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



AIR POLLUTION AND CLIMATE CHANGE: DEVELOPING A FRAMEWORK FOR INTEGRATED CO-BENEFITS STRATEGIES Stockholm 17 - 19 September 2008

The principal conclusions and recommendations made by the conference are summarized in the paragraphs below:

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

6. <u>Ground-level ozone and black carbon aerosols are both air pollutants and act</u> <u>as warming agents (see para. 8 below). Methane is a precursor of ozone formation</u> <u>and a GHG.</u> Urgent action to decrease their concentrations in the atmosphere could provide opportunities, not only for significant air pollution benefits (e.g. health and cropyield 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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PNAS

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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



IPCC-AR4 (2007) Concludes:

For a CO₂ doubling, the most likely climate sensitivity is 3 C warming with a 90% confidence interval of 2 to 4.5^oC

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^oC

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



Committed warming derived from IPCC Forcing & IPCC climate sensitivity

Detecting Climate Change due to Increasing Carbon Dioxide

Roland A. Madden and V. Ramanathan

SCIENCE

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-

electricities that is not the

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 CO_2 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.





2007 Fossil Fuel: 8.5 Pg C



Carbon-based power consumption reduction to stabilize CO₂



Original diagram: Hoffert et al, Nature, 1998

2007 Carbon emission: 8.5 Gtons/Yr as CO₂ 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, N₂O and Ozone will also likely increase (barring continued economic collapse into 2050).

Global Radiative Forcing due to GHGs & ABCs

Ramanathan and Feng, 2008



Nazarenko, 2004; Chung and Seinfeld, 2005





How should We Unmask the ABC Effect ?

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

SO₂ Emissions



Ramanathan 2007 tlesen Fndn

The wrong way to go

Ramanathan, 2008



Indian Ocean Experiment: An integrated analysis of the climate forcing and effects of the great Indo-Asian haze

V. Ramanathan, 1 P. J. Crutzen, 1, 2 J. Lelieveld, 2 A. P. Mitra, 3 D. Althausen, 4 J. Anderson, 5 M. O. Andreae, 2 W. Cantrell, 6 G. R. Cass, 7 C. E. Chung, 1 A. D. Clarke, 8 J. A. Coakley, 9 W. D. Collins, 10 W. C. Conant, 1 F. Dulac, 11 J. Heintzenberg, 4 A. J. Heymsfield, 10 B. Holben, 12 S. Howell, 8 J. Hudson, 13 A. Jayaraman, 14 J. T. Kiehl, 10 T. N. Krishnamurti, 15 D. Lubin, 1 G. McFarquhar,10 T. Novakov, 16 J. A. Ogren, 17 I. A. Podgorny,1 K. Prather,18 K. Priestley,19 J. M. Prospero, 20 P. K. Quinn, 21 K. Rajeev,22 P. Rasch,10 S. Rupert,1 R. Sadourny,23 S. K. Satheesh,1 G. E. Shaw,24 P. Sheridan,17 and F. P. J. Valero1



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

Traps sunlight and heats the air

Reflects sunlight like mirrors and cool

RAMANATHAN ET AL.: INDIAN OCEAN EXPERIMENT—AN INTEGRATED ANALYSIS



Aerosol Single Scattering Albedo

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 Albed0

Observations :

0.05 < Absorption < 0.2

Models :

0.01 < Absorption < 0.1



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.

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 2 August 2007 | www.nature.com/nature | \$10

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Atmospheric brown clouds enhance climate warming

Ramanathan et al, Nature, 448, 2007







INDOEX data from John Ogren; Ref: Ramanathan et al, 2001

UAV CAMPAIGN IN THE TROPICAL INDIAN OCEAN Corrigan, Roberts, Ramana and Ramanathan, 2008







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.



CFORS model vs. IMPROVE (Hadley et al., 2007)



Black carbon or brown carbon? The nature of light-absorbing carbonaceous aerosols

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Elemental Carbon Black Carbon Organics HULIS LAC



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...



HKHT Glacier Retreat

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 andSoot 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



ABCs surround the HKHT

9 November 2006



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.



1979-2000 MAM Snow BC+Dust Forcing

Link between Fuel Policies and Climate Change Ramanathan, 2008

С 0 G	oal il as	SO2 (-) SO2 (-)	NOx (Ozone +)	indoor (BC+) Diesel (BC+)
	Gas	1521	2854	4780
	(B cub met)	(959)	(1465)	(2000)
	Oil	65	85	116
	(Mbarrels)	(42)	(47)	(53)
	Coal	2570	4154	7173 World
	(Mton)	(1373)	(1615)	(1883) (OECD)
		<u>1980</u>	2005	2030

Carbon (as CO₂) emission by the 3 fuels Coal emits 25 Kg Carbon /Giga-Joules Oil emits 20 Kg Carbon /Giga-joules Natural Gas emits 15 Carbon /Giga-joules

Switching to Natural Gas reduces future warming commitment; but unmasks the aerosol cooling and accelerates approach to the committed warming

Ramanathan, 2008



PROJECT SURYA सूर्य

Reduction of Air Pollution and Global Warming by Cooking with Renewable Sources

Ramanathan & Balakrishnan, 2007





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



2) <u>Slow</u> <u>Himalayan-</u> <u>Tibetan glacier</u> <u>retreat</u> Reduced Climate Change

Alter the balance between absorbing and scattering aerosol

3) <u>Monsoon</u> <u>disturbances</u>

Win/Win Strategy of Biofuels and Biomass burning

+ Decrease PM2.5

+ Decrease BC faster than Sulfate aerosol;

Decrease Ozone: CO and NOx