



**If local action on air pollution control can control black carbon, why do we need a climate approach towards black carbon?.....**

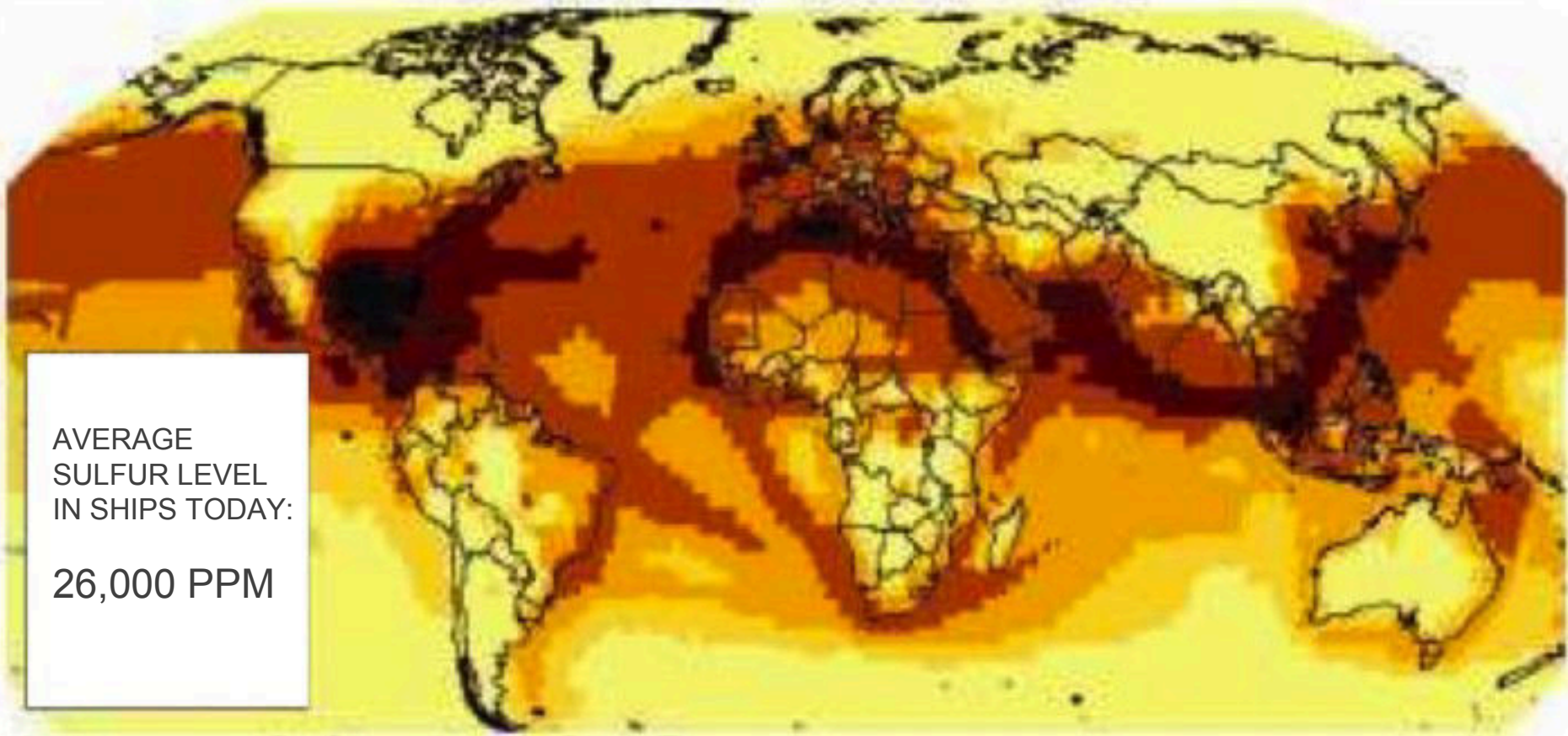
**Only public health approach cannot help to address widely dispersed pollution sources..... This action is limited to cities and towns and industrial areas.....**

**Emissions from ships, brick kilns, scattered burning are more dispersed.....**





## Particulates follow the world's shipping lanes





**A twist in the story.....**



## If you clean up local air pollution, warming may actually increase



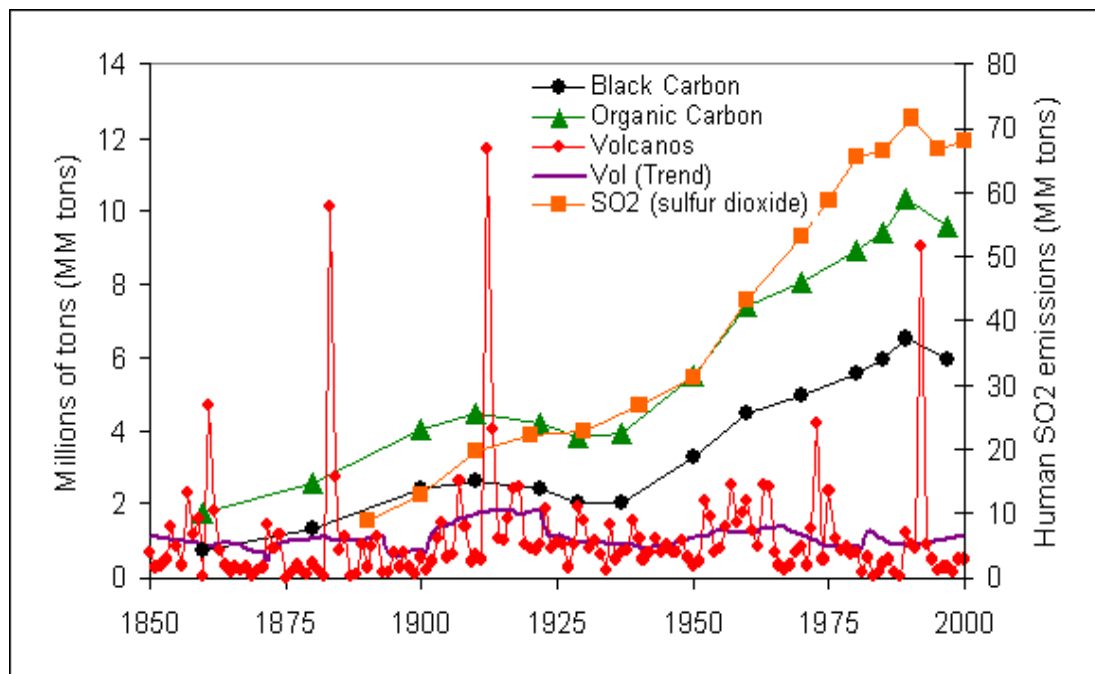
### Unmask warming

- Cleaning up dirty air would slow down the rate of warming, but would also unmask the 'committed' warming that has already occurred due to accumulated emissions of long-lived GHGs like CO<sub>2</sub>.
- All of the warming has not shown up fully yet because of the cooling aerosols. **Currently, roughly 40 per cent of the committed warming is masked by the cooling aerosols (Ramanathan).**
- Scientists warn that a great part of this masked warming is expected to unfold during the 21st century, as air pollution laws across the world take effect and the cooling effect of aerosols is unmasked.





## Sulphates and organic compounds that cool the atmosphere are declining.....



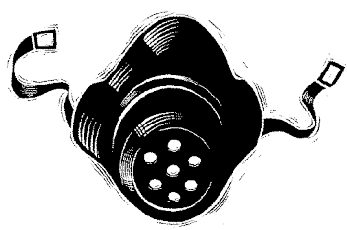
Source: Michael Alexander, Cornell University

SO<sub>2</sub> and OC are **cooling**.

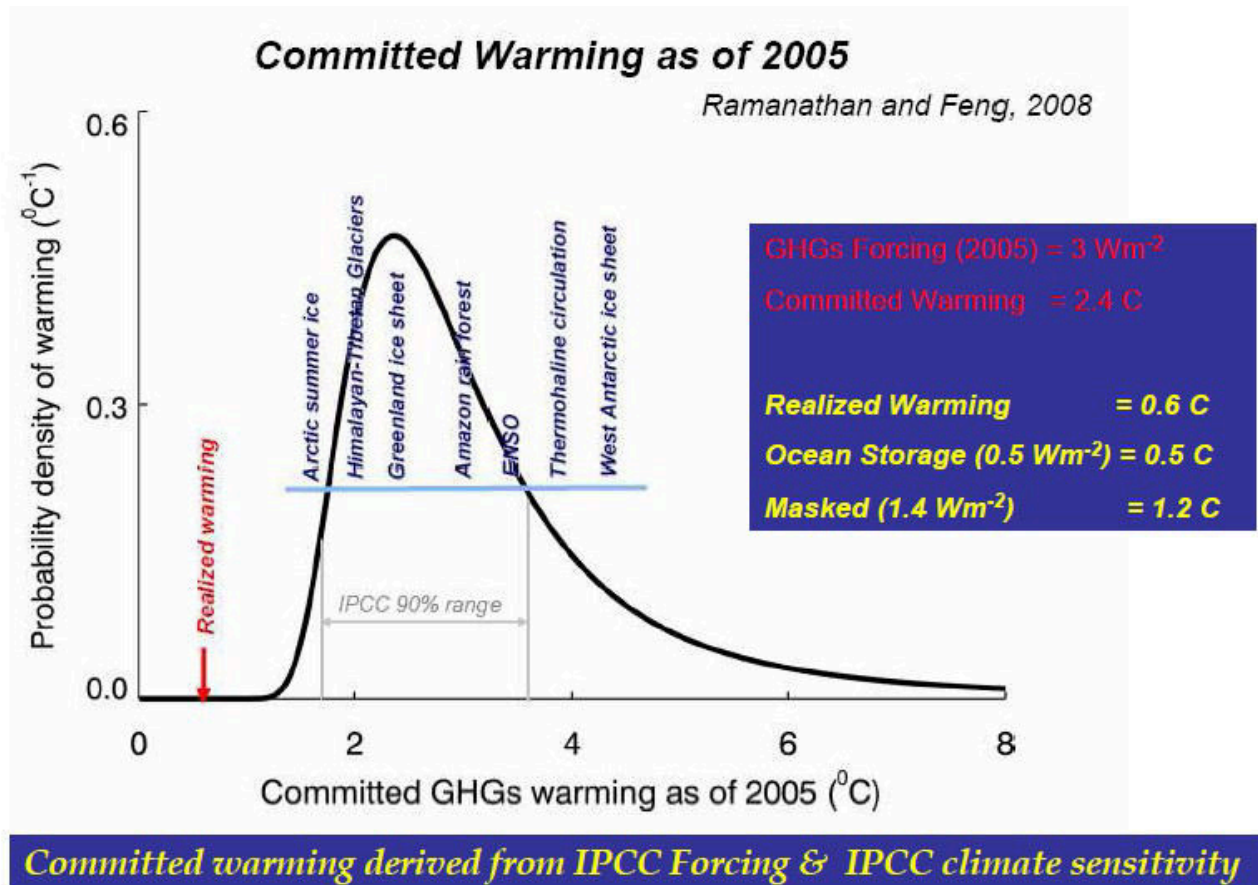
They also contribute to cloud formation (which is called AIE – aerosol indirect effects); amplifying **total cooling**.

BC is **warming**. Its effect on cloud formation is very uncertain, but scientists believe the combination of BC and AIE is **net warming**. When deposited on ice or snow, BC accelerates melting. This is called the “albedo” effect and it is also **warming**.

All aerosols taken together exert a **net cooling** effect.



# Risk of more warming if local air pollution eliminated.....





# Yet another view -- Balancing the Climate Scale on a Global Basis



## Lost Cooling:

Up to  $-2.0 \text{ W/m}^2$   
if  $\text{SO}_x$  emissions  
were eliminated

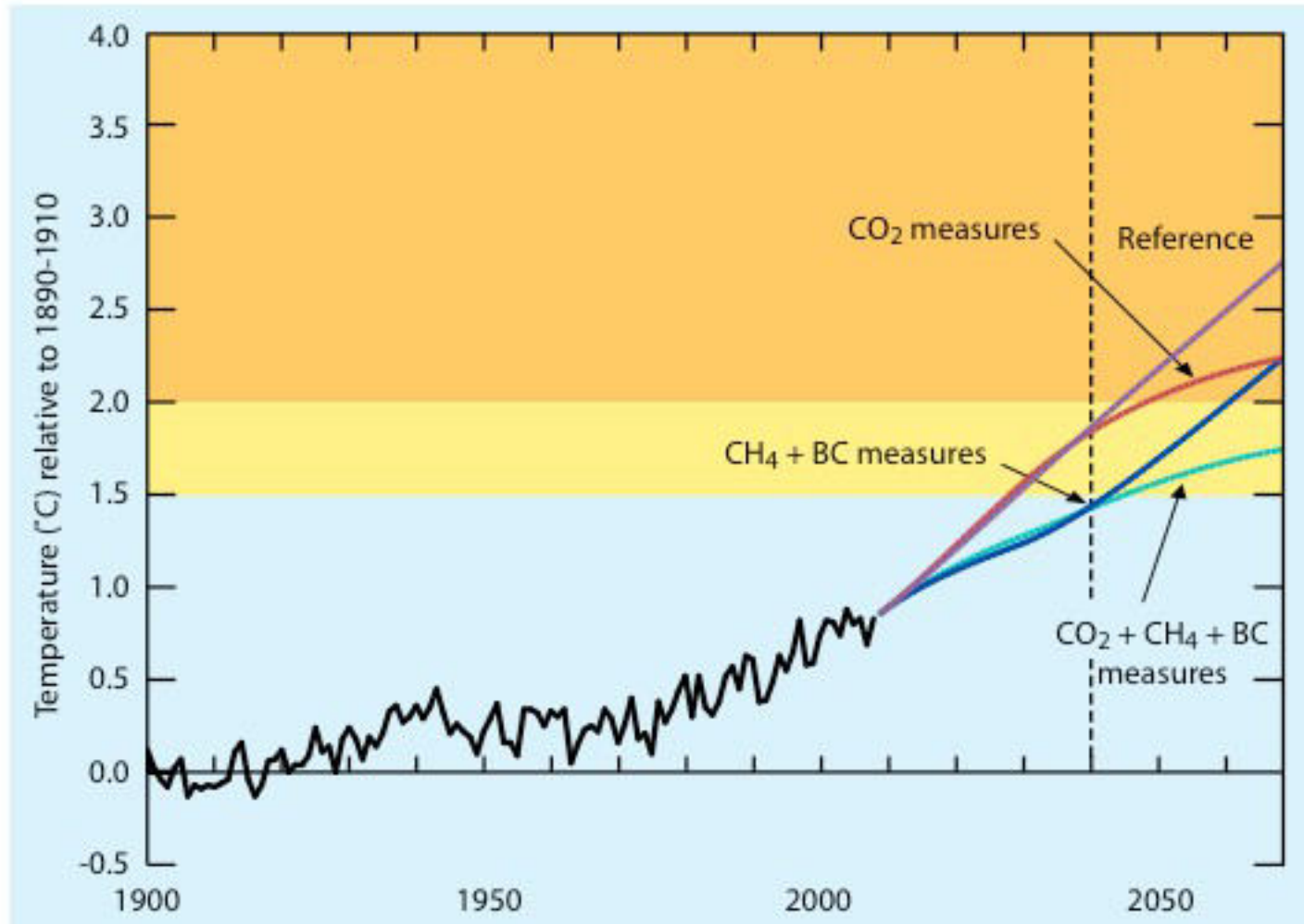
## Avoided Warming:

Up to  $1.8 \text{ W/m}^2$   
if BC, methane and  
ozone precursors  
were eliminated





# Temperature change with and without mitigation



UNEP/WMO, 2011-- BC and methane measures between 2010 and 2030, with measures to reduce carbon dioxide, would improve the chances of keeping the Earth's temperature increase to less than 2°C relative to pre-industrial levels. The uncertainty of the temperature projections in 2070 is shown by the lines on the right (UNEP, 2011)



## What are the uncertainties?

The scientists are saying the estimates of BC warming are being revised upward now as methods have improved. **There is more certainty about the effect of BC**

But..., the uncertainty remains relatively large for the cooling and cloud effects. This has to do with co-emitted organic aerosols.

**But key sources of BC like diesel, brick kilns and fossil coal burning in cook stoves can be addressed for BC emissions without worrying whether this will also cause cloud cooling.**

**The science has removed the uncertainty around the climate benefits of reducing diesel black carbon.**





## 'BC Measures' that reduce emissions of black carbon and co-emissions (e.g. OC, CO)

- Diesel vehicles (particle filters+)
- Coal briquettes replacing coal in residential stoves
- Pellet stoves & boilers replacing residential wood burning in industrialized countries
- Clean-burning cookstoves in developing countries
- Modern brick kilns
- Modern coke ovens
- Ban of open burning of agricultural waste



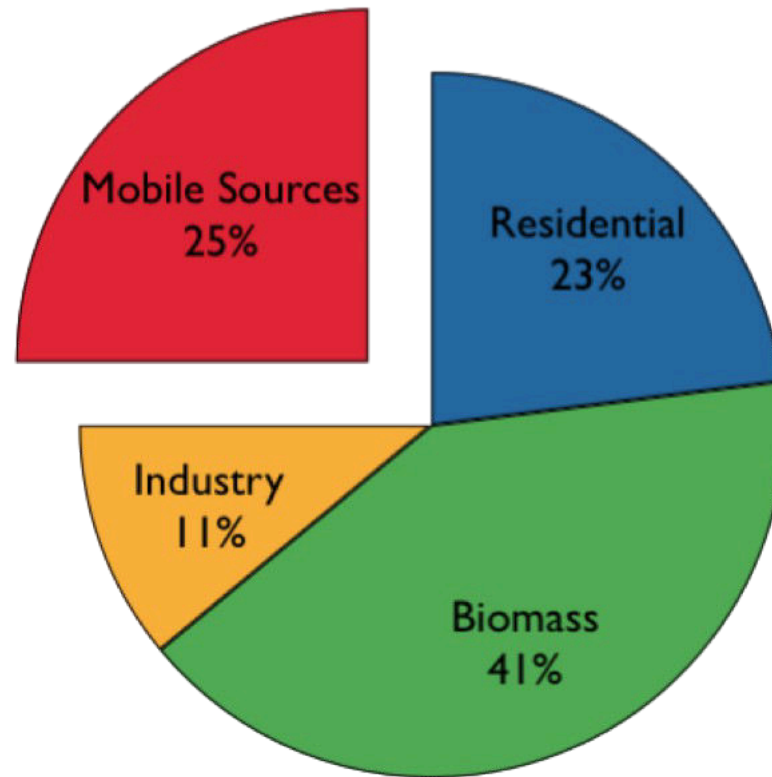




**Strong focus on transport and diesel.....**



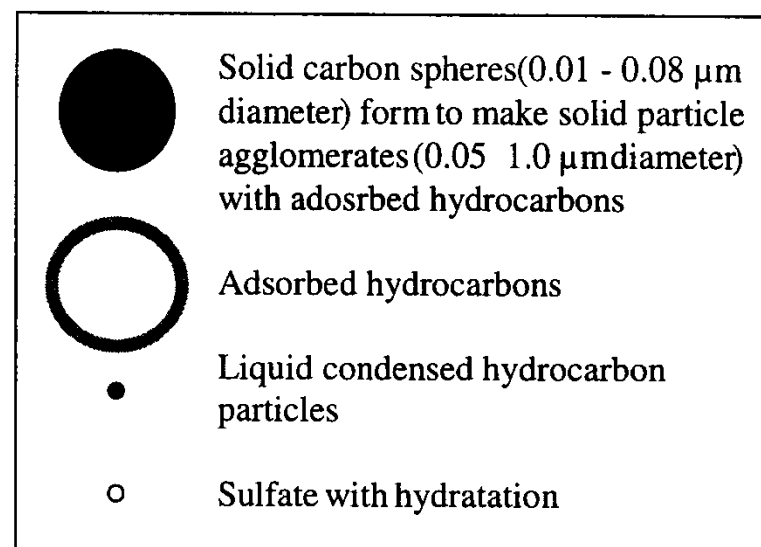
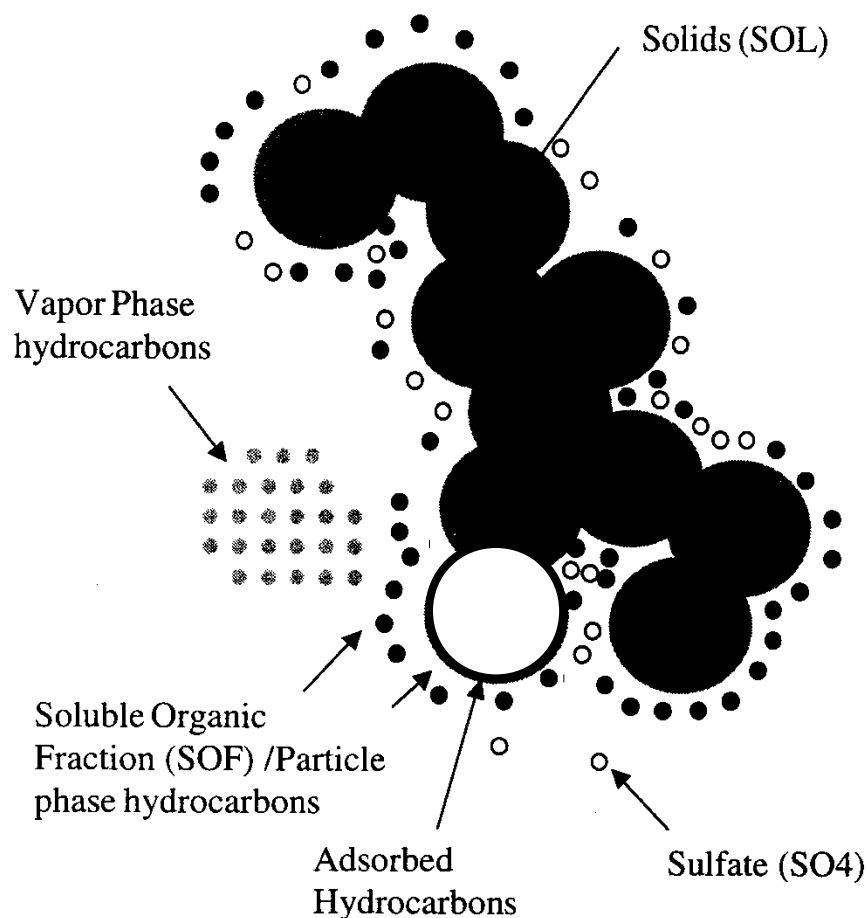
## Mobile Sources Are Responsible For ~25% Of Global Black Carbon Emissions





# Black carbon and diesel

## Black Carbon is the Core of Diesel PM





# ....removing BC gives positive climate benefit Example from Delhi

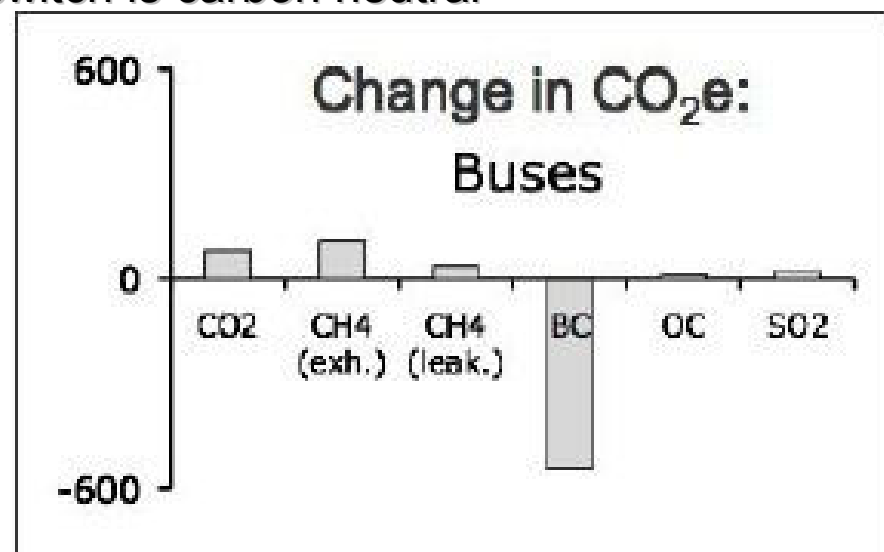


## Delhi CNG programme

New study shows that in comparison with the warming potential of black carbon emissions from the older diesel fleet, CNG has been less warming.....

-- When black carbon from diesel is not considered estimated CO<sub>2</sub> (e) increase due to switch

-- When black carbon is taken into account -- switch is carbon neutral  
Upto 30% reduction in CO<sub>2</sub> (e)





# Why diesel makes us climate insecure?

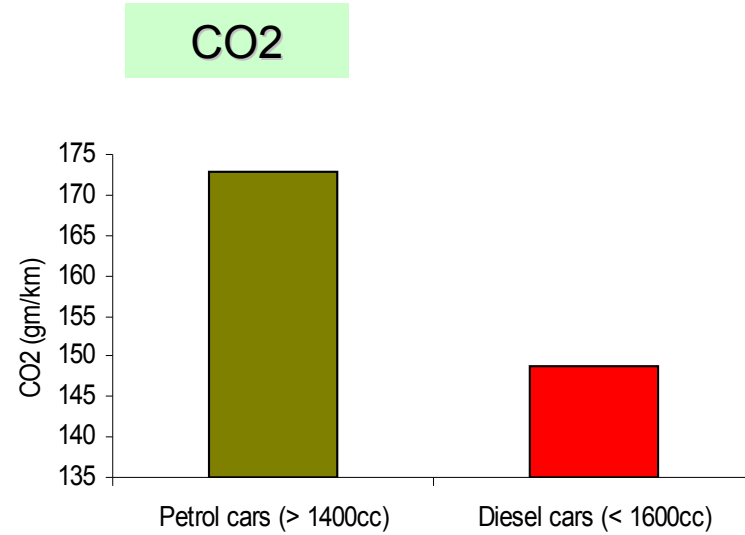


**Rebound Effect:** Diesel fuel has higher carbon content than petrol. If more diesel is burnt encouraged by its cheaper prices and more driving, more heat-trapping CO<sub>2</sub> will escape.

**Black carbon emissions from diesel vehicles are several times more heat trapping** than CO<sub>2</sub>

**CO<sub>2</sub> emissions from the upstream diesel refining process will increase:** European Commission has found lifetime pollution costs of Euro IV compliant diesel car is much higher than petrol cars.

**This nullifies the marginal greenhouse gas reduction benefit of diesel car and costs higher to the society.**





## **Current level of diesel technology in India cannot help.....**



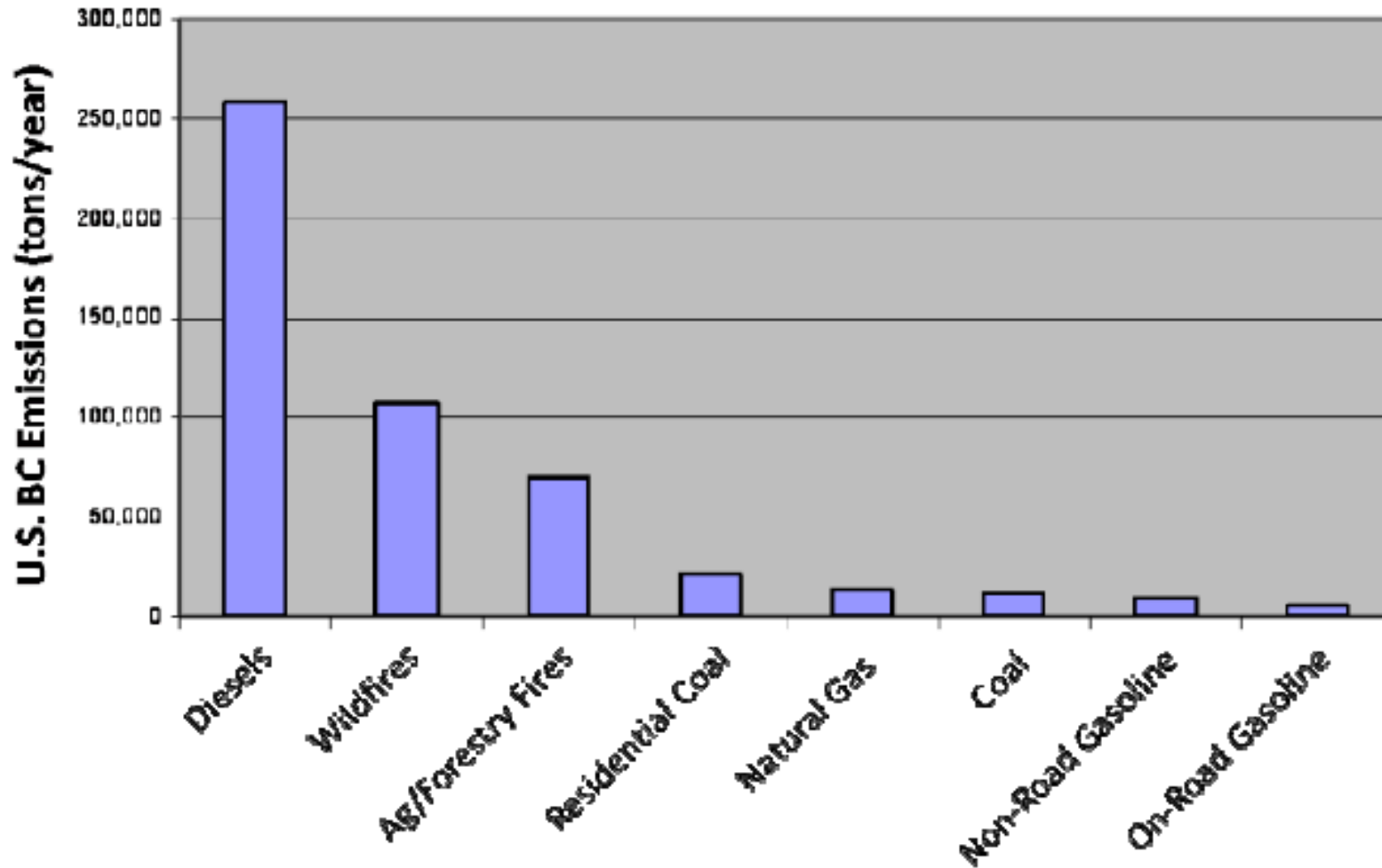
Even under Euro IV particle standards, diesel vehicles may still warm the climate for well over the next 100 years (Jacobson's assessment)

And even if the most stringent California standards were introduced worldwide, diesel may still warm the climate more than gasoline cars for 13 to 54 years.





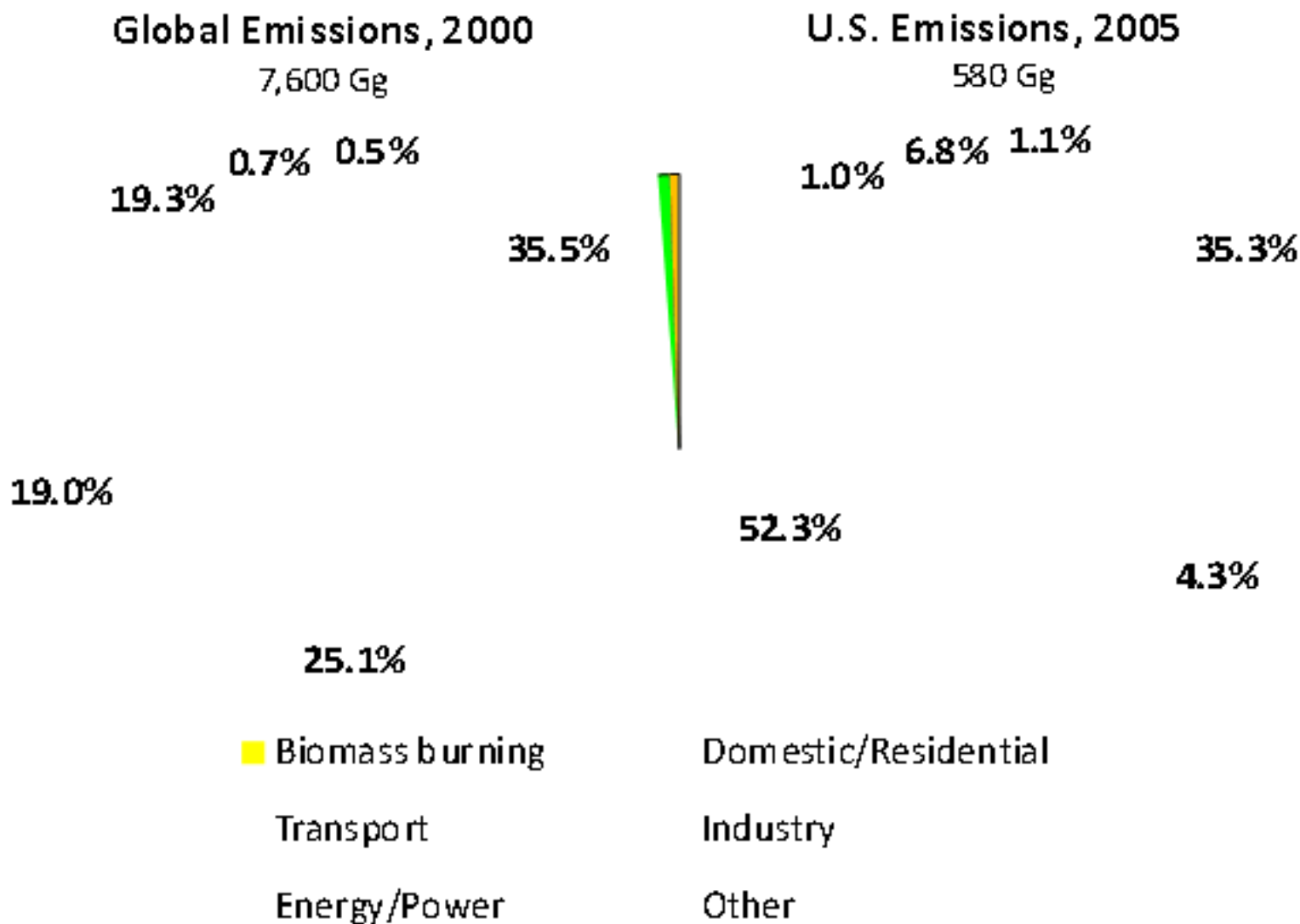
## Even US's biggest BC challenge is diesel



BC regulations emerging in California..



**Even US.....!!!!!!!**





**Global positioning????**



## **Intense global discussions.....**



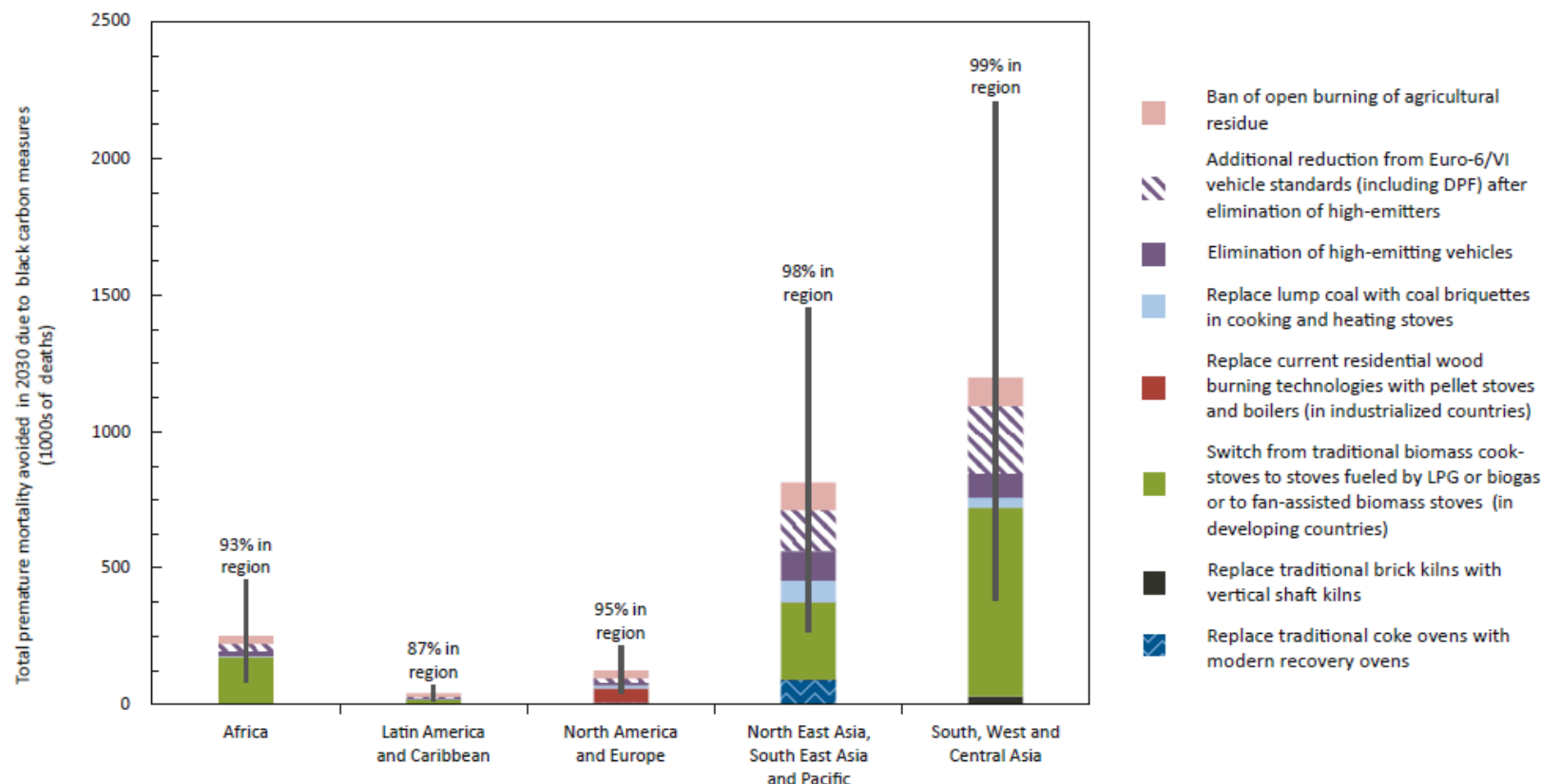
**IPCC report of 2014 is expected to include BC science and mitigation strategies**

**Spurt of studies globally to propagate co-benefit science, that addresses health and climate concerns together....**

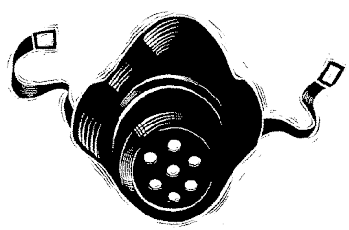
- UNEP Integrated Assessment of Black Carbon and Tropospheric Ozone
- Convention on Long-Range Transboundary Air Pollution (CLRTAP)
  - Black Carbon Expert Group
  - Gothenburg Protocol Negotiations
- U.S. EPA Report to Congress on Black Carbon...



# Co benefits: The main mantra



**UNEP report** -- The annual reduction in premature deaths from the implementation of different black carbon measures in each region in 2030. The percentage given above each bar indicates the proportion of avoided deaths from outdoor air pollution in region that implements the measures. Vertical grey bars indicate the uncertainty range in the mortality figures



## UNEP report foreshadows the emerging trend .....



- **UNEP report 2012 Proposes 16 measures for BC and methane emissions ... It states:**
  - About half of the 0.4 degree C climate benefit in 2050 comes from implementing BC measures – mainly in Asia and Africa – and other half from methane measures in Asia, Europe, North America.
  - In N America and Europe largest climate benefit from methane emissions from coal mining, oil and gas production, and better management of municipal waste...
  - Although reduction in SLFs substantially slow the rate of climate change over the next few decades... they will make modest contribution to longer term climate change ... Therefore reducing SLF complements but does not replace CO2 emissions reduction.....

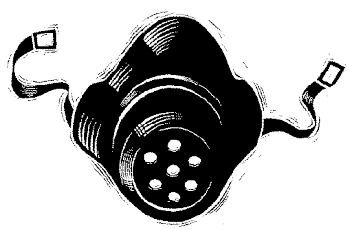




## A call for multi-tiered action.....



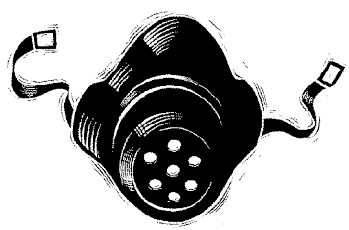
- **UNEP report proposes:**
  - **National efforts**
  - **Regional air pollution agreements, organisations and initiatives**
  - **Global action** to support national and regional initiatives – through existing institutional arrangements, ensure adequate financial support, enhance capacity, and provide technical assistance at the national level...



## Black Carbon Mitigation Measures: part of 16 measures of UNEP



- **Diesel Engines** – particulate filters on all on-road and off-road sources including cars, trucks, construction equipment, locomotives (note: requires low sulfur fuel  $\leq 50$  ppm, ideally  $\leq 15$  ppm)
- **Marine vessels** – slow speed shipping, cleaner fuel, slide valves, emulsified fuel, particulate filters, scrubbers
- **Brick kilns** – improved firing techniques, better fuel quality, exhaust after-treatment, hollow bricks, alternative building materials
- **Coke ovens** – higher temperature combustion, cleaner fuels, possibly exhaust after-treatment
- **Cook stoves** – fan equipped biomass stoves, briquettes instead of raw coal, natural gas where available
- **Forest, grassland and agricultural burning** – reduce as much as possible, particularly in areas near ice or snow



## Emerging multilateral mechanism?



- **Kyoto protocol is not being discussed as the mechanism for BC mitigation**
- **A group of countries under the newly titled Climate and Clean Air Coalition created** – a separate and distinct international forum, governance structure and funding mechanism to pursue short term climate forcers mitigation...  
UNEP is a partner and the secretariat
  - A lot will depend on the member countries that have the powers to decide – India is not a member yet. Right now its only a workshop based approach. Most of developing world is out of it.....
- **Specific initiatives on heavy duty diesel BC (also brick kilns etc)**
- **International maritime organisation exploring controls of international maritime BC etc**



# Whither India?



Wait and watch.....

Ministry of Environment and Forests has initiated black carbon study.....

National Climate Action Plan has taken on board the principle of co-benefits: Stringent action on air quality can give co-benefits

National Mission on cook stoves has included black carbon mitigation as one of its objectives



## Concerns that will shape black carbon diplomacy.....



The new science can spur action in the developing world if it does not fall victim to the political tug-of-war on the negotiating table.

Caution against using this science to change the geo-politics of the climate debate, shifting blame to the poorer countries to buy more time to meet CO<sub>2</sub> reduction targets.

**Science is clear -- Action on air pollution/black carbon can be complementary but not a substitute for cutting down CO<sub>2</sub>.**

CO<sub>2</sub> is the largest positive forcing agent. Any delay in CO<sub>2</sub> emissions reductions extends its climate impacts...

**Get proactive... Set the terms of debate and action right now.....**



**Thank you**