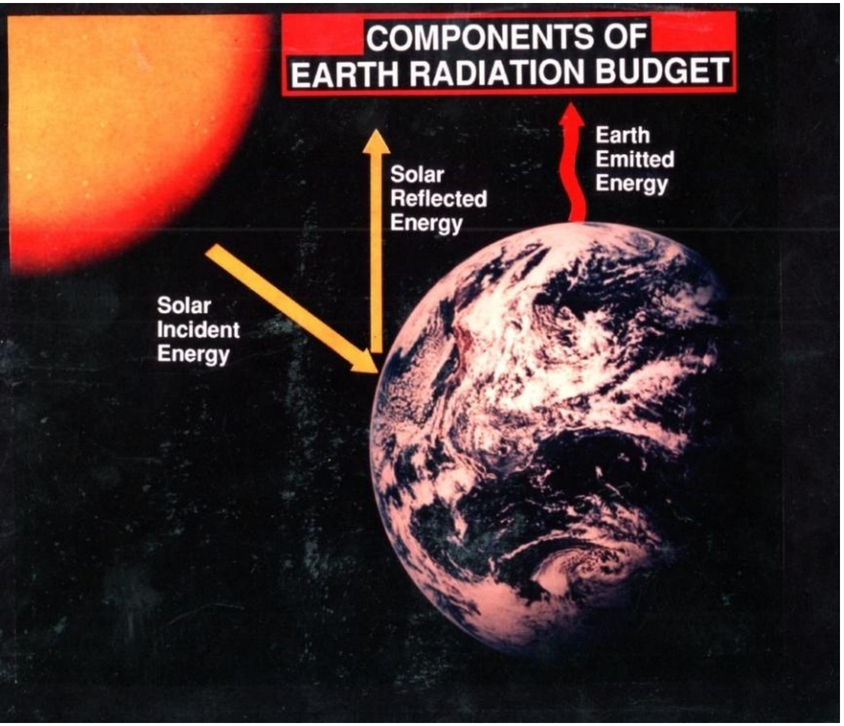
Black carbon forcing and its climate effects

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

Global Atmospheric Pollution Forum

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.**_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.

PNAS 2008

PERSPECTIVE

On avoiding dangerous anthropogenic interference with the climate system: Formidable challenges ahead

V. Ramanathan* and Y. Feng

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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

COMMENTARY

Global warming: Stop worrying, start panicking?

Hans Joachim Schellnhuber*[†‡]

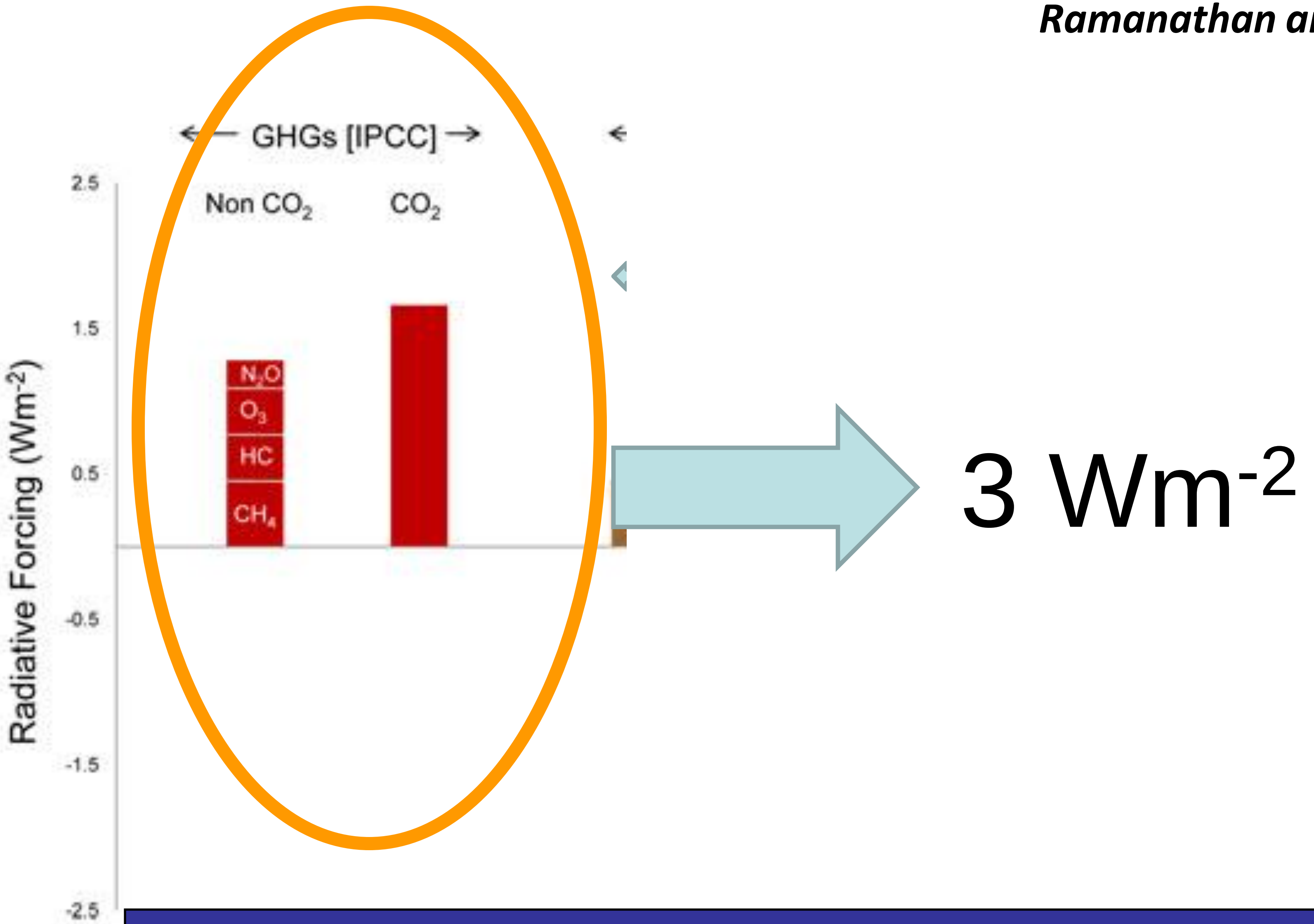
**Potsdam Institute for Climate Impact Research, P.O. Box 60 12 03, 14412 Potsdam, Germany; and [†]Environmental Change Institute and Tyndall Centre, Oxford University, Oxford OX1 3QY, United Kingdom*

In 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

Ramanathan and Feng, 2008

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 4.5^0C

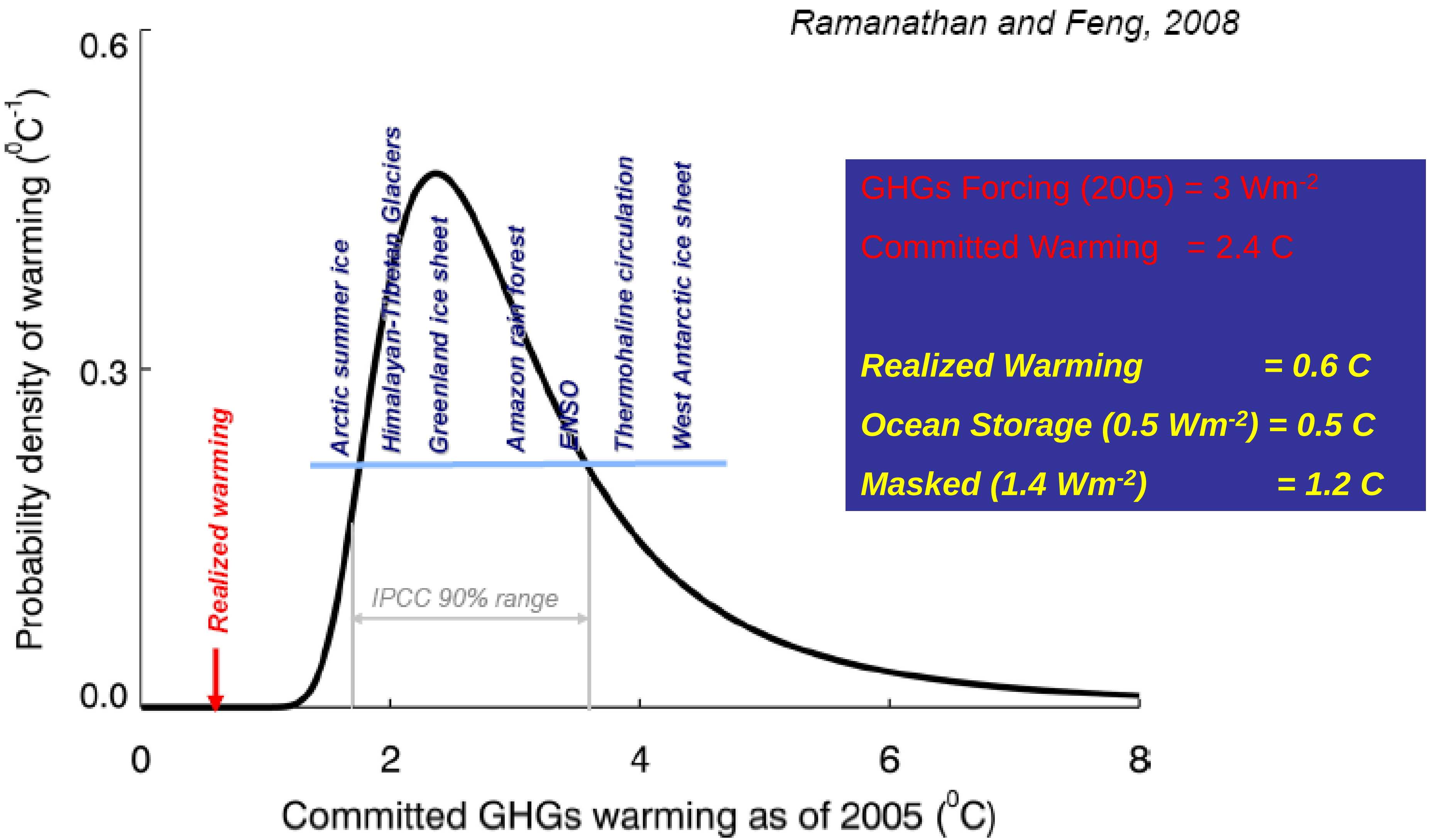
For doubling of CO_2, TOA forcing is : 3.7 Wm^{-2}

So it takes about 1.25 Wm^{-2} (3.7/3) to warm the planet by 1^0C

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

The committed (or the inevitable) warming is 2.4^0C

Committed Warming as of 2005



Committed warming derived from IPCC Forcing & IPCC climate sensitivity

15 August 1980, Volume 209, Number 4458 SCIENCE

1980

Detecting Climate Change due to Increasing Carbon Dioxide

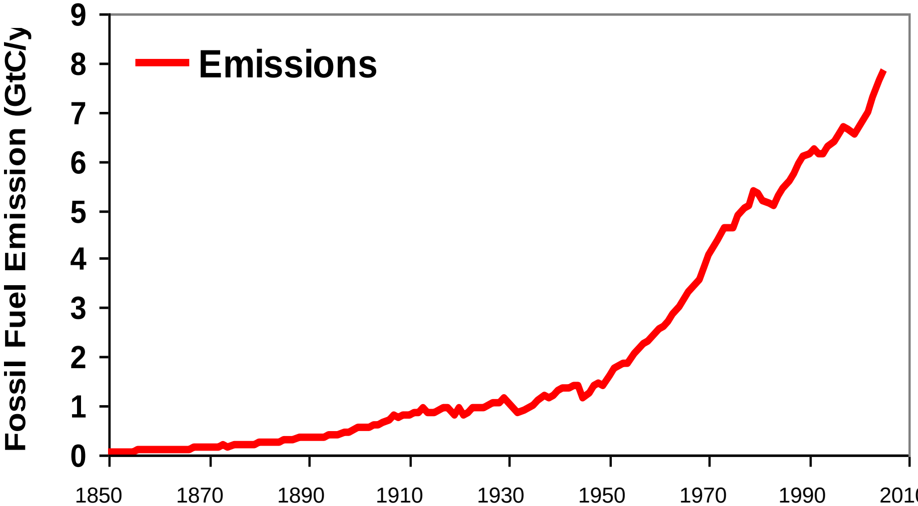
Roland A. Madden and V. Ramanathan

The possible climatic effects of large increases in atmospheric CO_2 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 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

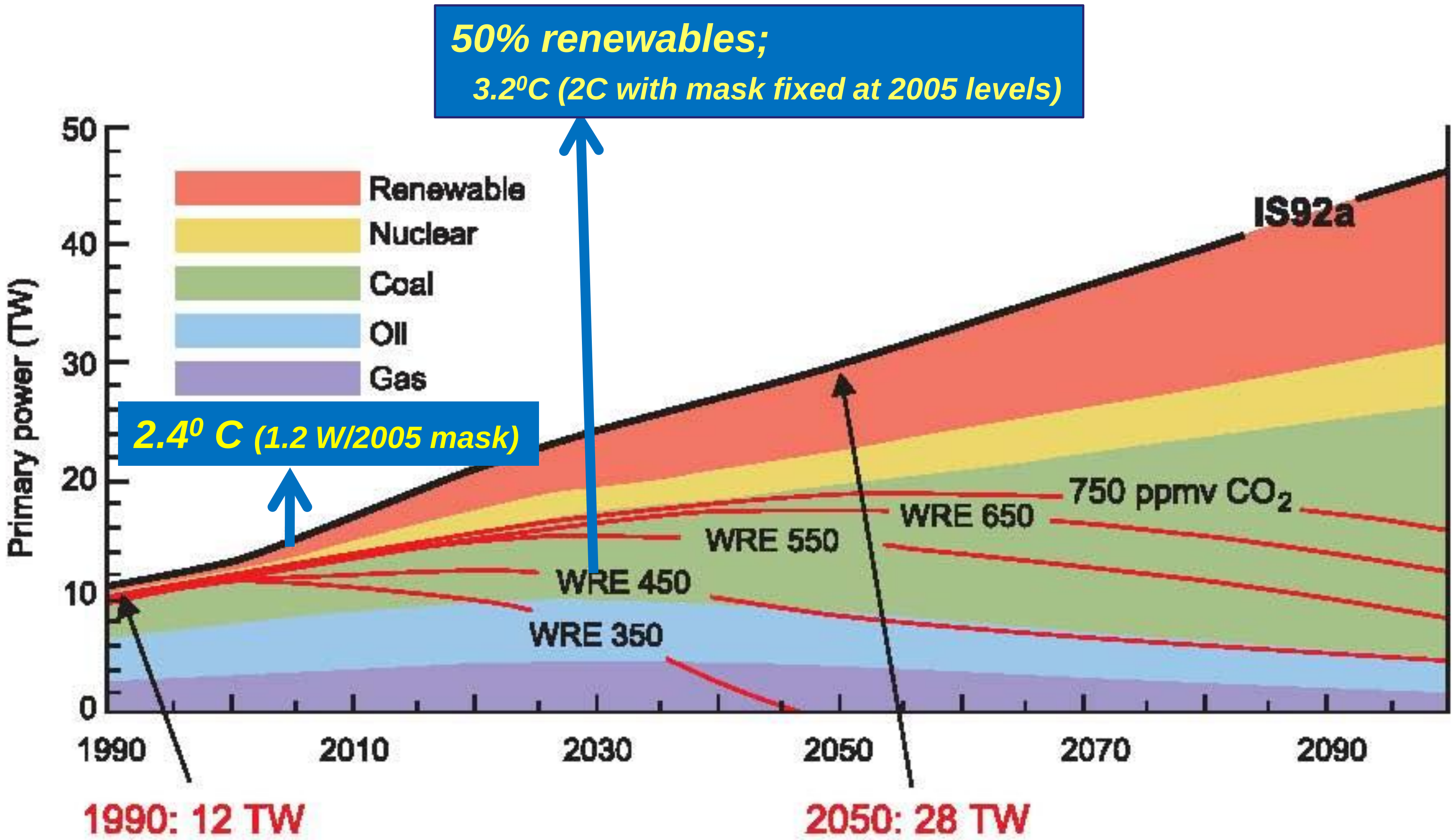


1990 - 1999: 0.9% y^{-1}

2000 - 2007: 3.5% y^{-1}

Data Source: G. Marland, T.A. Boden, R.J. Andres, and J. Gregg at CDIAC

Carbon-based power consumption reduction to stabilize CO_2



Original diagram: Hoffert et al, Nature, 1998

2007 Carbon emission: 8.5 Gtons/Yr as CO_2

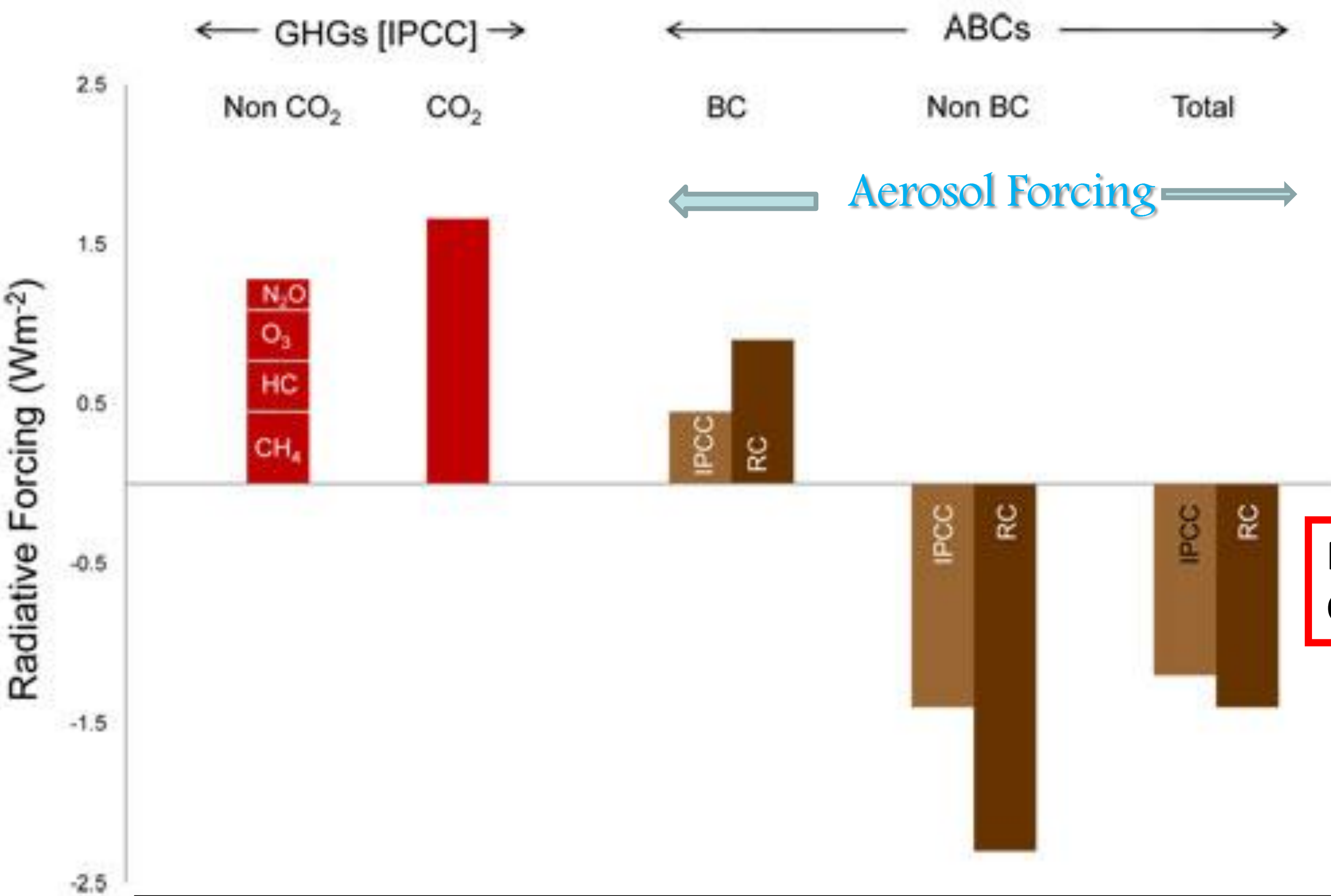
At fixed emission, by 2030 we will add: 108 Gtons

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_2O and Ozone will also likely increase (barring continued economic collapse into 2050).

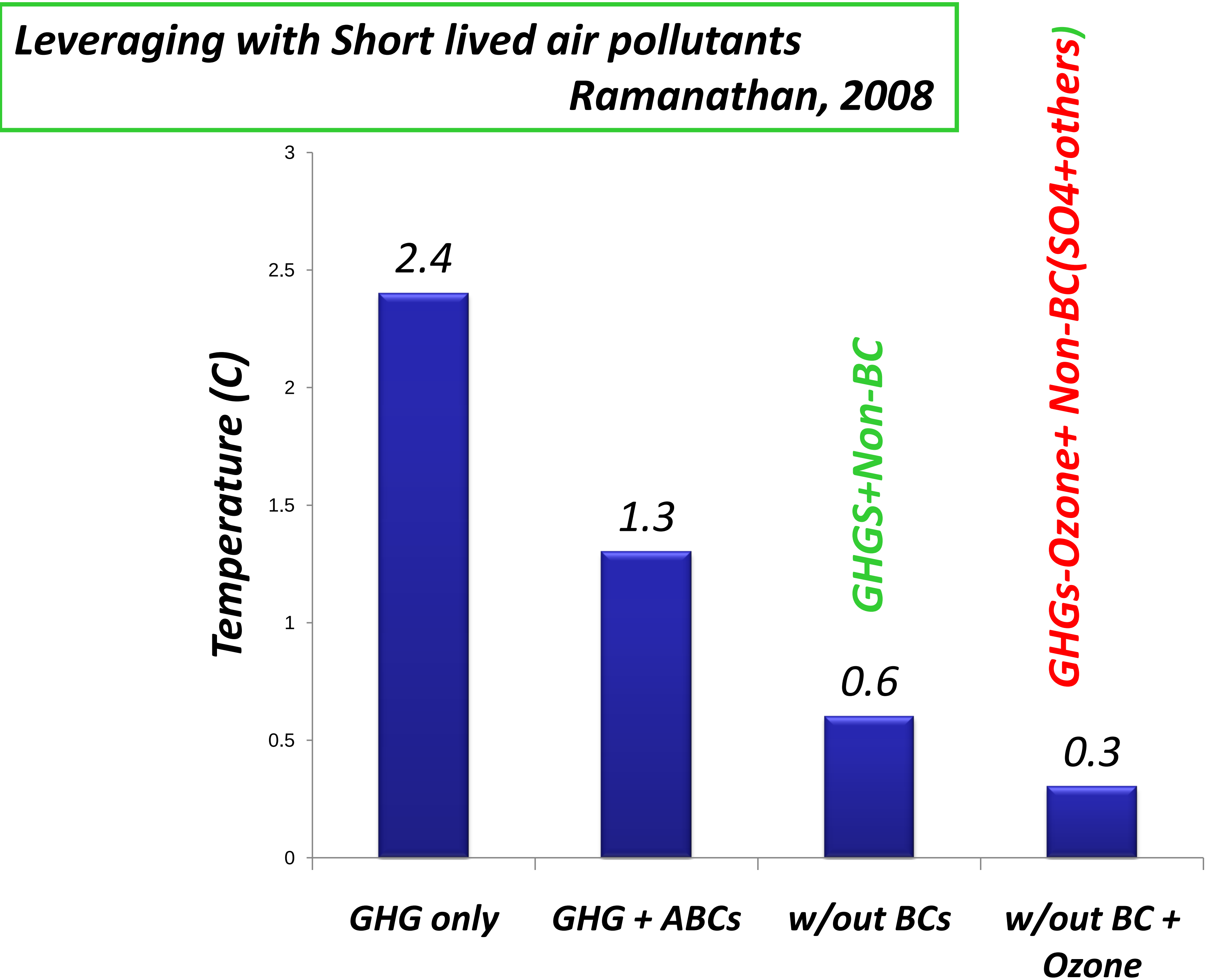
Global Radiative Forcing due to GHGs & ABCs

Ramanathan and Feng, 2008



RC: Ramanathan & Carmichael, 2008

For high BC heating, also see: Jacobson, 2001; Hansen and Nazarenko, 2004; Chung and Seinfeld, 2005

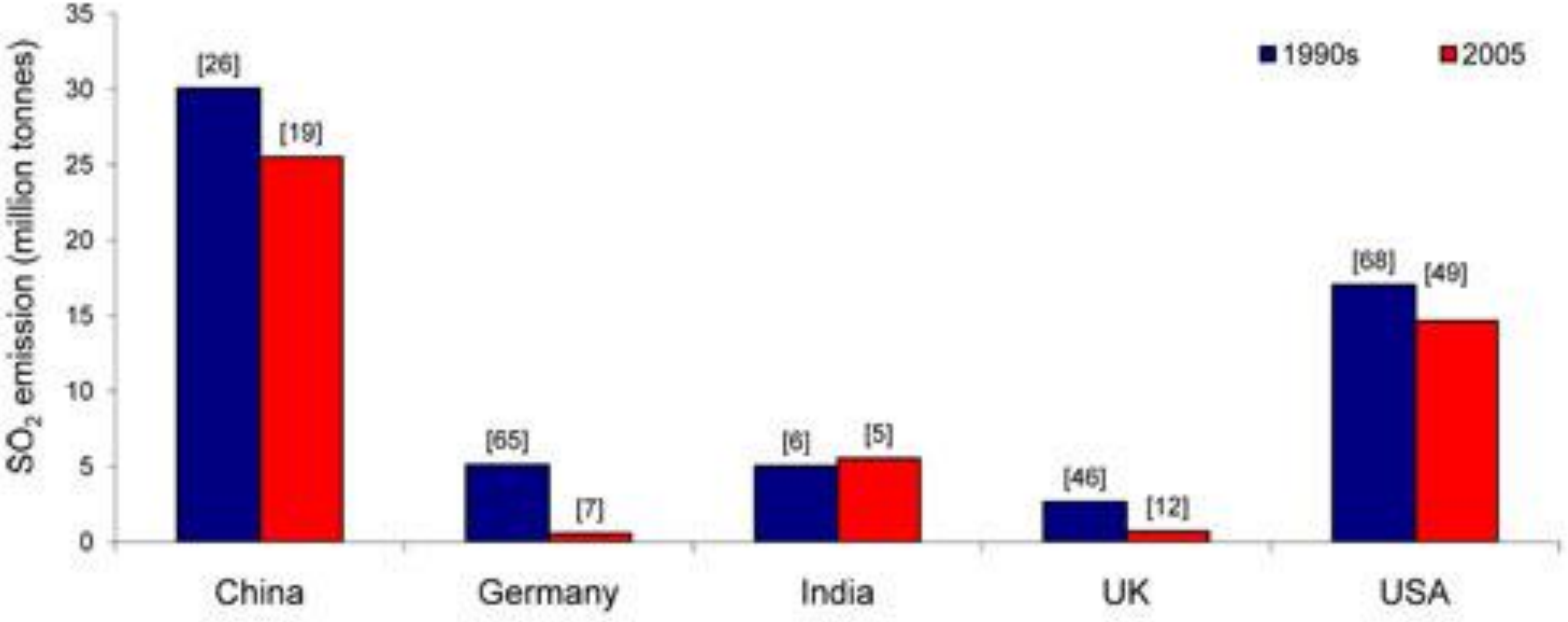


Leveraging with Short lived air pollutants
Ramanathan, 2008
Temperature (C)
3
2.5
2
1.5
1
0.5
0
2.4
1.3
0.6
0.3
GHGS+Non-BC
GHGs-Ozone+ Non-BC(SO4+others)
GHG only
GHG + ABCs
w/out BCs
w/out BC + Ozone

How should We Unmask the ABC Effect ?

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

SO_2 Emissions

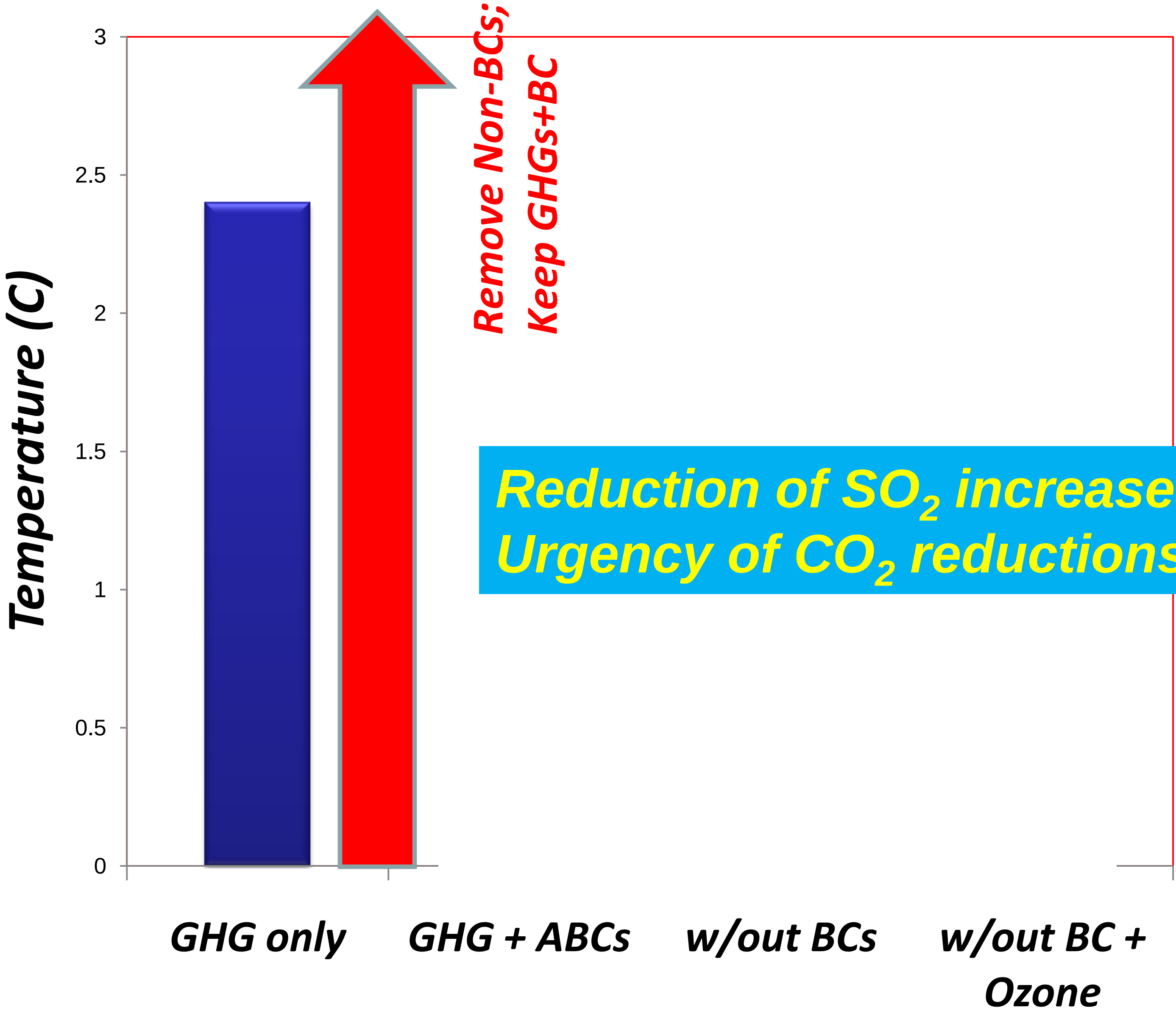


Ramanathan 2007

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

The wrong way to go

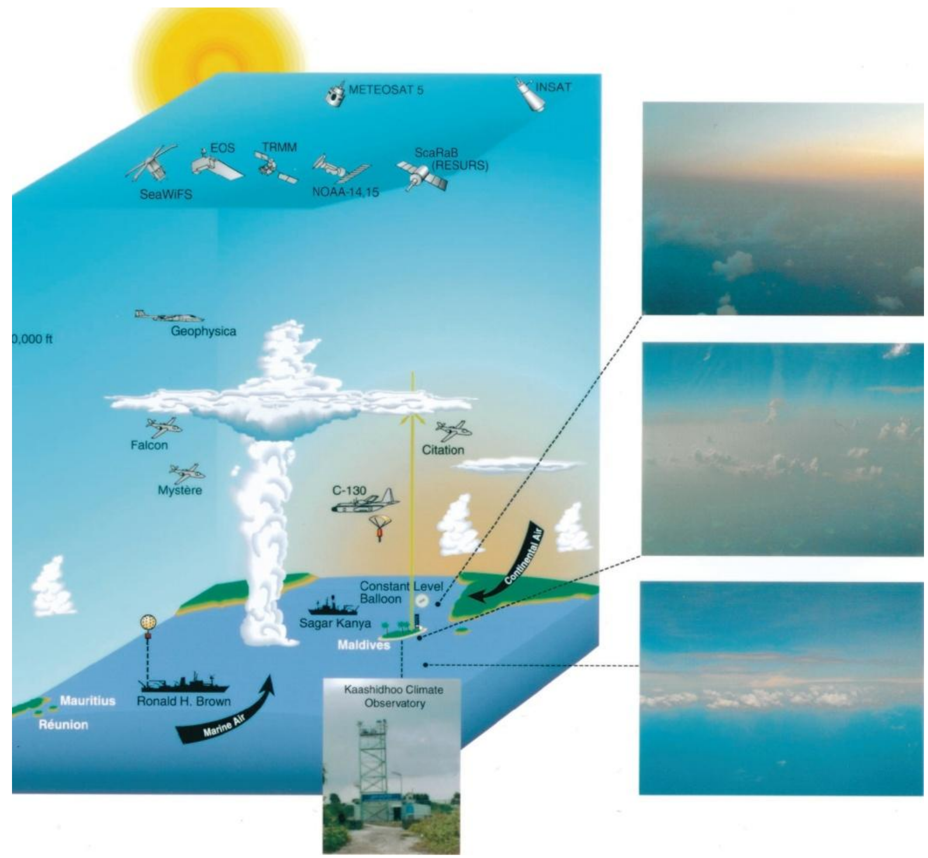
Ramanathan, 2008



Reduction of SO_2 increases the Urgency of CO_2 reductions.

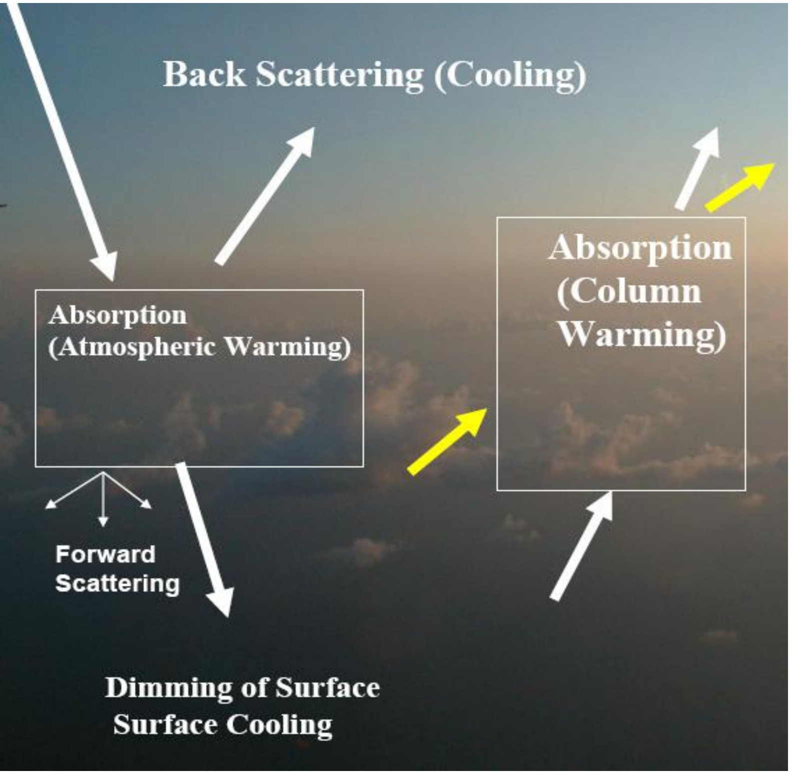
Indian Ocean Experiment: An integrated analysis of the climate forcing and effects of the great Indo-Asian haze

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

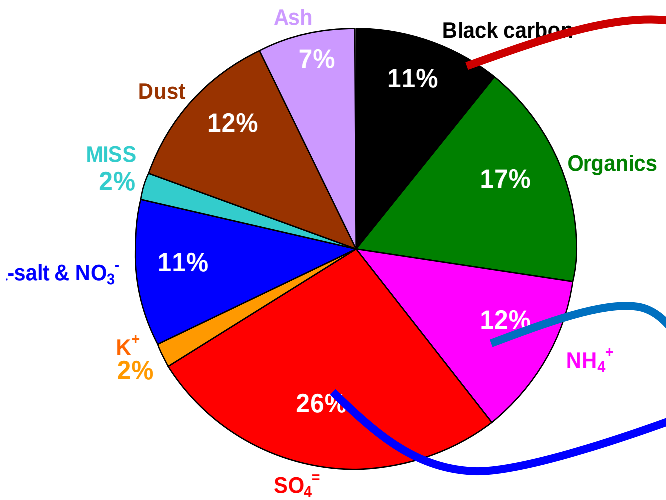


J Geophysical Research, 2001

ABCs: How do they influence climate ?

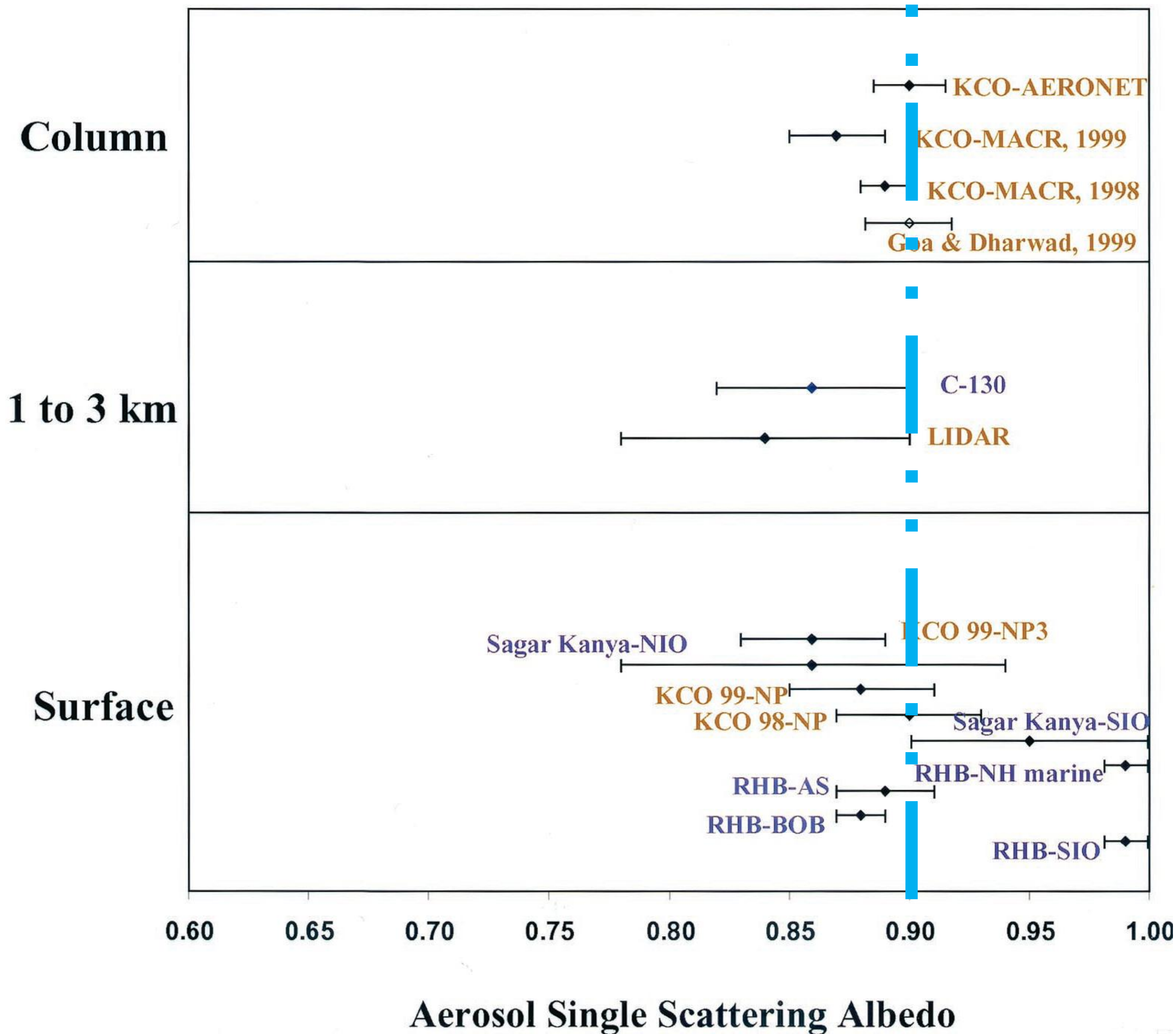


- The absorption of solar radiation by the surface and the atmosphere is the fundamental driver for the physical climate system , for atmospheric chemistry, and for all life on the planet.
- ABCs have altered this forcing significantly



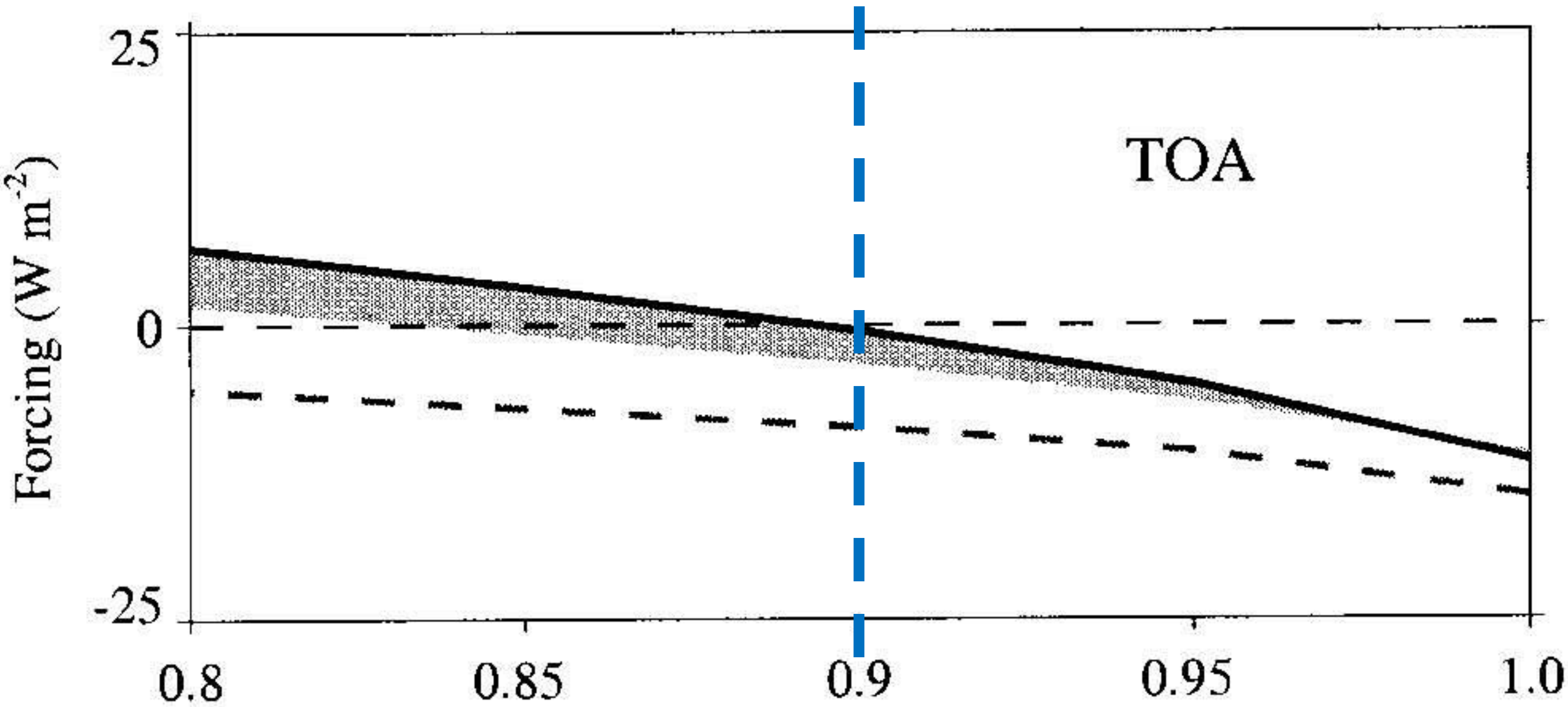
Traps sunlight and heats the air

Reflects sunlight like mirrors and cool


Column
KCO-AERONET
KCO-MACR, 1999
KCO-MACR, 1998
Goa & Dharwad, 1999
1 to 3 km
C-130
LIDAR
Surface
KCO 99-NP3
Sagar Kanya-NIO
KCO 99-NP
KCO 98-NP
Sagar Kanya-SIO
RHB-NH marine
RHB-AS
RHB-BOB
RHB-SIO
0.60
0.65
0.70
0.75
0.80
0.85
0.90
0.95
1.00
Aerosol Single Scattering Albedo

Sensitivity of Forcing to Aerosol Absorption

Podgorny and Ramanathan, 2001



Single Scattering Albedo

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 :

$0.05 < \text{Absorption} < 0.2$

Models :

$0.01 < \text{Absorption} < 0.1$

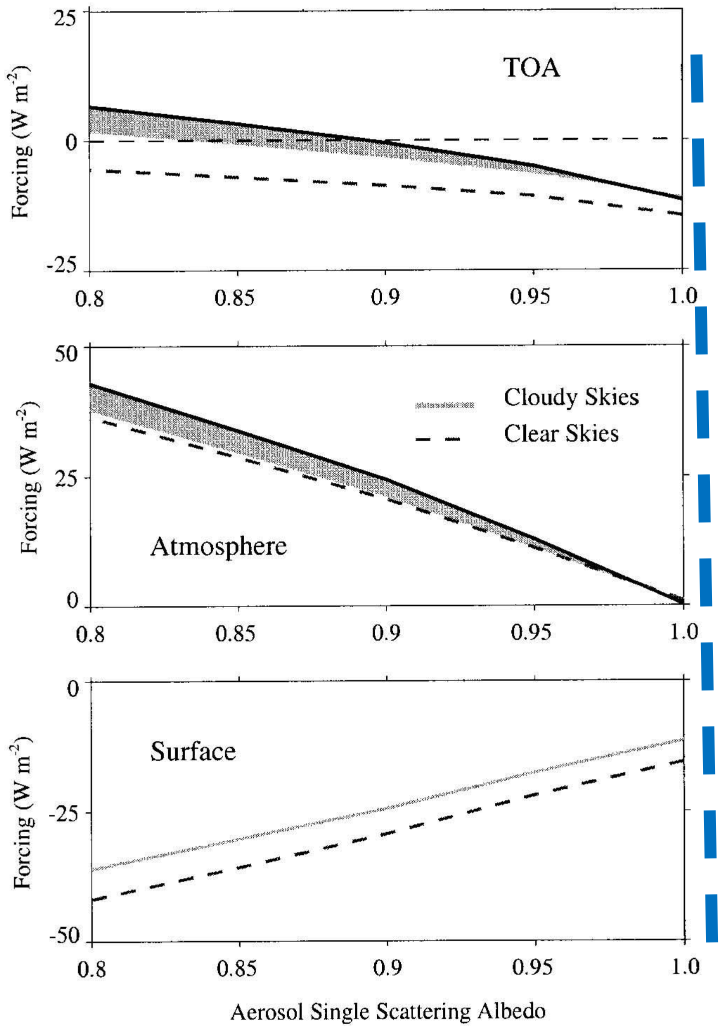
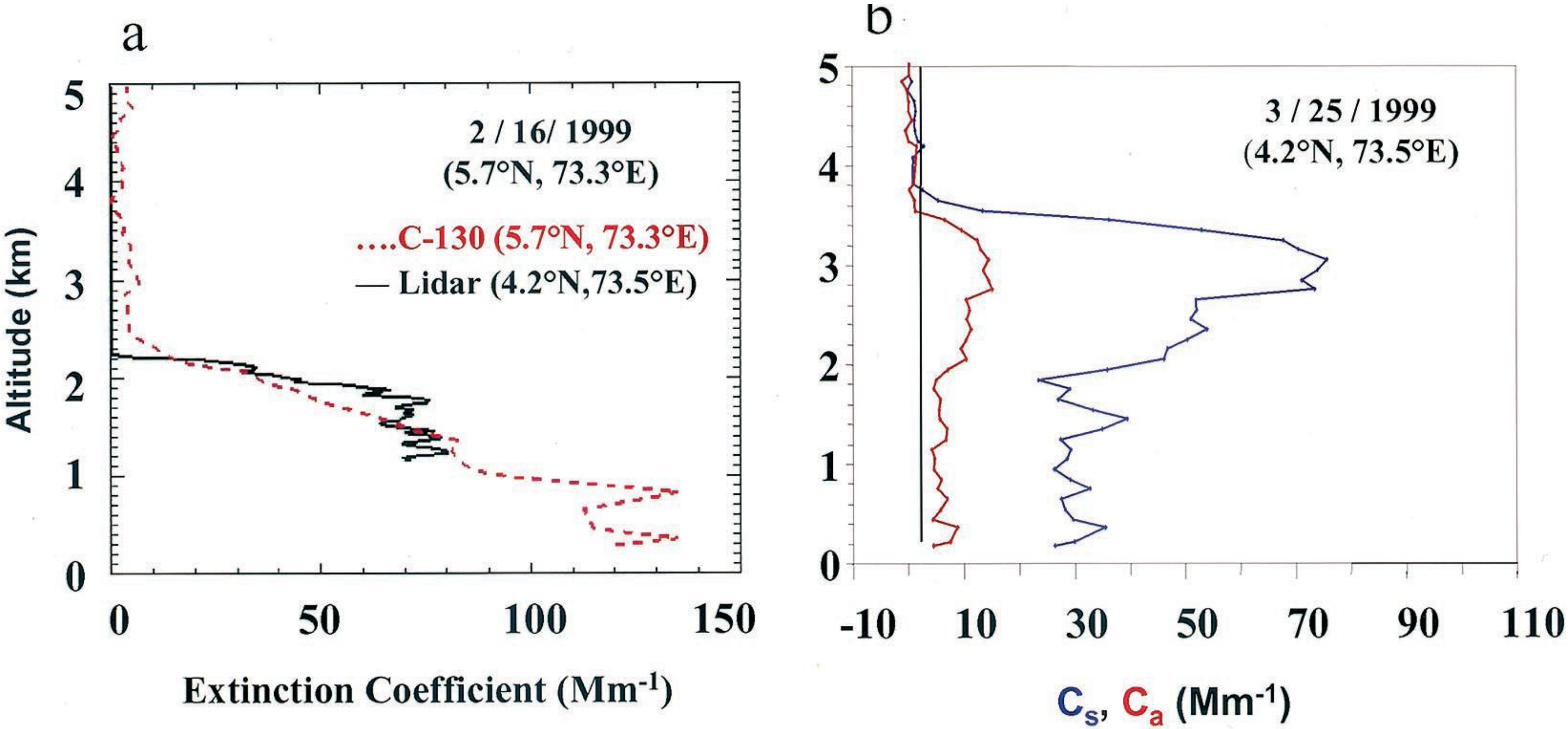


Figure 5. TOA (top), atmospheric (middle), and surface (bottom), radiative forcing for clear (solid line) and cloudy (shaded area) skies as a function of aerosol single-scattering albedo. Aerosol optical thickness is 0.4, cloud fraction is 25%, and cloud optical thickness is 15. Solid black line and 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

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

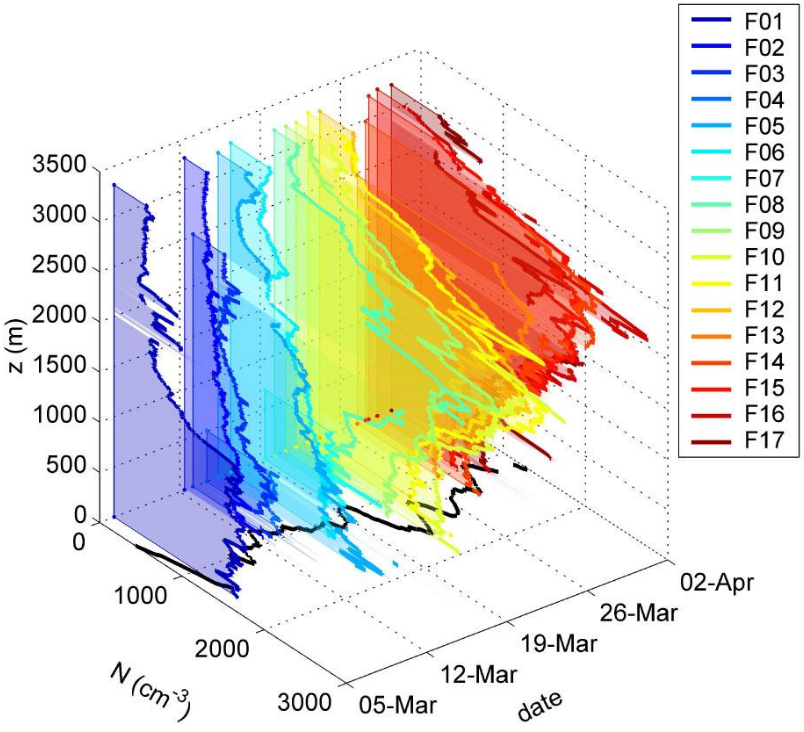


Fig. 8. Total particle concentration by altitude during MAC experiment (March 2006). The legend identifies flight numbers. The solid black line in the zero altitude plane shows the total particle concentration collected at the surface station.

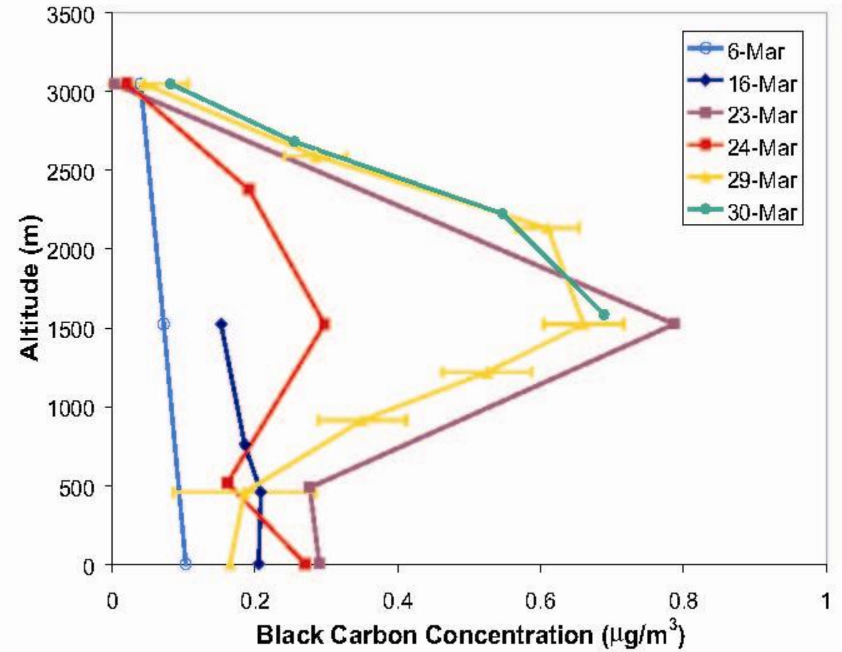
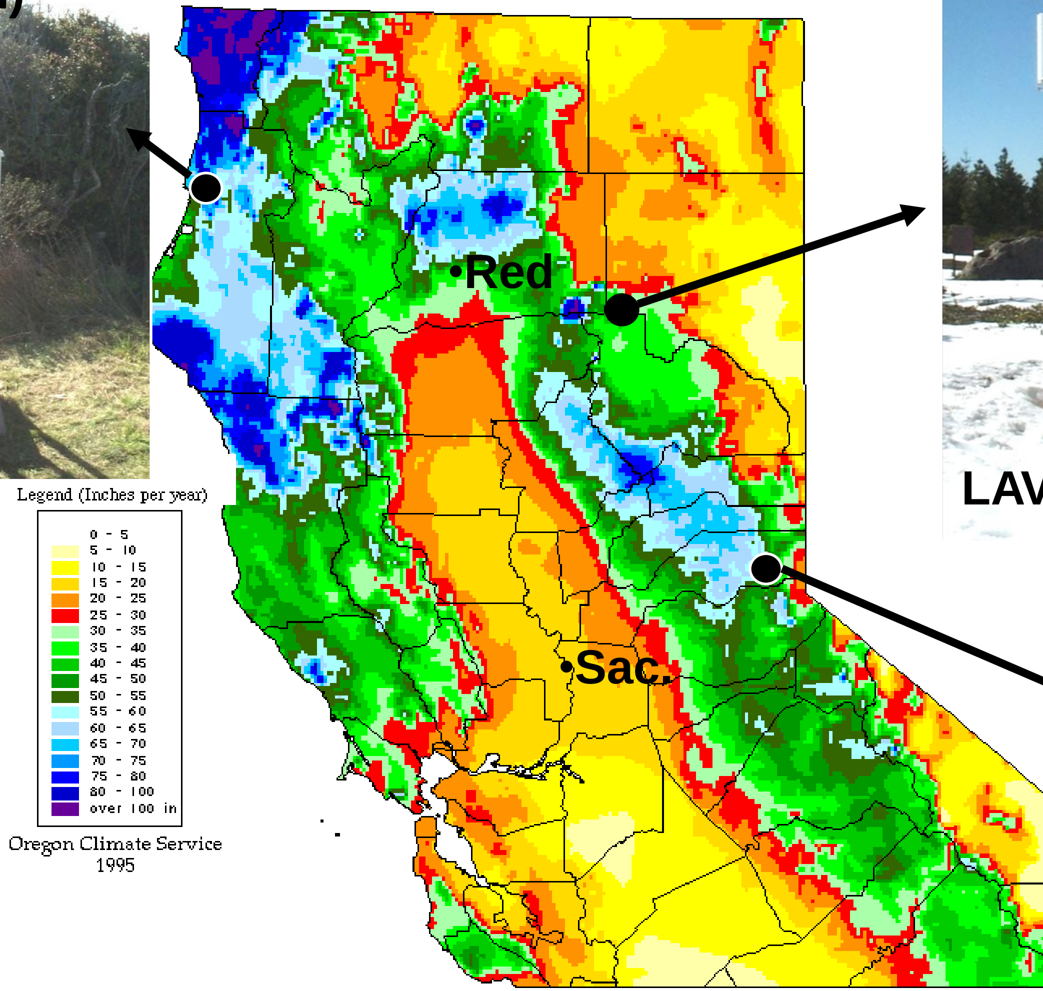


Fig. 13. Black carbon concentration altitude profiles during MAC experiment (March 2006). Error bars are only shown for a single flight to keep the plot legible and are representative of all flights.

Field Sites

THD (107 m)



Annual Average Precipitation (Inc
Northern California

Period: 1961-1990

LAVO (1732 m)

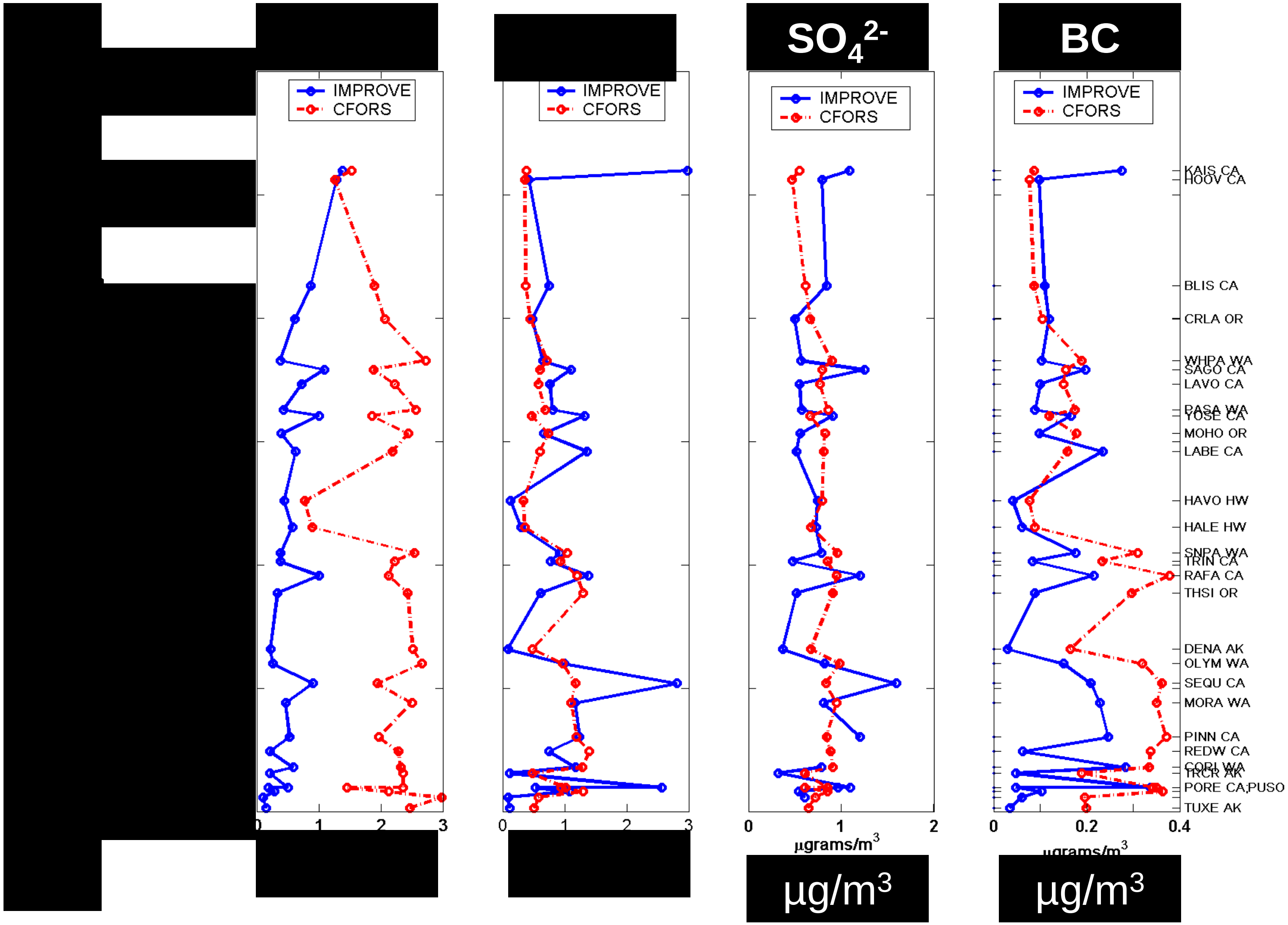
CSSL (2100 m)

http://www.wrcc.dri.edu/pcpn/ca_north.gif

CFORS model vs. IMPROVE

(Hadley et al., 2007)

[redacted]



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

M. O. Andreae1 and A. Gelencs´er2
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 Veszpr´em, P.O. Box 158, H-8201 Veszpr´em,

Elemental Carbon

Black Carbon

Organics

HULIS

LAC

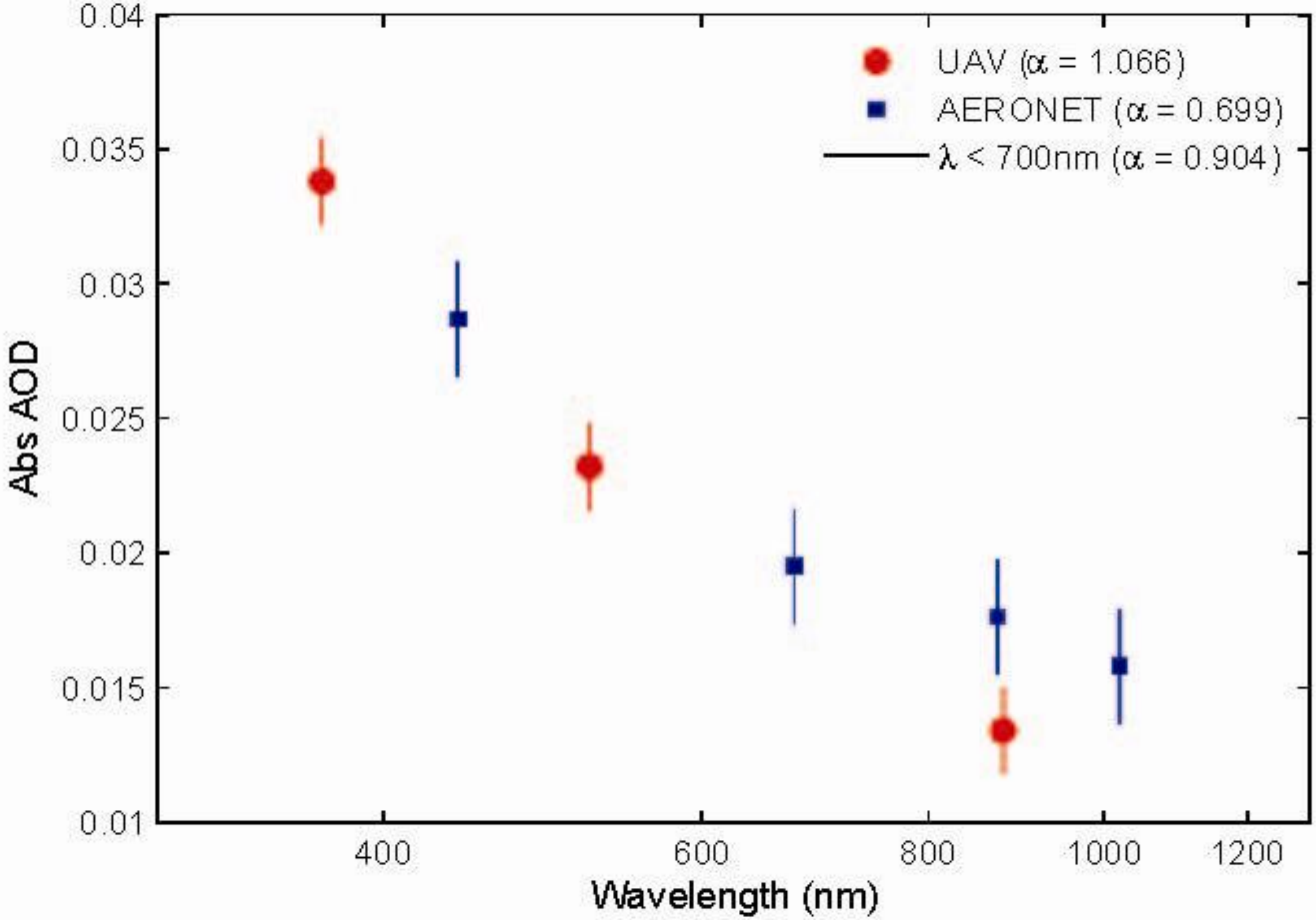
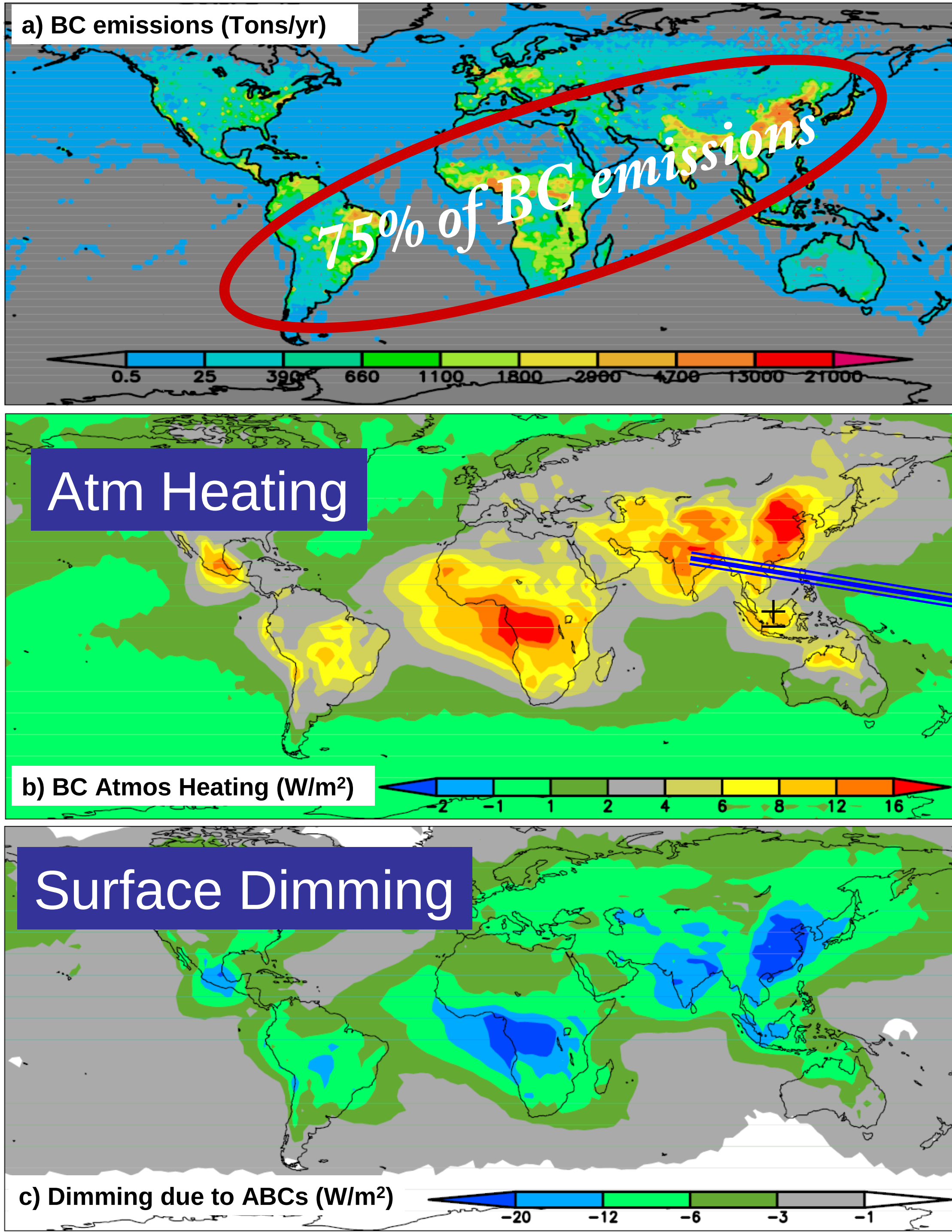


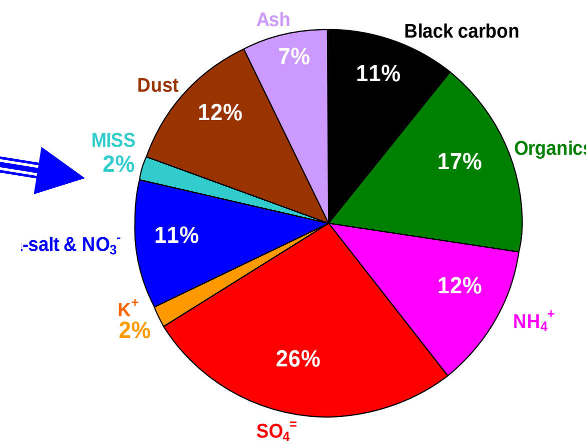
Fig. 16. Comparison of spectral dependence of absorption AOD derived from both UAV absorption photometer and AERONET measurements.

Corrigan et al 2008

ABCs: Emission & Global Forcing

Ramanathan and Carmichael, Nature_Geoscience 2008



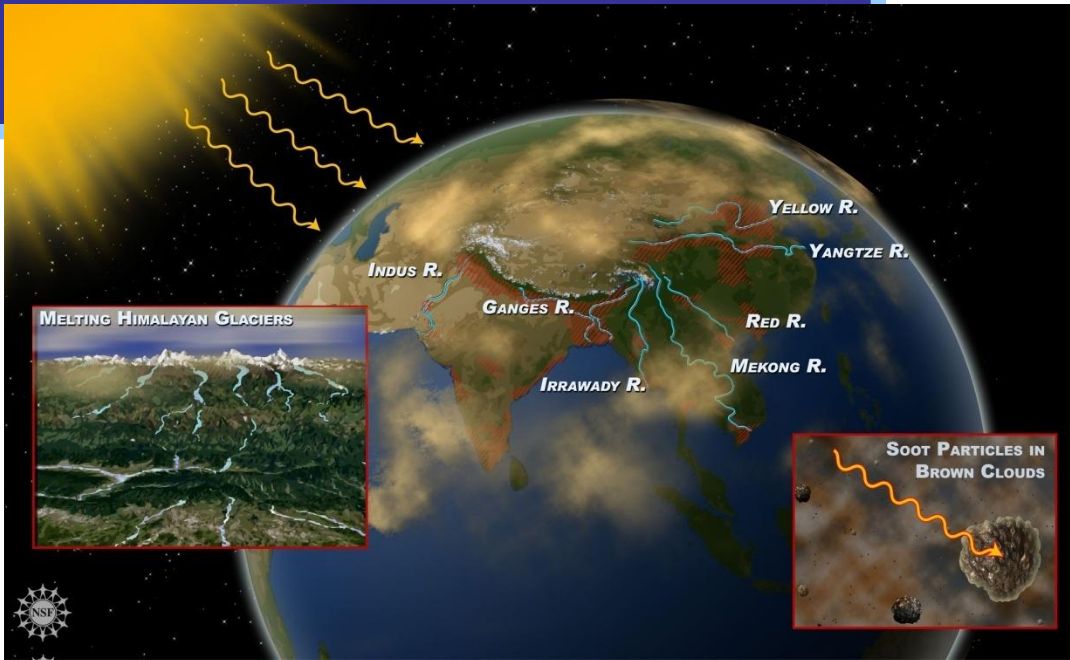


Ramanathan et al, 2001

Hindu Kush-Himalayan-Tibetan Glaciers: Water Fountain of Asia

- 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…



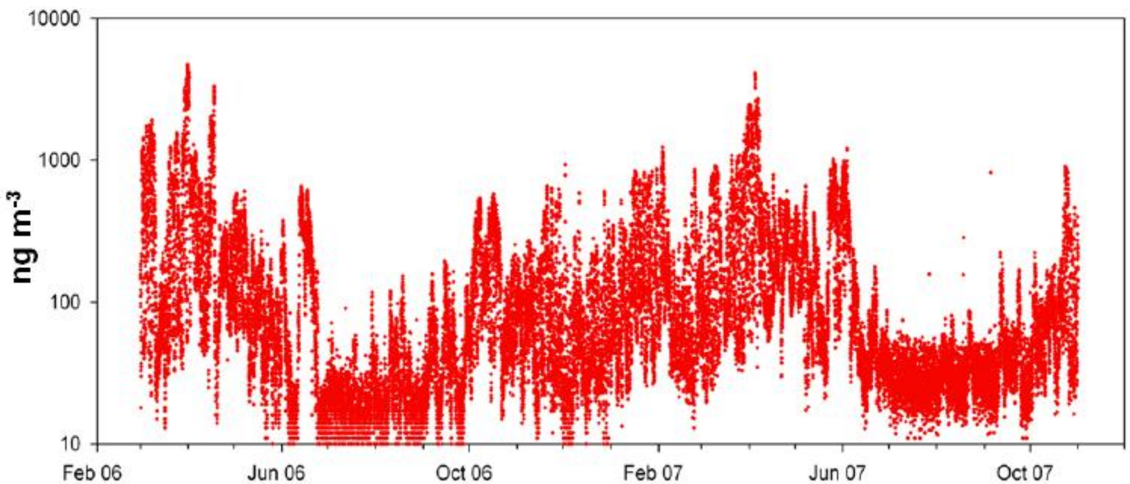
HKHT Glacier Retreat

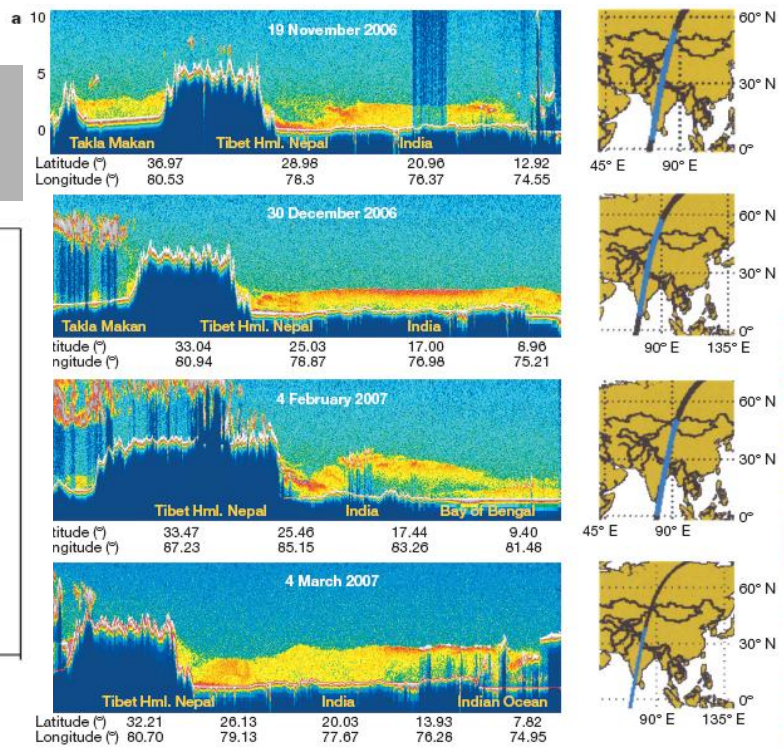
The glacier retreat is primarily attributed in IPCC report and other studies to warming by GHGs

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***

ABCs surround the HKHT

New ABC data reveal significant amount on BC even at 5 km altitude



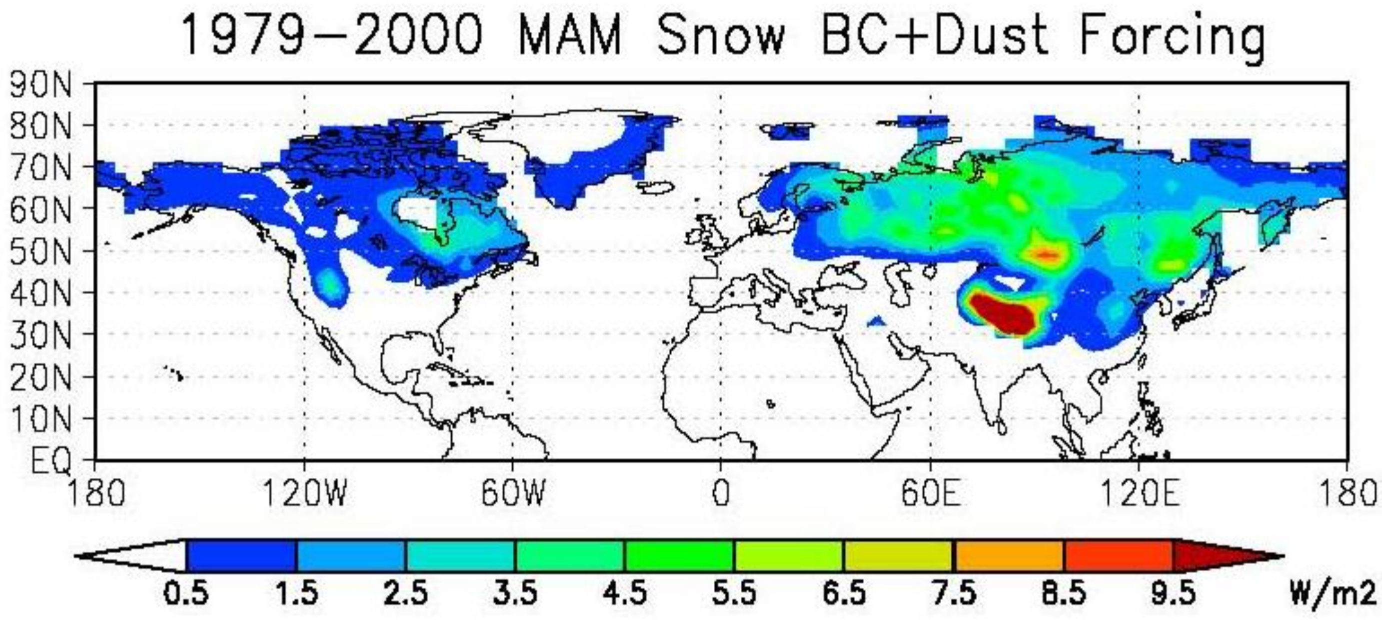


Springtime warming and reduced snow cover from carbonaceous particles

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

	1980	*2005*	*2030*	
Coal (Mton)	**2570** (1373)	**4154** (1615)	**7173** (1883)	**World** (OECD)
Oil (Mbarrels)	**65** (42)	**85** (47)	**116** (53)	
Gas *(B cub met)*	***1521*** *(959)*	***2854*** *(1465)*	***4780*** *(2000)*	

Coal	***SO2 (-)***		***indoor (BC+)***
Oil	***SO2 (-)***	***NOx (Ozone +)***	***Diesel (BC+)***
Gas			

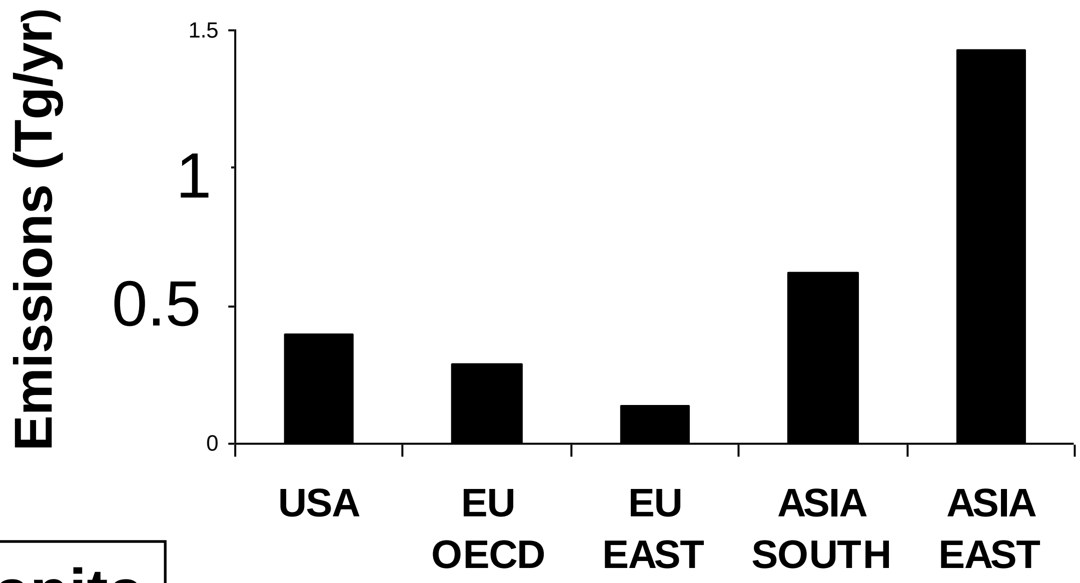
Carbon (as CO_2) emission by the 3 fuels

Coal emits 25 Kg Carbon /Giga-Joules
Oil emits 20 Kg Carbon /Giga-joules
Natural Gas emits 15 Carbon /Giga-joules

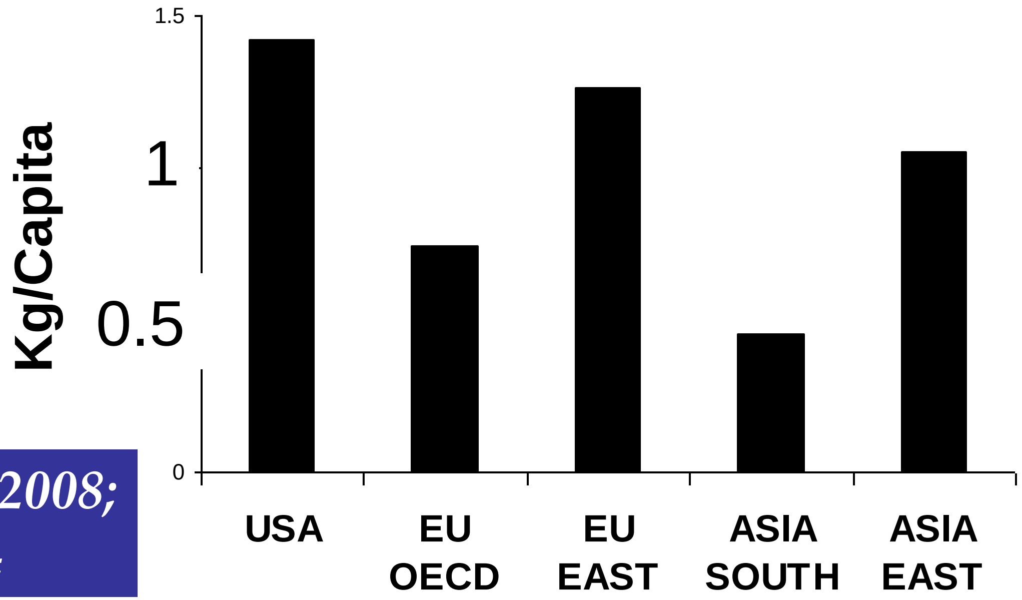
Switching to Natural Gas reduces future warming commitment; but unmasks the aerosol cooling and accelerates approach to the committed warming

Ramanathan, 2008

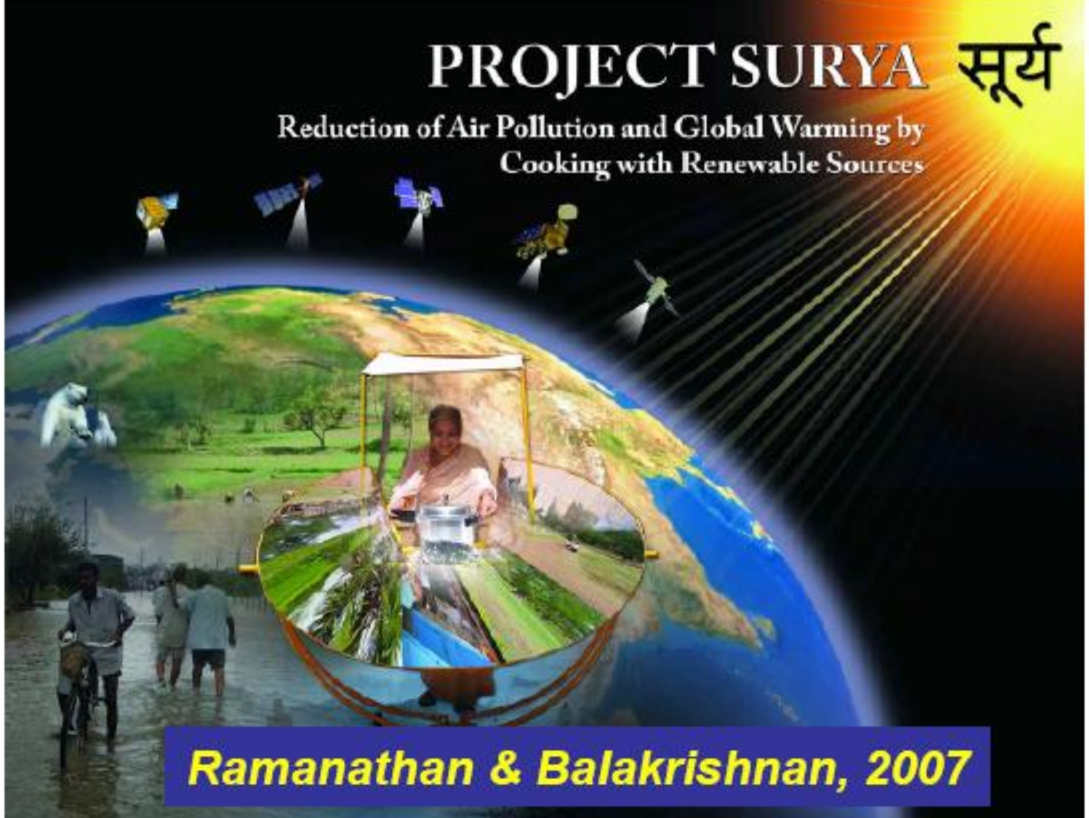
BC emission

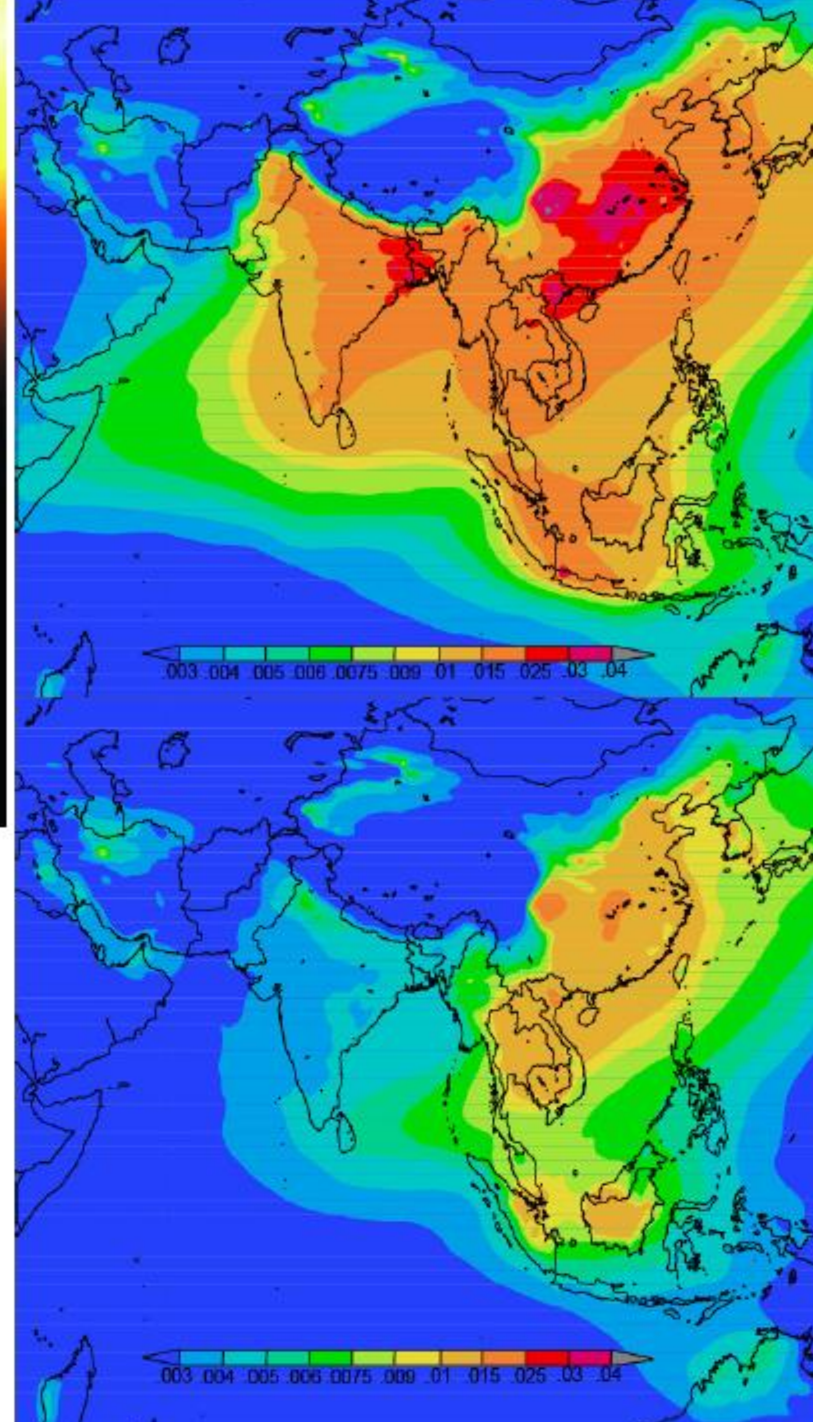


BC Emission/Capita



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


PROJECT SURYA सूर्य
Reduction of Air Pollution and Global Warming by
Cooking with Renewable Sources
Ramanathan & Balakrishnan, 2007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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.

सूर्य PROJECT SURYA

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

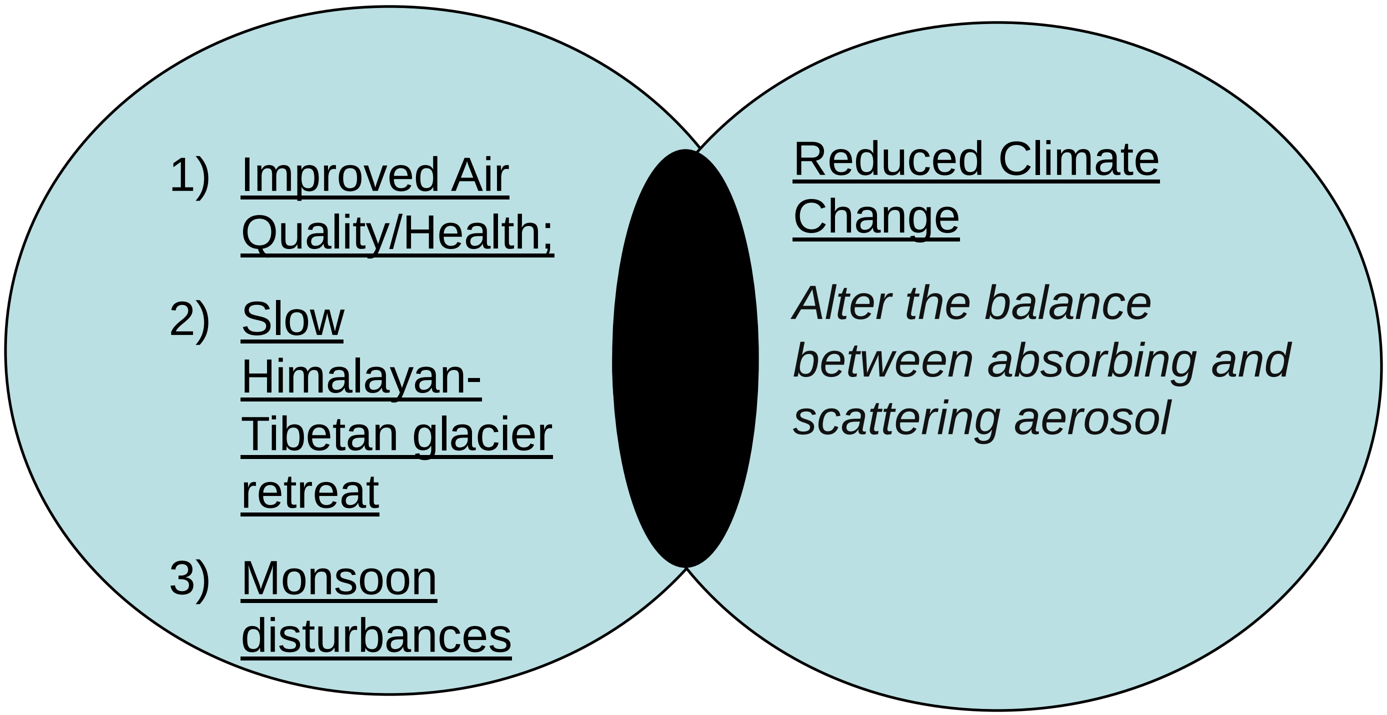
Nucleating more cloud drops can also lead to deepening of clouds…

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



Win/Win Strategy of Biofuels and Biomass burning

+ Decrease PM2.5

+ Decrease BC faster than Sulfate aerosol;

Decrease Ozone: CO and NOx