Black carbon forcing and its climate effects
V. Ramanathan, Scripps Institution of Oceanography
UC San Diego
International Workshop on Black Carbon
London 5-6 January 2009

The blanket of manmade greenhouse gases that are surrounding the planet now is sufficient to push the climate system beyond the threshold level for iconic changes to the climate system.

It is in this context that short lived warming agents come into prominence: BC and Ozone
The principal conclusions and recommendations made by the conference are summarized in the paragraphs below:

1. *Current science emphasizes the urgent need to address air pollution and climate change in an integrated way.* We should no longer treat these two issues separately as we strive to achieve sustainable development and a low carbon society.

6. *Ground-level ozone and black carbon aerosols are both air pollutants and act as warming agents (see para. 8 below). Methane is a precursor of ozone formation and a GHG.* Urgent action to decrease their concentrations in the atmosphere could provide opportunities, not only for significant air pollution benefits (e.g. health and crop-yield benefits) but also for rapid climate benefits by helping to slow global warming and avoid crossing critical temperature and environmental thresholds.
On avoiding dangerous anthropogenic interference with the climate system: Formidable challenges ahead

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Edited by William C. Clark, Harvard University, Cambridge, MA, and approved July 24, 2008 (received for review May 1, 2008)

The observed increase in the concentration of greenhouse gases (GHGs) since the preindustrial era has most likely committed the world to a warming of 2.4°C (1.4°C to 4.3°C) above the preindustrial surface temperatures. The committed warming is inferred from the most recent Intergovernmental Panel on Climate Change (IPCC) estimates of the greenhouse forcing and climate sensitivity. The

Global warming: Stop worrying, start panicking?

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n their excellent Perspectives article in this issue (1), Ramanathan and Feng (R&F) sound a harsh wake-up call for those concerned about anthropogenic climate change: the authors maintain that the greenhouse gas (GHG) and add the insights up in three disturbing conjectures:

(i) Our planet is already committed to anthropogenic warming in the range of 1.4–4.3°C, where 2.4°C is the most likely amount. The main reason why only

by masterly back-of-the-envelope reasoning. The paper performs a basically static thought experiment by pulling back the aerosol veil while keeping all other factors fixed. In the real world, some aerosol emissions will be harder to reduce than
Global Radiative Forcing due to GHGs & ABCs
Ramanathan and Feng, 2008

For high BC heating, also see: Jacobson, 2001; Hansen and Nazarenko, 2004; Chung and Seinfeld, 2005
IPCC-AR4 (2007) Concludes:

For a CO$_2$ doubling, the most likely climate sensitivity is 3°C warming with a 90% confidence interval of 2 to 4.5°C

For doubling of CO$_2$, TOA forcing is : 3.7 Wm$^{-2}$

So it takes about 1.25 Wm$^{-2}$ (3.7/3) to warm the planet by 1°C

The GHGs so far have added 3 Wm$^{-2}$ forcing

The committed (or the inevitable) warming is 2.4°C
Committed Warming as of 2005

Ramanathan and Feng, 2008

GHGs Forcing (2005) = 3 Wm$^{-2}$
Committed Warming = 2.4°C
Realized Warming = 0.6°C
Ocean Storage (0.5 Wm$^{-2}$) = 0.5°C
Masked (1.4 Wm$^{-2}$) = 1.2°C

Committed warming derived from IPCC Forcing & IPCC climate sensitivity
Detecting Climate Change due to Increasing Carbon Dioxide

Roland A. Madden and V. Ramanathan

The possible climatic effects of large increases in atmospheric CO₂ due to burning of fossil fuels may constitute one of the important environmental problems of the coming decades. Research efforts are being made to reduce the large uncer-

We first discuss a long time series of surface temperatures and the rationale on which our estimates of the inherent variability or noise are based. Next we present the model results for surface warming due to the CO₂ increase. By

Summary. The observed interannual variability of temperature at 60°N has been investigated. The results indicate that the surface warming due to increased carbon dioxide which is predicted by three-dimensional climate models should be detectable now. It is not, possibly because the predicted warming is being delayed more than a decade by ocean thermal inertia, or because there is a compensating cooling due to other factors. Further consideration of the uncertainties in model predictions and of the likely delays introduced by ocean thermal inertia extends the range of time for the detection of warming, if it occurs, to the year 2000. The effects of increasing carbon dioxide should be looked for in several variables simultaneously in order to minimize the ambiguities that could result from unrecognized compensating cooling.
Data Source: G. Marland, T.A. Boden, R.J. Andres, and J. Gregg at CDIAC

- **1990 - 1999**: 0.9% y\(^{-1}\)
- **2000 - 2007**: 3.5% y\(^{-1}\)

2007 Fossil Fuel: 8.5 Pg C
Carbon-based power consumption reduction to stabilize CO$_2$

2007 Carbon emission: 8.5 Gtons/Yr as CO$_2$

At fixed emission, by 2030 we will add: 108 Gtons

If we reduce emission by 50% by 2030, We will still be adding: 81 Gtons

With increasing population (to 8.5 Billion) and increasing demands for transportation by the rapid increase in middle class, N$_2$O and Ozone will also likely increase (barring continued economic collapse into 2050).
Global Radiative Forcing due to GHGs & ABCs

Ramanathan and Feng, 2008

For high BC heating, also see: Jacobson, 2001; Hansen and Nazarenko, 2004; Chung and Seinfeld, 2005
Leveraging with Short lived air pollutants
Ramanathan, 2008

<table>
<thead>
<tr>
<th>Condition</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHG only</td>
<td>2.4</td>
</tr>
<tr>
<td>GHG + ABCs</td>
<td>1.3</td>
</tr>
<tr>
<td>w/out BCs</td>
<td>0.6</td>
</tr>
<tr>
<td>w/out BC + Ozone</td>
<td>0.3</td>
</tr>
</tbody>
</table>

GHGs+Non-BC

GHGs-Ozone+ Non-BC(SO4+others)
How should We Unmask the ABC Effect?

……..With great care. Same care we give for decommissioning thermonuclear devices.

SO₂ Emissions

[Bar chart showing SO₂ emissions for China, Germany, India, UK, and USA for 1990s and 2005.]

Research Funded by NSF; NOAA; California Energy Commission; Vetlesen Fndn

Ramanathan 2007
The wrong way to go
Ramanathan, 2008

Reduction of SO$_2$ increases the Urgency of CO$_2$ reductions.
Indian Ocean Experiment: An integrated analysis of the climate forcing and effects of the great Indo-Asian haze


J Geophysical Research, 2001
ABCs: How do they influence climate?

- The absorption of solar radiation by the surface and the atmosphere is the fundamental driver for the physical climate system, for atmospheric chemistry, and for all life on the planet.

- ABCs have altered this forcing significantly.

  - Reflects sunlight like mirrors and cool
  - Traps sunlight and heats the air
Sensitivity of Forcing to Aerosol Absorption

Podgorny and Ramanathan, 2001
Comparison with IPCC – GCMs

A detailed comparison of the field Observations with models have not been undertaken.

Summary of INDOEX and ABC data:

Absorption : 1 – Single Scattering Albedo

Observations :

0.05 < Absorption < 0.2

Models :

0.01 < Absorption < 0.1
TOA forcing may not tell the complete story of BC effects on Climate. Redistribution of the solar energy between atmosphere and surface may have a large effect on climate.

Figure 5. TOA (top), atmospheric (middle), and surface (bottom), radiative forcing for clear (solid line) and cloudy (shaded area) skies as a function of aerosol single-scattering albedo. Aerosol optical thickness is 0.4, cloud fraction is 25\%, and cloud optical thickness is 15. Solid black line and the other edge of the gray region represent the cases with aerosol above and below cloud (see Figure 1), respectively.
The heat is on

Atmospheric brown clouds enhance climate warming

INDOEX data from John Ogren;
Ref: Ramanathan et al, 2001
Fig. 8. Total particle concentration by altitude during MAC experiment (March 2006). The legend identifies flight numbers. The solid black line in the zero altitude plane shows the total particle concentration collected at the surface station.

Fig. 13. Black carbon concentration altitude profiles during MAC experiment (March 2006). Error bars are only shown for a single flight to keep the plot legible and are representative of all flights.
Field Sites

THD (107 m)

LAVO (1732 m)

CSSL (2100 m)

Annual Average Precipitation (Inc Northern California)

Period: 1961-1990

http://www.wrcc.dri.edu/pcpn/ca_north.gif
CFORS model vs. IMPROVE
(Hadley et al., 2007)
Black carbon or brown carbon? The nature of light-absorbing carbonaceous aerosols
M. O. Andreae1 and A. Gelencsér2
1Max Planck Institute for Chemistry, Biogeochemistry Department, P.O. Box 3060, 55020 Mainz, Germany
2Air Chemistry Group of the Hungarian Academy of Sciences, University of Veszprém, P.O. Box 158, H-8201 Veszprém,
Fig. 16. Comparison of spectral dependence of absorption AOD derived from both UAV absorption photometer and AERONET measurements.

Corrigan et al 2008
ABCs: Emission & Global Forcing

Ramanathan and Carmichael, Nature Geoscience 2008

Ramanathan et al, 2001
The observed retreat of the Himalayan-Hindu Kush-Tibetan glaciers is one of the major environmental problems facing the Asian region, since these glaciers and snow packs feed major Asian river systems including the Ganges, Brahmaputra, Mekong and Yangtze.

Chinese Academy of Sciences:

5% shrinkage since 1950s in volume of China’s over 46000 glaciers over last 24 years...
The glacier retreat is primarily attributed in IPCC report and other studies to warming by GHGs.

The present report adds that soot in ABCs is another likely major contributor to the retreat of the glaciers and snow packs: **Soot heating of the air and soot deposition on snow and increasing absorption of sunlight by snow and ice**

New ABC data reveal significant amount on BC even at 5 km altitude.
Springtime warming and reduced snow cover from carbonaceous particles

M. G. Flanner1, C. S. Zender2, P. G. Hess1,3, N. M. Mahowald1,3, T. H. Painter4, V. Ramanathan5, and P. J. Rasch1

ACPD 8, 19819–19859, 2008

3) Equilibrium climate experiments suggest that fossil fuel and biofuel emissions of BC+OM induce 95% as much springtime snow cover loss over Eurasia as anthropogenic carbon dioxide, a consequence of strong snow-albedo feedback and large BC+OM emissions from Asia.
# Link between Fuel Policies and Climate Change

Ramanathan, 2008

<table>
<thead>
<tr>
<th></th>
<th>1980</th>
<th>2005</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coal</strong> (Mton)</td>
<td>2570 (1373)</td>
<td>4154 (1615)</td>
<td>7173 (1883)</td>
</tr>
<tr>
<td><strong>Oil</strong> (Mbarrels)</td>
<td>65 (42)</td>
<td>85 (47)</td>
<td>116 (53)</td>
</tr>
<tr>
<td><strong>Gas</strong> (B cub met)</td>
<td>1521 (959)</td>
<td>2854 (1465)</td>
<td>4780 (2000)</td>
</tr>
</tbody>
</table>

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<tbody>
<tr>
<td><strong>Coal</strong></td>
<td>SO2 (-)</td>
<td></td>
<td>indoor (BC+)</td>
</tr>
<tr>
<td><strong>Oil</strong></td>
<td>SO2 (-)</td>
<td>NOx (Ozone +)</td>
<td>Diesel (BC+)</td>
</tr>
<tr>
<td><strong>Gas</strong></td>
<td></td>
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</tbody>
</table>
Switching to Natural Gas reduces future warming commitment; but unmask the aerosol cooling and accelerates approach to the committed warming

Ramanathan, 2008
BC emission

BC Emission/Capita

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

1. **Introduce cleaner-cooking technologies.**
   
   Economic conditions force roughly half the world’s population to cook with biomass fuels. Working with communities in rural Asia, where significant numbers of people cook using biomass fuels, Project Surya will provide sustainable, effective, incentive-based dissemination plans to enable residents to switch to solar cookers, biogas plants, and other cleaner-cooking technologies.

2. **Gather data on climate and health outcomes.**

   Pollutant gases and particulates from cooking fires have a major impact on global and regional climate changes, as well as on public health. Project Surya's interdisciplinary team will undertake an unprecedented effort to measure and document the impact of cleaner-cooking practices on people and the planet.

3. **Use the data to scale up and expand the project.**

   Building on success in India, scale up Project Surya to other regions of the world where biomass-fueled cooking is prevalent. Additionally, expand Project Surya’s integrated approach to other sectors of human activity.
**Other indirect and feedback effects of BC on Climate Forcing:**

BC heating of the cloudy air evaporating the clouds: So-called semi-direct forcing.

*A heating effect*

BC, as it ages, becomes cloud nuclei and produces more cloud drops.... Reduction in precipitation and increase in cloud fraction and albedo;

*A Cooling Effect*

Nucleating more cloud drops can also lead to deepening of clouds...

*A Heating effect*

By BC stabilizing boundary layer, can increase life time of Aerosols

*Heating or cooling effect*
Reducing the Impacts of BC and Ozone: Cobenefits

1) Improved Air Quality/Health;
2) Slow Himalayan-Tibetan glacier retreat
3) Monsoon disturbances

Win/Win Strategy of Biofuels and Biomass burning

- Decrease PM2.5
- Decrease BC faster than Sulfate aerosol
- Decrease Ozone: CO and NOx

Reduced Climate Change

Alter the balance between absorbing and scattering aerosol