Black Carbon: A Major Issue for mitigating global and regional climate changes
V. Ramanathan
Scripps Institution of Oceanography, UCSD

9th Intl Conf on Carbonaceous Particles in the Atmosphere

Los Angeles Smog, Dec 27, 2002

MODIS 2001

ABCs over S Asia
Sources of greenhouse Gases and Aerosols in Brown Clouds.
Ramanathan et al 2007
Global Atmosphere

Source: Washington, NCAR, 2005

January 1:0  NCAR/NCIIEP
The Non-CO2 trace gases contribute as much as CO2 to the increase in atmospheric Greenhouse effect: Ramanathan et al, JGR, 1983
Satheesh & Ramanathan, 2000

March 21, 1999: Arabian Sea; Thick haze (9.2°N, 73.5°E)

March 25, 1999: Clouds under thick haze (3.0°N, 74.5°E)

February 24, 1999: Just North of ITCZ; Haze extends up to top of Cu (0.5°N, 73.3°E)

March 24, 1999: South of ITCZ; Almost pristine clouds (7.5°S, 73.5°E)

INDOEX Observations Ramanathan et al 2001
For high BC heating, also see: Jacobson, 2001; Hansen and Nazarenko, 2004; Chung and Seinfeld, 2005
a) BC emissions (Tons/yr)

b) BC Atmos Heating (W/m²)

c) Dimming due to ABCs (W/m²)

ABCs: Emission & Global Forcing

Ramanathan and Carmichael, Nature Geoscience 2008

Ramanathan et al, 2001
Major Rainfall Shifts during the last 50 Years
Chung and Ramanathan 2006

Observed Trends in Summer Rainfall: 1950 to 2002

The Sahelian Drought
The Weakening Indian Monsoon
N-S Shift in Asian rainfall
South Asian Dimming: Sunlight at the ground has decreased by 7%

Ramanathan et al, PNAS, 2005

ABC_1998 (Annual mean over India)
Will South Asian Monsoon become a Climate Tipping Point?

Business as usual Scenario for ABCs

Ramanathan et al 2005
Understanding the physical processes responsible for aerosol–monsoon water cycle interactions is fundamental to improving prediction and enhancing vigilance of climatic hazards in the Asian monsoon region.
Black carbon or brown carbon? The nature of light-absorbing carbonaceous aerosols
M. O. Andreae1 and A. Gelencsér2
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Elemental Carbon
Black Carbon
Organics
HULIS
LAC
Warming Trends in Asia amplified by brown cloud solar absorption

Miniaturized Instruments for UAV

Roberts, Ramana and Corrigan

Optical Particle Counter (580 g) → $N_{OPC}; 0.3 < D_p < 3 \, \mu m$

Pyranometer (190 g) → irradiance 0.3 – 2.8 μm

Aethalometer (820 g) → absorbing aerosol

T/RH probe (50 g) → Temperature & RH

Aerosol inlet & splitter (150 g) → unbiased aerosol sampling

PAR radiometer (45 g) → irradiance 400 – 700 nm

LWC probe (450 g) → Cloud water (g m⁻³)

Cloud Droplet Spectrometer (1.4 kg) → distr. 1 < D < 50 μm

Condensation Particle Counter (870 g) → $N_{CN}; D_p > 10 \, \text{nm}$

Video camera (280 g) → cloud targeting

Roberts, Ramana and Corrigan

T/RH probe (50 g) → Temperature & RH
Capturing vertical profiles of aerosols and black carbon over the Indian Ocean using autonomous unmanned aerial vehicles

C. E. Corrigan, G. C. Roberts, M. V. Ramana, D. Kim, and V. Ramanathan
Closure between UAV derived Absorption Optical Depth And AERONET Abs. AOD

Fig. 16. Comparison of spectral dependence of absorption AOD derived from both UAV absorption photometer and AERONET measurements.
Albedo, atmospheric solar absorption and heating rate measurements with stacked UAVs
M. V. Ramana,* V. Ramanathan, D. Kim, G. C. Roberts and C. E. Corrigan
Center for Atmospheric Sciences, Scripps Institution of Oceanography, University of California at San Diego, La Jolla, USA
Warming trends in Asia amplified by brown cloud solar absorption

Veerabhadran Ramanathan\textsuperscript{1}, Muvva V. Ramana\textsuperscript{1}, Gregory Roberts\textsuperscript{1}, Dohyeong Kim\textsuperscript{1}, Craig Corrigan\textsuperscript{1}, Chul Chung\textsuperscript{1} & David Winker\textsuperscript{2}
Warming trends in Asia amplified by brown cloud solar absorption

Veerabhadran Ramanathan¹, Muvva V. Ramana¹, Gregory Roberts¹, Dohyeong Kim¹, Craig Corrigan¹, Chul Chung¹ & David Winker²

Chung and Seinfeld, 2005
Hindu Kush-Himalayan-Tibetan Glaciers: Water Fountain of Asia
Black Carbon deposition on Snow is a major source for arctic sea ice retreat

Present-day climate forcing and response from black carbon in snow

Mark G. Flanner,1 Charles S. Zender,1 James T. Randerson,1 and Philip J. Rasch2

Black carbon mass concentration in the Sierra Nevada snow pack
O. L. Hadley, C.E. Corrigan, V. Ramanathan; Scripps Institution of Oceanography
T.W. Kirchstetter; Lawrence Berkeley National Lab; S. S. Cliff UC Davis

Annual Average Precipitation (Inches Northern California
Period: 1961-1990

HD (107 m)

HD (100 m)

LAVO (1732 m)

CSSL (2100 m)
Ambient vs. precipitation concentration

Lassen Volcano National Park

- μgrams of BC/m² deposited in one snow day
- ng BC/m³ in the surface air (6 hour time step)
- mm of snow depth deposited (6 hour time step)
Pacific Dust Expt
May 21 2007; 22 UTC

Black Carbon & Dust
5 km; 8 km

Beijing Olympics Campaign (CAPMEX)
June to Sept -08

Long Range Transport Of Black Carbon

CIFEX : N California
Hadley et al, 2006

Stith and Ramanathan, 2006
Beijing Olympics Campaign (Aug and Sept 2008)

California Air Pollution and Climate Forcing Campaign
NASA Dryden; Antelope Valley, CA; May 08 to Marc 09

Corrigan, Nguyen, Lehmann, Ramana, Ramanathan
Simulated BC ($\mu g/m^3$) in the Lowest layer at UTC, 08/14/2008

Simulated Sulfate ($\mu g/m^3$) in the Lowest layer at UTC, 08/14/2008
Black Carbon over NASA Dryden

![Graph showing Black Carbon (BC) vs. Altitude (feet) with data points for 10-Jul and 13-May.](image-url)
UAV-BC profile
CEC funded
Corrigan et al, 2008

Thomas W. Kirchstetter\textsuperscript{a,*}, Jeffery Aguiar\textsuperscript{a}, Shaheen Tonse\textsuperscript{a}, David Fairley\textsuperscript{b}, T. Novakov\textsuperscript{a}
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
How should We Unmask the ABC Effect?

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

SO$_2$ Emissions

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

Ramanathan 2007
BC emission

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

Indoor cheap sensors: 2000 sensors

Traveling Laboratory

ABC Observatories

Physicians

Ramanathan and Balakrishnan, 2007
Why is Venus so hot?

Ramanathan, 2006

http://www.solarviews.com/raw/venus/venusvis.gif