Black carbon & India

V. Ramanathan,
Scripps Institution of Oceanography
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Hotel Ashok, New Delhi, India, Oct 14, 20

Oh, Mother earth, ocean-girdled and mountain-breasted, pardon me for trampling on you.    Sanskrit Prayer
Abstract. The infrared bands of chlorofluorocarbons and chlorocarbons enhance the atmospheric greenhouse effect. This enhancement may lead to an appreciable increase in the global surface temperature if the atmospheric concentrations of these compounds reach values of the order of 2 parts per billion.

One molecule of CFC has the same greenhouse effect as the addition of more than 10000 molecules of Carbon Dioxide to the Atmosphere
Climate- Chemical Interactions due to Trace Gases
The Non-CO2 trace gases contribute as much as CO2 to the increase in atmospheric Greenhouse effect: Ramanathan et al, JGR, 1983
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.
“Unequivocal” Warming of the Planet: IPCC, 2001 & 2007

Global Mean Temperature

Difference (°C) from 1961 - 1990 vs. Estimated actual global mean temperatures (°C)
Committed Warming as of 2005

Ramanathan and Feng, 2008

Probability density of warming (°C⁻¹)

Committed GHGs warming as of 2005 (°C)

Realized warming

Arctic summer ice

Himalayan-Tibetan Glaciers

Greenland ice sheet

Amazon rain forest

Thermohaline circulation

West Antarctic ice sheet

IPCC 90% range
Impact of Proposed CO$_2$ Reductions in 2009 G8 Meeting
Ramanathan & Xu 2009

By 2050
440 ppm
1 Wm$^{-2}$ Heating
0.8 C warming
Committed
There may be a way out:

Reduce short lived warming agents:

Black Carbon (<2 weeks);
Ozone (< 2 months);
Methane (<15 years)
HFCs & HCFCs (<15 years)

Buy few decades time:

to develop transformational technologies for a massive thinning of the GHGs blanket
**Non-\(\text{CO}_2\) climate warmers**

Contribution to 2005 forcing relative to \(\text{CO}_2(1.66 \, \text{Wm}^{-2})\)

**Greenhouse Gases**

- Ozone (troposphere) : 20%
- Methane : 30%
- Halocarbons : 20%

**Particles (Aerosols)**

- Black Carbon (soot/smoke) : 27% to 55%*

**Total Non-\(\text{CO}_2\)** : 97% to 125%

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All numbers except the red are IPCC values; Long lived \(\text{N}_2\text{O}\) not included

* Ramanathan & Carmichael; 2008
Global Black Carbon Emissions 2000
(8 Mtons/Yr)

Non-Residential (Fossil Fuels) 2600 (33%)

Residential: Cooking and Heating 2050 (25%)

Bio-Fuels (1480); Coal & Diesel (565)

Open Burning: 3325 (42%)

Forest Fires (1240)
Savanna Burning (1720)
Crop Residues (325)

Source: Bond et al, 2004; Uncertainty: about a factor of 2 or more
BC emission

Ref: Ramanathan and Feng, 2008; Data source: Bond et al 2004
Indian Ocean Experiment:

Europe/India/USA Collaboration

Lead Funding Agencies:
NSF; ISRO; MPI

Lead Institutions:

Scripps Inst. Of Oceanography; Univ of California at San Diego, USA

National Physical Laboratory, New Delhi, India

Max Planck Inst for Chemie, Mainz, Germany

Pis: Ramanathan, Crutzen & Mitra

The Indian Ocean Experiment (INDOEX), an international field experiment, has been collecting data since 1996, featuring an intensive field campaign conducted in Spring 1999. For details, see http://www-indoex.ucsd.edu.

Participating Institutions

Austria
Universität Innsbruck

Canada
York University, Toronto

Europe
Arctic Platform for Earth Observation (Geophysical, Finland)
European Organisation for the Exploration of Meteorological Satellites (Meteosat-5)
France
Laboratoire d'Optique Atmosphérique
Laboratoire de Météorologie Dynamique du CNRS
Laboratoire de Météorologie Physique, Université Blaise Pascal
Laboratoire des Sciences du Climat et de l’Environnement, CNRS
Laboratoire Interuniversitaire des Systèmes Atmosphériques
Service d’Aéronomie

Germany
Forschungszentrum Jülich
GFZ-Forschungszentrum GeoForschung, Dortmund
Max Planck Institut für Chemie
Max Planck Institut für Klimaforschung
Max Planck Institut für Meteorologie
Meteorologisches Institut der Universität Hamburg
Universität Bremen

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Indian Institute of Science, Bangalore
Indian Institute of Technology, New Delhi

Indian Institute of Tropical Meteorology, Pune
Indian Meteorological Department, New Delhi
Indian Space Research Organization, Bangalore
National Centre for Medium Range Weather Forecasting, New Delhi
National Institute of Oceanography, Goa
National Physical Laboratory, New Delhi
Physical Research Laboratory, Ahmedabad
Space Applications Centre, Ahmedabad
Space Physics Laboratory, Thiruvananthapuram

Israel
Tel Aviv University

Le Reunion
Université de La Réunion

Italy
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University of Murcia, Requena

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Ministry of Home Affairs, Housing and Environment
Netherlands
Netherlands Meteorological Institute
Technische Universität Braunschweig
Universität Utrecht

South Africa
University of Witwatersrand, Johannesburg

Sweden
Meteorologiska Institutionen, Stockholm University

United Kingdom
Imperial College, London

United States
Center for Clouds, Chemistry and Climate
Arizona State University, Tempe
Atmospheric Research Laboratory
Colorado University, Boulder
Desert Research Institute
Florida State University, Tallahassee
NASA - Goddard Space Flight Center
Naval Research Laboratory
NOAA - Pacific Marine Environmental Laboratory
North Carolina State University, Raleigh
Oregon State University, Corvallis
Pennsylvania State University, University Park
Scripps Institution of Oceanography
SeaSpace Corporation
University Corporation for Atmospheric Research
University of Alaska, Fairbanks
University of California, Irvine
University of California, Riverside
University of California, San Diego
University of Hawaii, Manoa
University of Maryland, College Park
University of Miami
University of Washington, Seattle
A Brown Cloud in LA

Dec 27, 2002
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.

Sulfates: Reflect sunlight like mirrors and cool

Soot: Traps sunlight and heats the air
What does black carbon look like?
Ramanathan et al, 2001

Clean air;
Southern Indian Ocean, 8S

South of ITCZ
8.8°S 71.0°E, Altitude 775 m

Within ITCZ
6.1°S 71.0°E, Altitude 817 m

North of ITCZ
7.9°N 71.6°E, Altitude 685 m

Southern Indian Ocean, 6S Polluted
Arabian Sea Polluted
Back Scattering (Cooling)

Absorption (Atmospheric Warming)

Absorption (Column Warming)

Forward Scattering

Dimming of Surface
Surface Cooling

Suppression of Rain;
BC Global Radiative Forcing Estimates:
Masking of Global Warming: 2002

{A Synthesis of ground, aircraft and satellite observations}

Chung, Ramanathan, Kim, Podgorny, 2005

b) Atmospheric Absorption

Heating of Blanket by BC & Others

c) Surface Net

Dimming: Mirrors & BC

Chung, Ramanathan, Kim, Podgorny, 2005
IABCs have led to large dimming over Asia; At least by 6% over China and India
Changes in the characteristics of rain events in India

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Figure 3. Summary of the trends in heavy and moderate rain days occurring during the summer monsoon season in different regions. Asterisks denote a significant trend at the 5% level.
Atmospheric brown clouds: Impacts on South Asian climate and hydrological cycle


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Contributed by V. Ramanathan, January 25, 2005

A Fully Coupled Ocean-Atmosphere Model Study from 1870 to 2025; Five Ensemble Runs:
The NCAR Parallel Climate Model;
GHG gas and volcanic forcing from 1870;
ABC forcing from INDOEX and past emissions histories
**South Asian Dimming**

Solar Radiation at the Surface: Simulated And Observed (12 stations)

The Dimming Led to a Decrease in Evaporation From Indian Ocean

Source: Ramanathan et al, Proceedings of National Academy of Sciences, March 2005
Observed Trend in Indian Ocean Surface Temperatures 1951 to 2002
Chung & Ramanathan J Clim, 2006

GHG Warming

Cleaner SIO

Polluted NIO

ERSST
Kaplan SST
Hadley SST

Brown cloud cooling
Changes in Summer Monsoon Rainfall averaged over India

Smoothed Indian rainfall
(June-September mean)

Ramanathan et al 2005
Model Prediction: ABCs induced dimming is likely to increase Frequency of droughts during 2000 to 2030

Ramanathan et al, 2005
Hindu Kush-Himalayan-Tibetan Glaciers:

Water Fountain of Asia
Multiple Stressors on Glaciers and Snowpacks

- Recovering from little-ice age
- Land degradation
- Greenhouse gases
- Monsoon Variability
- BC deposition on snow & ice
- Atmospheric Brow Clouds i.e., Aerosols
- Atmospheric Warming

- Dimming; Less precip
- More precip as rain; More intense precip
- Black Carbon; Brown Carbon; Ozone

- More precip as rain; More intense precip
- BC deposition on snow & ice
- Dimming; Less precip
- Atmospheric Brow Clouds i.e., Aerosols
- Atmospheric Warming
- Greenhouse gases
- Monsoon Variability
- Recovering from little-ice age
Elevation dependency of recent and future minimum surface air temperature trends in the Tibetan Plateau and its surroundings

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1961 to 2006 Trend
ABCs surround the Himalayas

NASA, CALYPSO LIDAR
Ramanathan et al, 2007

ABC-Pyramid Station; Base Camp
Mt Everest; Fuzzi et al 08
Differential Temp Trend: Trop - Surface

Microwave Sounder

GCM- with GHGs+ABCs

GCM with GHGs

Observed Tropospheric Temp Trend: 1979-2007

Gautam et al, GRL, 2009

Ramanathan et al 2005
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
Health Burdon Of ABCs Is Enormous

No region is immune!

~800,000 excess deaths per year (in USA >50,000 deaths; $100B/yr)

Strong Motivator For Change!
Smoke and BC have Major Impacts on Health; Water Security and Food Security

- Greatest advantage for Policy Actions
  1. Short Lived in the air (about a week or less)
  2. Immediate response to mitigation laws
  3. Response felt locally by improved air quality
  4. Will reduce fatalities due to indoor and outdoor air pollution
Suggested Approach

Mitigation Technology is Available

1) Start with Fossil Fuel BC: Major reductions

   Diesel Particle Filters are in Market
   $250 Euros for diesel passenger car
   More than 99% reduction in BC

2) Initiate mitigation of Biofuel Cooking

   But Science is needed to refine numbers
New Delhi’s Pioneering Efforts

Switching to LPG resulted in:

Increase in CO2
Increase in Methane

But, when black carbon reductions from Buses were accounted for,

There was an overall reduction in CO2 of

300,000 tons of CO₂ Eq.
a) Baseline BC AOD for 2004/05

Rural Cooking

- Fire Wood
- Gas
- Coal
- Kerosene
- Dung
- Others

Biogas plants convert organic waste into gas

Parabolic solar cooker

Ramanathan and Balakrishnan, 2007
Ramanathan and Carmichael, 2008

b) BC AOD without biofuels
Lead Institutions
TERI, Delhi
Sri Ramchandra Univ, Chennai
JNU, Delhi
UCLA
UCSD

Before Stove Introduction
Black carbon and associated pollutants are released from extensive biofuel burning for heating and cooking using inefficient methods.

After Stove Introduction
The use of more efficient cooking technology is expected to reduce black carbon concentrations by 90% - resulting in a much cleaner local environment and greatly improving indoor and outdoor air quality, and reducing the atmospheric effects of such pollutants.