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

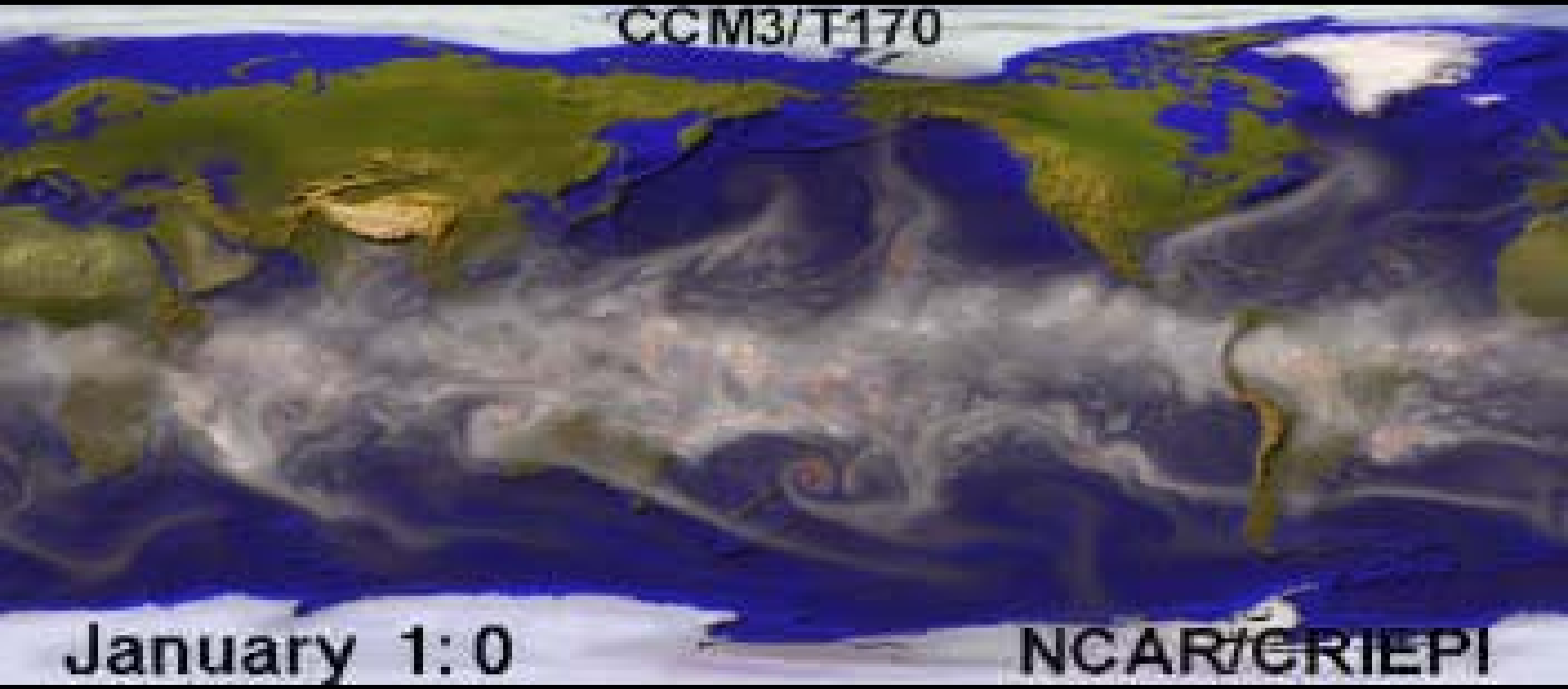
ABCs over S Asia

Sources of greenhouse Gases and Aerosols in Brown Clouds.

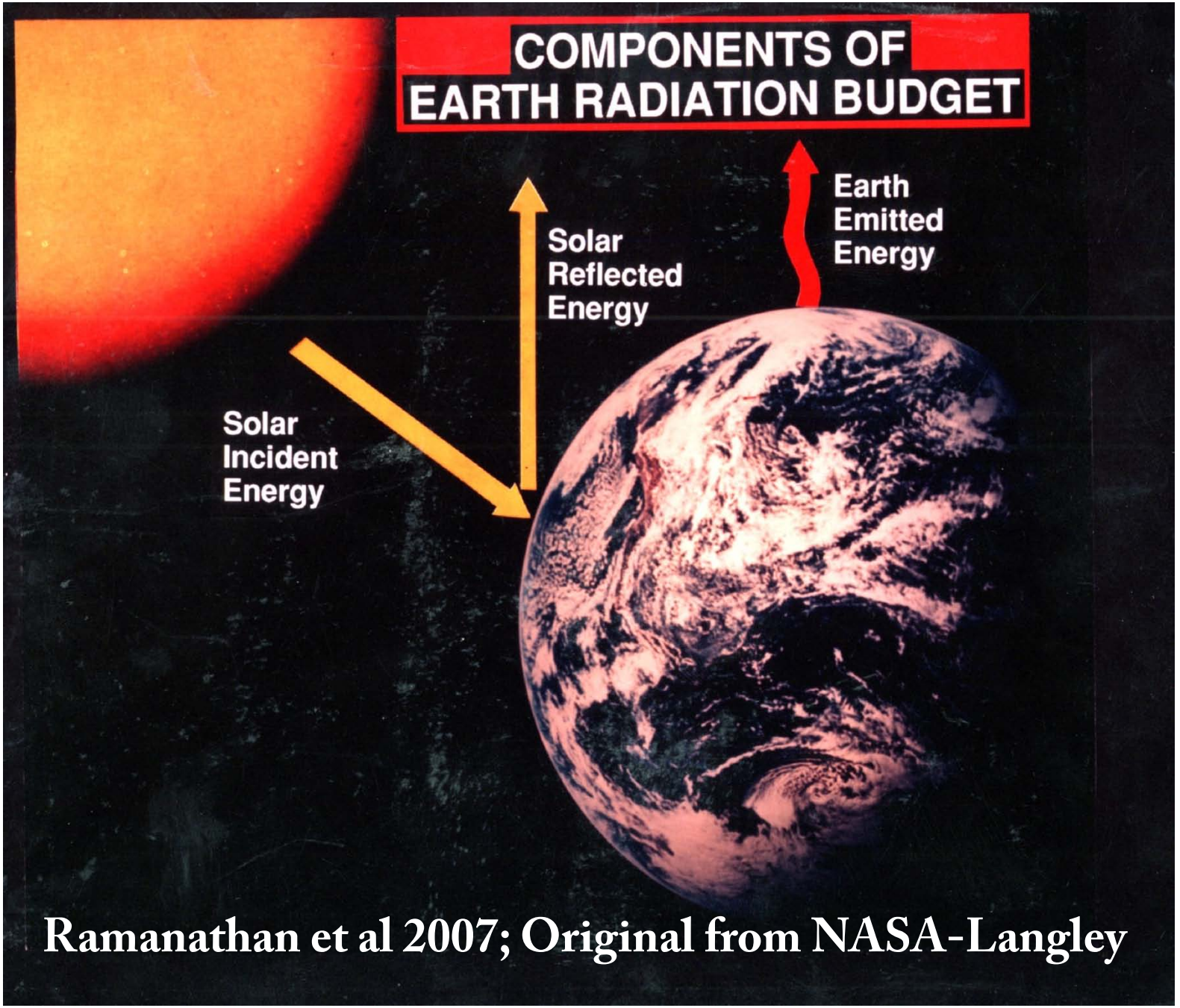
Ramanathan et al 2007

Global Atmosphere

Source: Washington, NCAR, 2005



Ramanathan 2007



Ramanathan et al 2007; Original from NASA-Langley

WORLD METEOROLOGICAL ORGANIZATION
GLOBAL OZONE RESEARCH AND MONITORING PROJECT—REPORT NO. 16

ATMOSPHERIC OZONE 1985

ASSESSMENT OF OUR UNDERSTANDING OF THE PROCESSES CONTROLLING ITS PRESENT DISTRIBUTION AND CHANGE

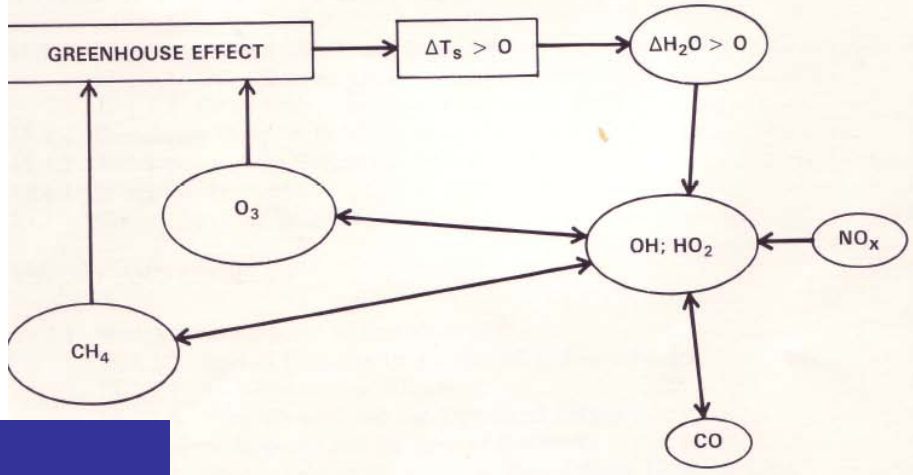
VOLUME III

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CHAPTER 15

TRACE GAS EFFECTS ON CLIMATE

CLIMATE – CHEMISTRY INTERACTIONS



Panel Members

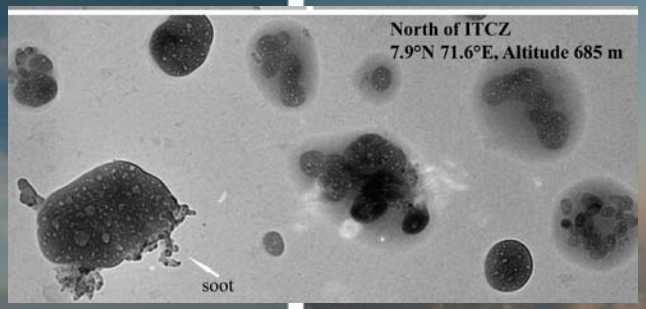
V. Ramanathan, Chairman

L.B. Callis, Jr.
R.D. Cess
J.E. Hansen
I.S.A. Isaksen
W.R. Kuhn
A. Lacis
F.M. Luther
J.D. Mahlman
R.A. Reck
M.E. Schlesinger

The Non-CO2 trace gases contribute as much as CO2 to the increase in atmospheric Greenhouse effect: Ramanathan et al, JGR, 1983

a

Satheesh
&Ramanathan, 2000

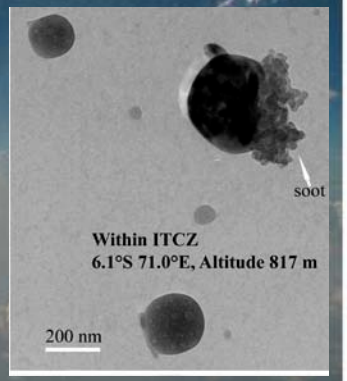


March 21, 1999: Arabian Sea; Thick haze (9.2°N, 73.5°E)

b

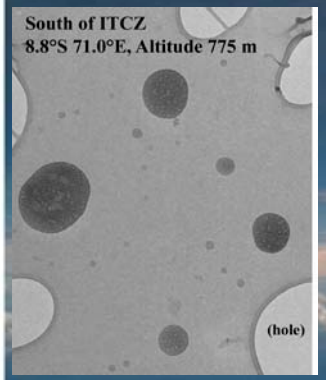
March 25, 1999: Clouds under thick haze (3.0°N, 74.5°E)

c



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

d



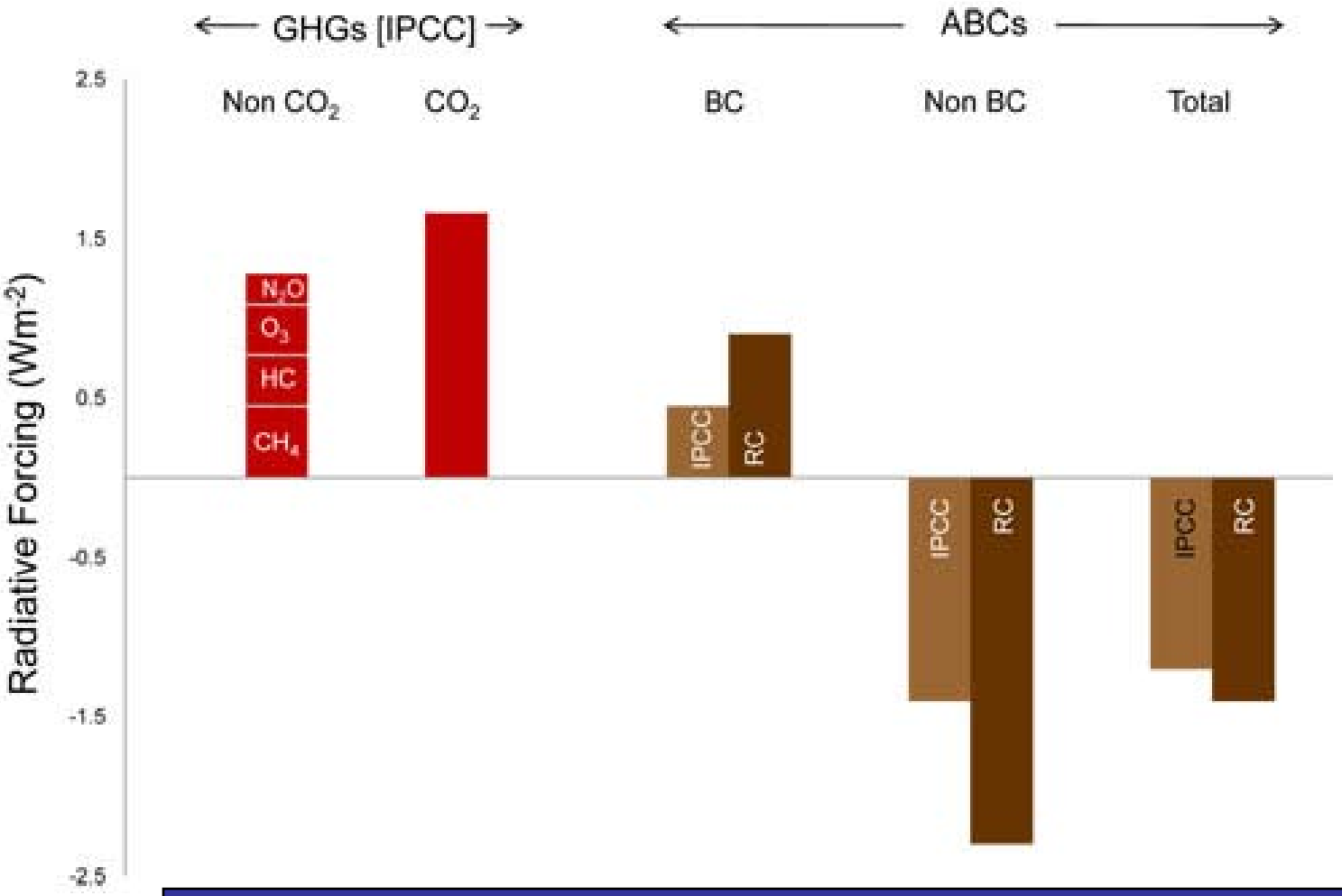
March 24, 1999: South of ITCZ;
Almost pristine clouds (7.5°S, 73.5°E)

INDOEX Observations Ramanathan et al 2001

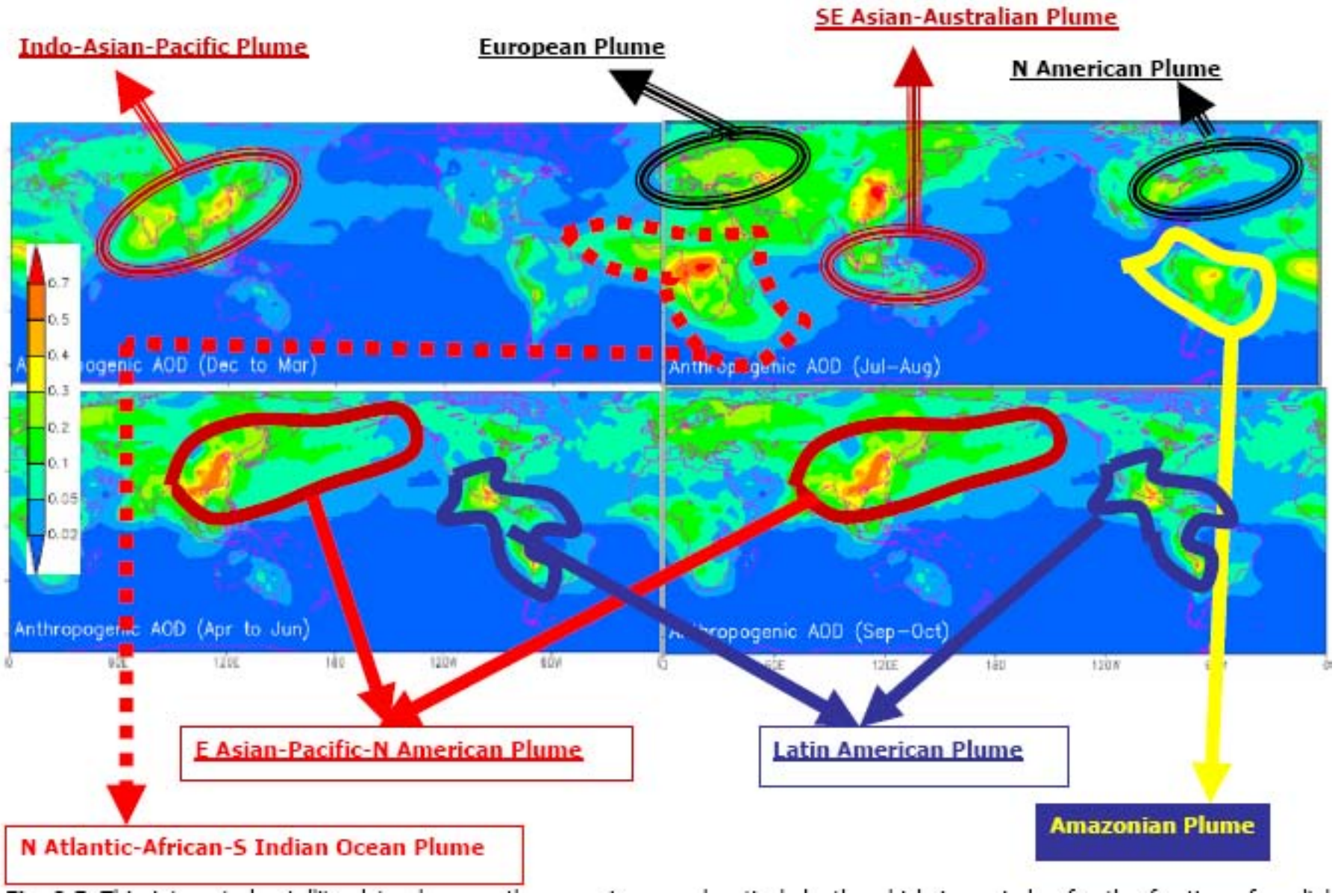
Global and regional climate changes due to black carbon

V. RAMANATHAN AND G. CARMICHAEL

nature geoscience | VOL 1 | APRIL 2008 | www.nature.com/naturegeoscience

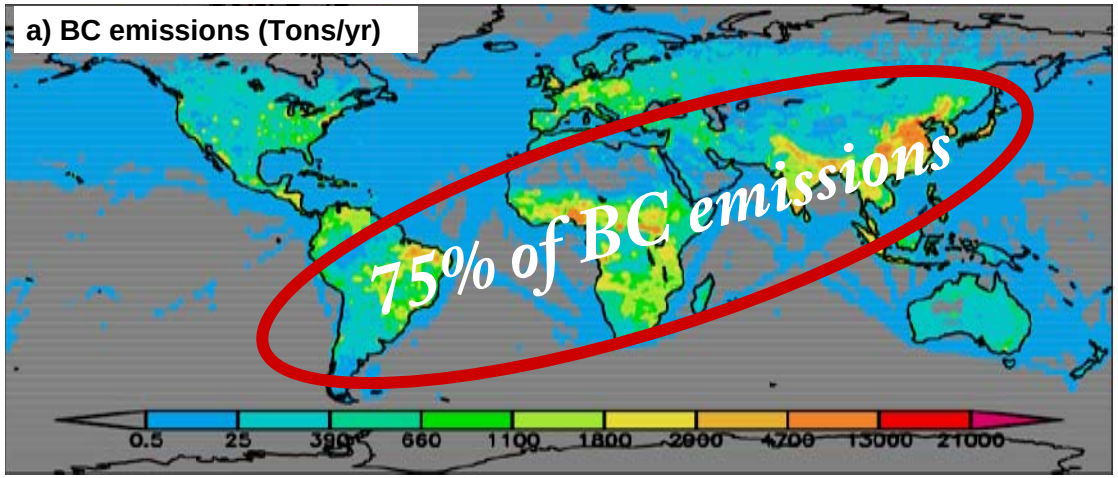


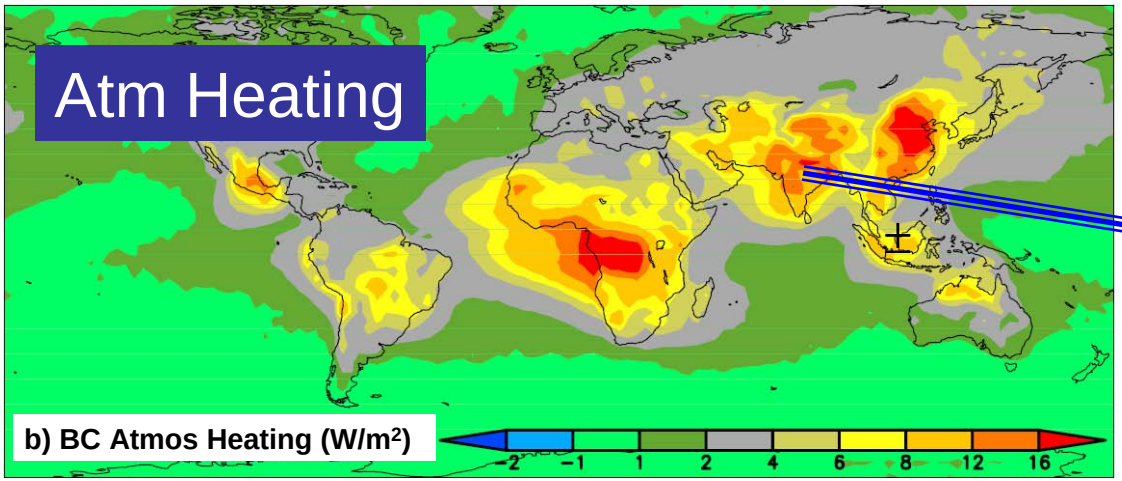
For high BC heating, also see: Jacobson, 2001; Hansen and Nazarenko, 2004; Chung and Seinfeld, 2005

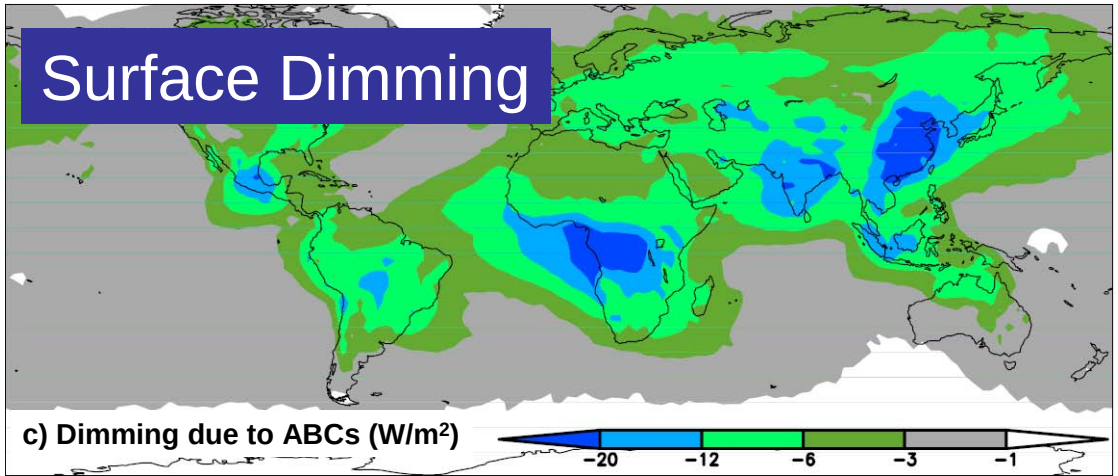

Indo-Asian-Pacific Plume
European Plume
SE Asian-Australian Plume
N American Plume
0.7
0.5
0.4
0.3
0.2
0.1
0.05
0.02
ogenic AOD (Dec to Mar)
Anthropogenic AOD (Jul–Aug)
Anthropogenic AOD (Apr to Jun)
Anthropogenic AOD (Sep–Oct)
E Asian-Pacific-N American Plume
Latin American Plume
N Atlantic-African-S Indian Ocean Plume
Amazonian Plume

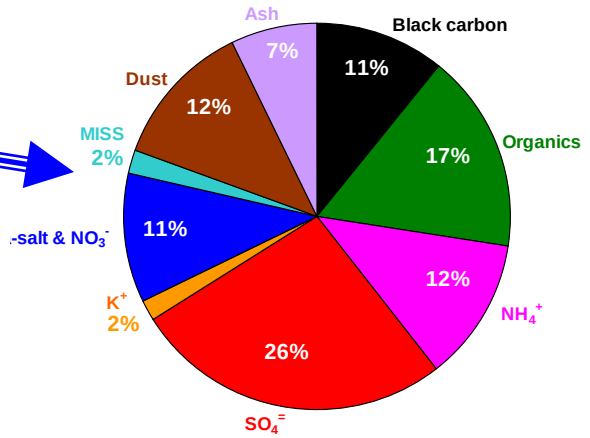
ABCs: Emission & Global Forcing

Ramanathan and Carmichael, Nature_Geoscience 2008





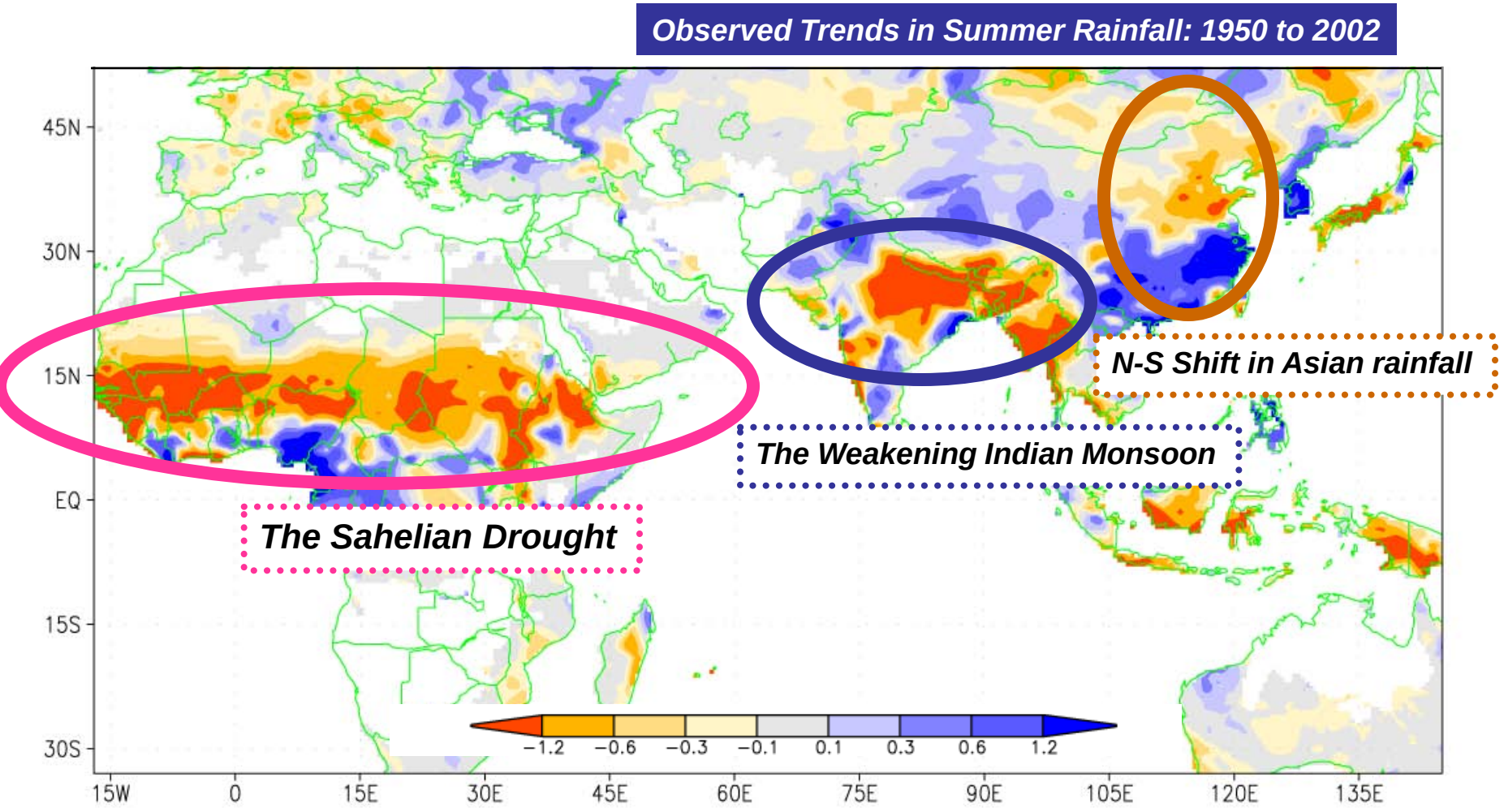




Ramanathan et al, 2001

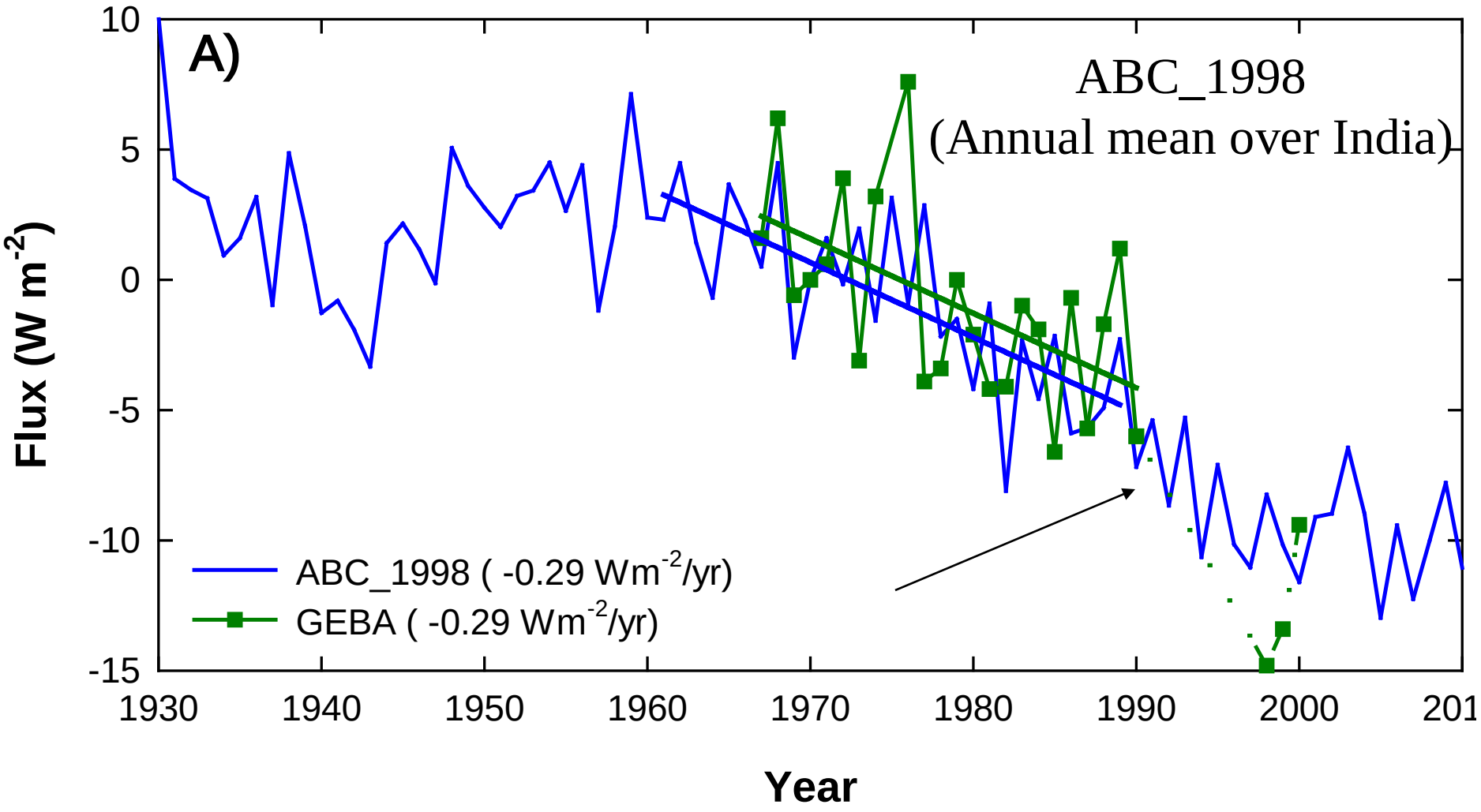
Major Rainfall Shifts during the last 50 Years

Chung and Ramanathan 2006

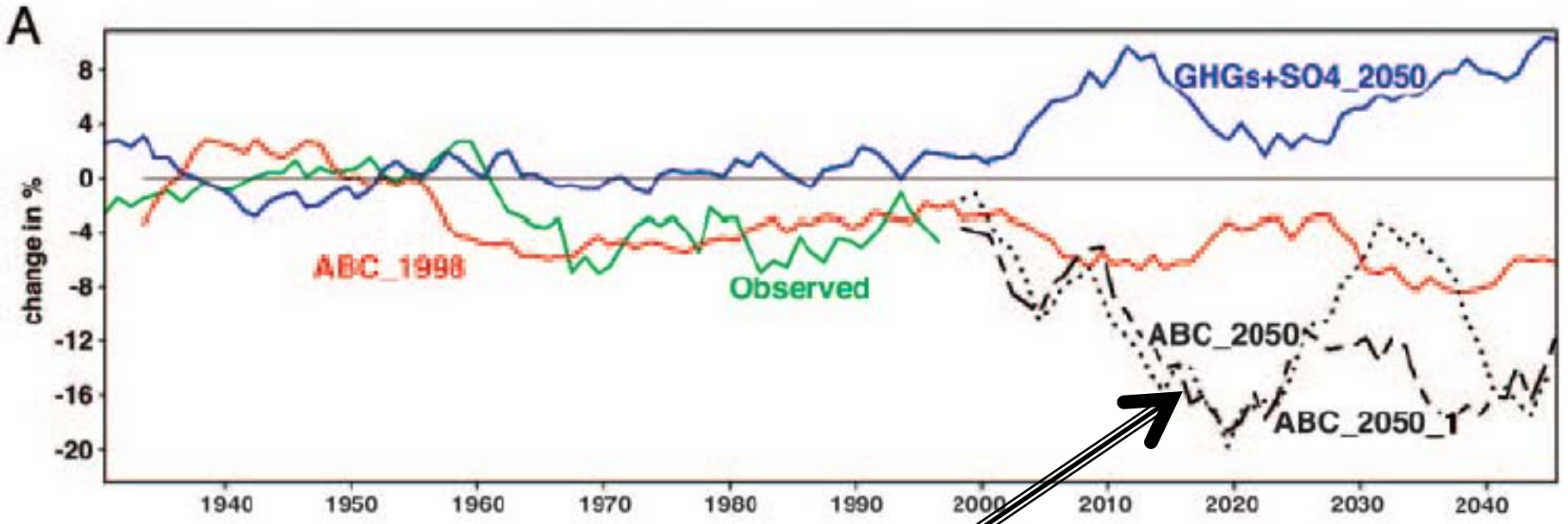


South Asian Dimming: Sunlight at the ground has decreased by 7%

Ramanathan et al, PNAS, 2005



Will South Asian Monsoon become a Climate Tipping Point?



Business as usual Scenario for ABCs

Ramanathan et al 2005

THE JOINT AEROSOL–MONSOON EXPERIMENT: A New Challenge for Monsoon Climate Research

BY K.-M. LAU, V. RAMANATHAN, G.-X. WU, Z. LI, S. C. TSAY, C. HSU, R. SIKKA, B. HOLBEN, D. LU, G. TARTARI, M. CHIN, P. KOUDELOVA, H. CHEN, Y. MA, J. HUANG, K. TANIGUCHI, AND R. ZHANG

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.

AMERICAN METEOROLOGICAL SOCIETY, BAMS, MARCH 2008 | 369

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

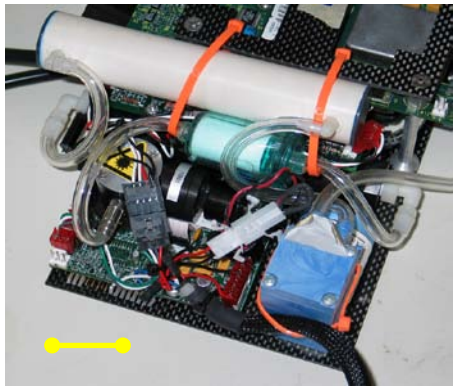
LAC

Warming Trends in Asia amplified by brown cloud solar absorption

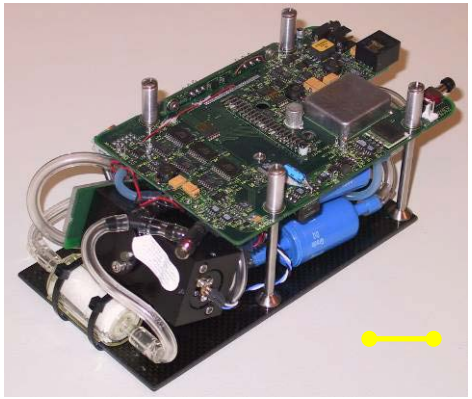
Ramanathan et al, Nature, 448, 575-578, 2007.

Miniaturized Instruments for UAV

Roberts, Ramana and Corrigan



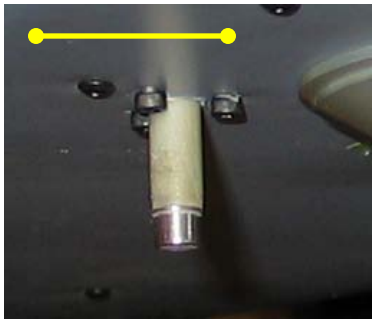
Optical Particle Counter (580 g)
→ N_{OPC}; $0.3 < D_p < 3$ μm



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

[=] 1 inch

Aethalometer (820 g)
→ absorbing aerosol

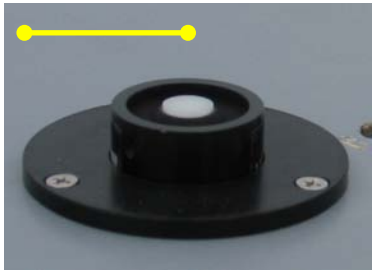


T/RH probe (50 g)
→ Temperature & RH

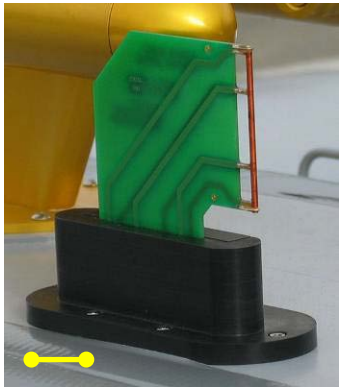
Aerosol inlet & splitter (150 g)
→ unbiased aerosol sampling

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

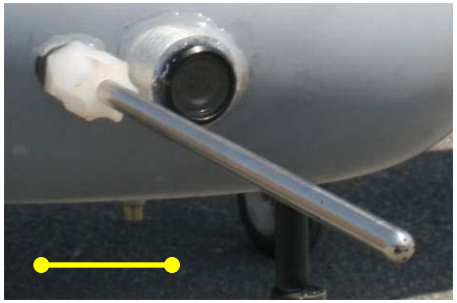
Pyranometer (190 g)
→ irradiance 0.3 – 2.8 μm



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



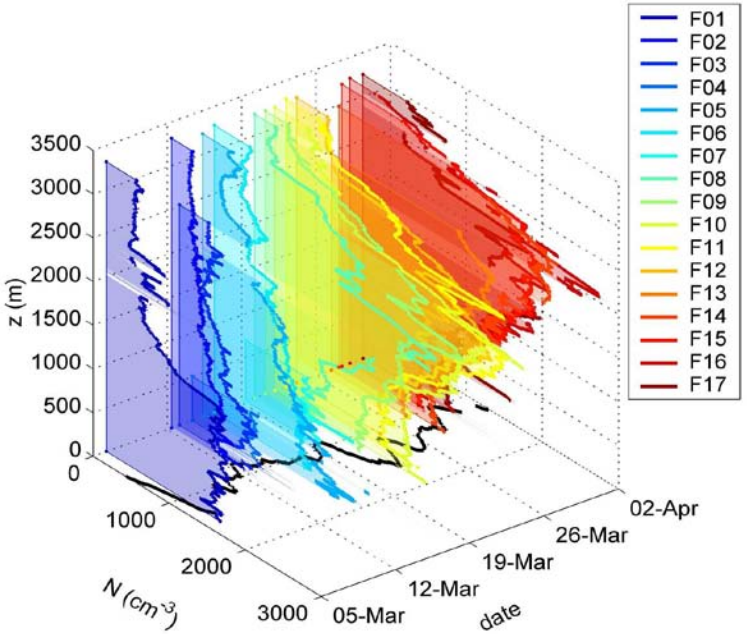
LWC probe (450 g)
→ Cloud water (g m^{-3})

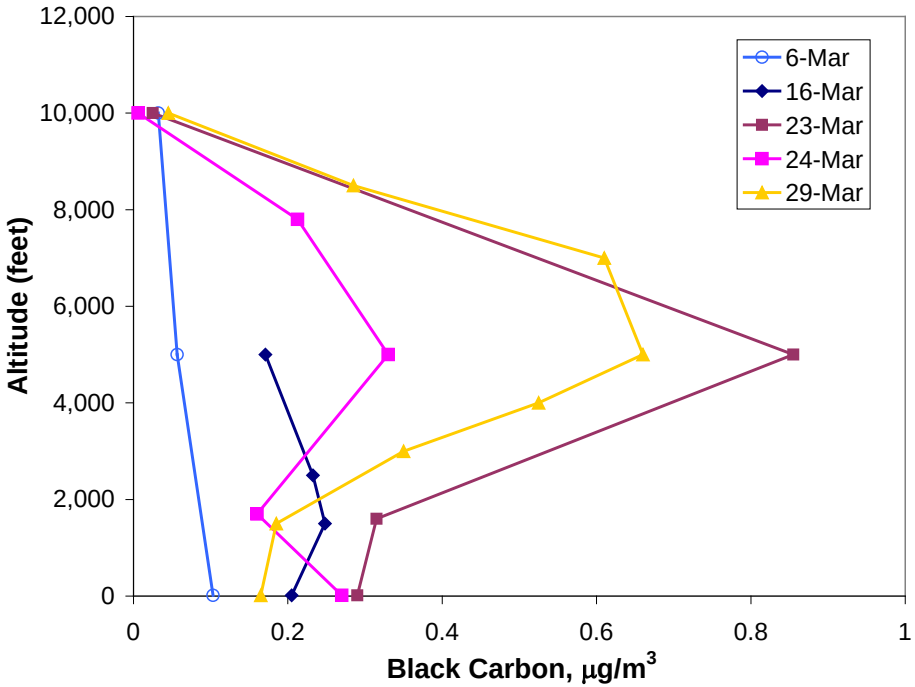


Video camera (280 g)
→ cloud targeting

Capturing vertical profiles of aerosols and black carbon over the Indian Ocean using autonomous unmanned aerial vehicles

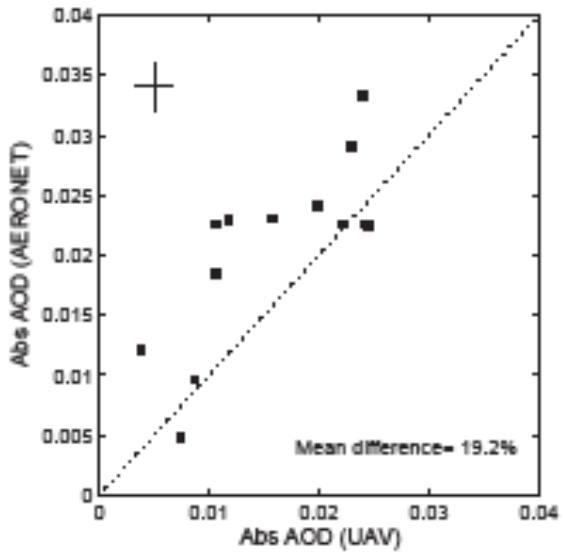
C. E. Corrigan, G. C. Roberts, M. V. Ramana, D. Kim, and V. Ramanathan





Corrigan et al., 2007

Closure between UAV derived Absorption Optical Depth And AERONET Abs. AOD



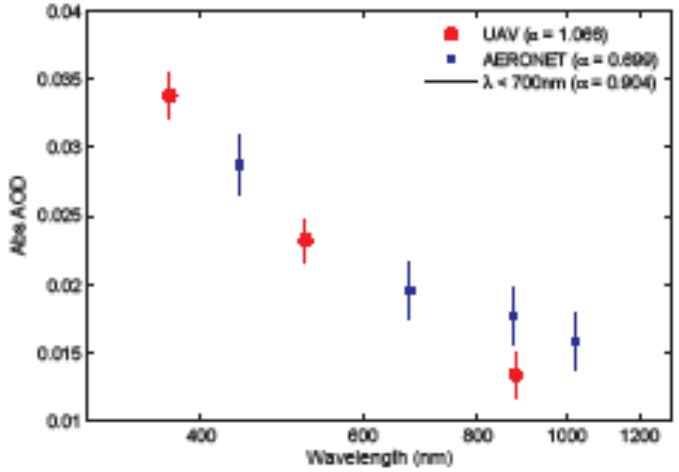
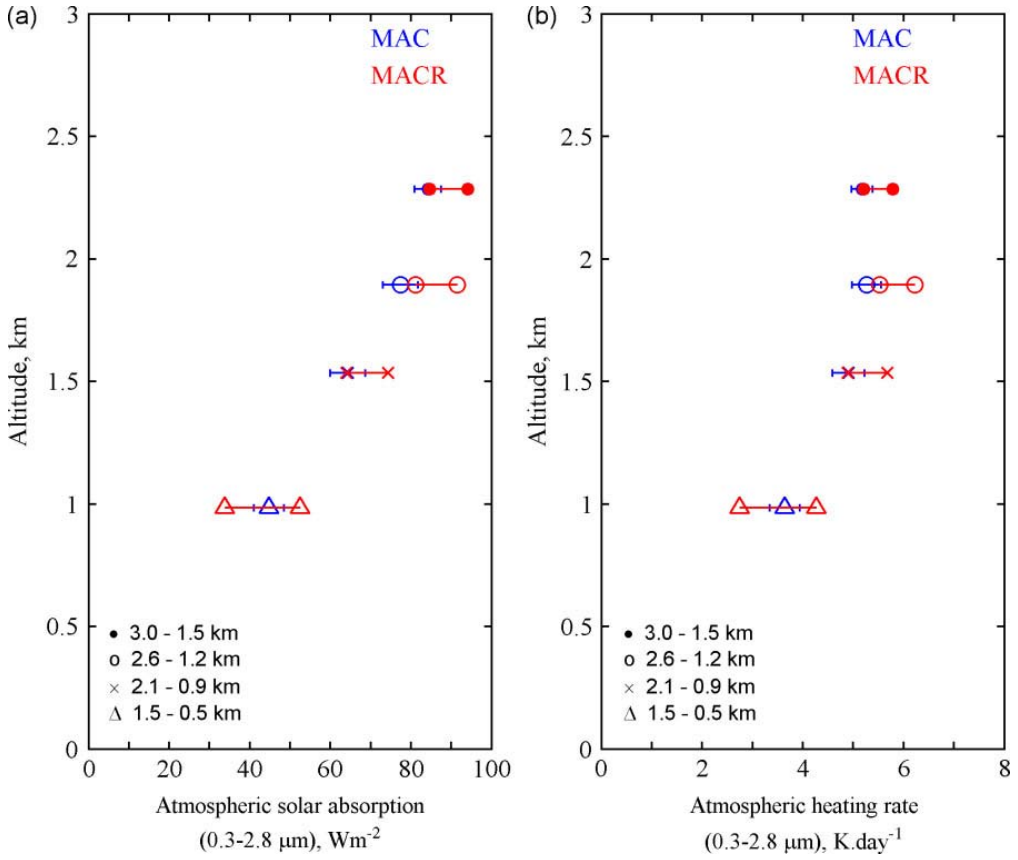
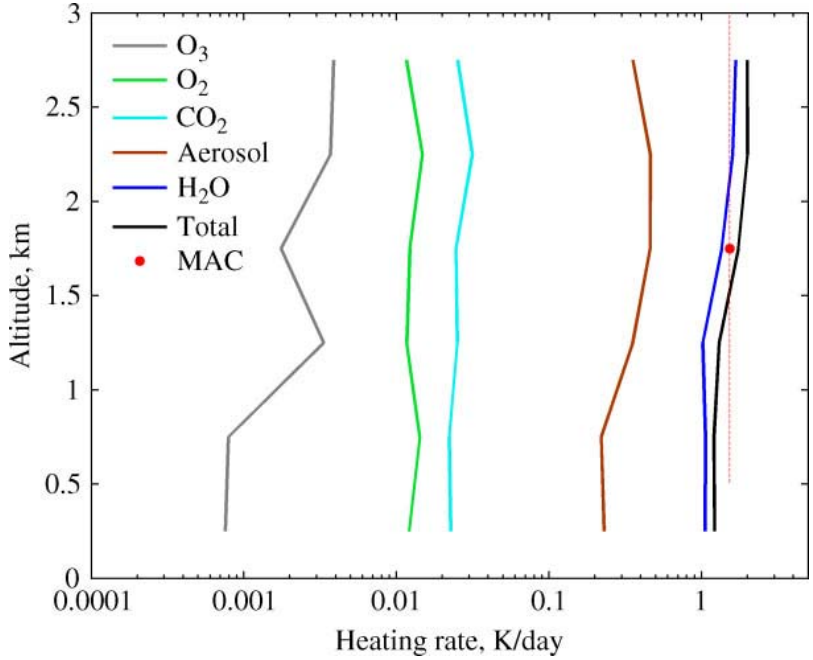


Fig. 16. Comparison of spectral dependence of absorption AOD derived from both UAV absorption photometer and AERONET measurements.

Albedo, atmospheric solar absorption and heating rate measurements with stacked UAVs

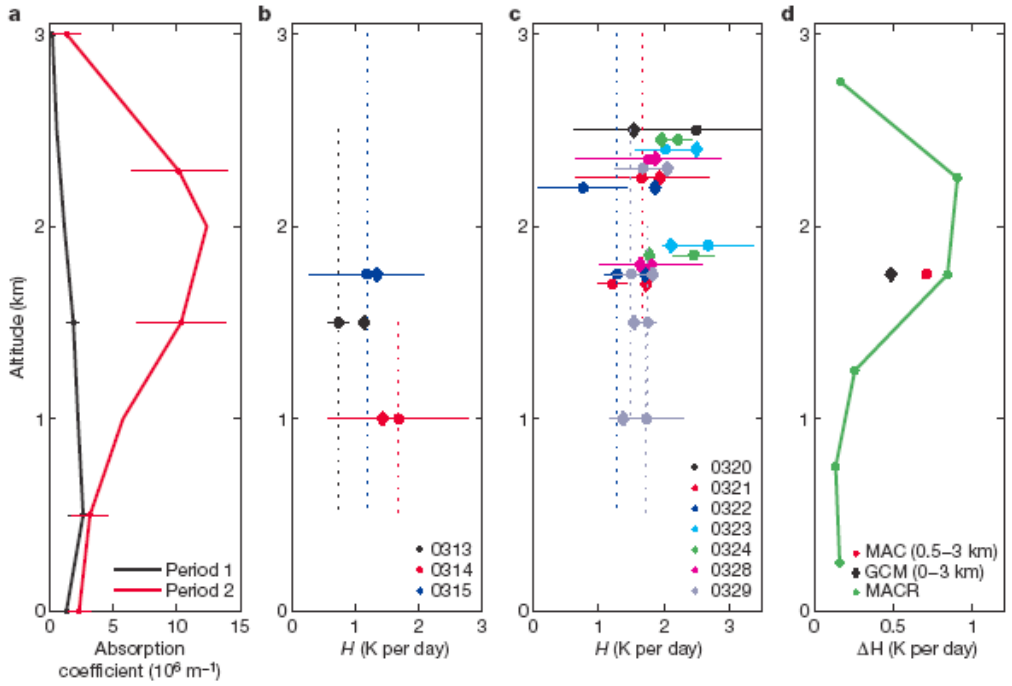
M. V. Ramana,* V. Ramanathan, D. Kim, G. C. Roberts and C. E. Corrigan
Center for Atmospheric Sciences, Scripps Institution of Oceanography, University of California at San Diego, La Jolla, USA





Warming trends in Asia amplified by brown cloud solar absorption

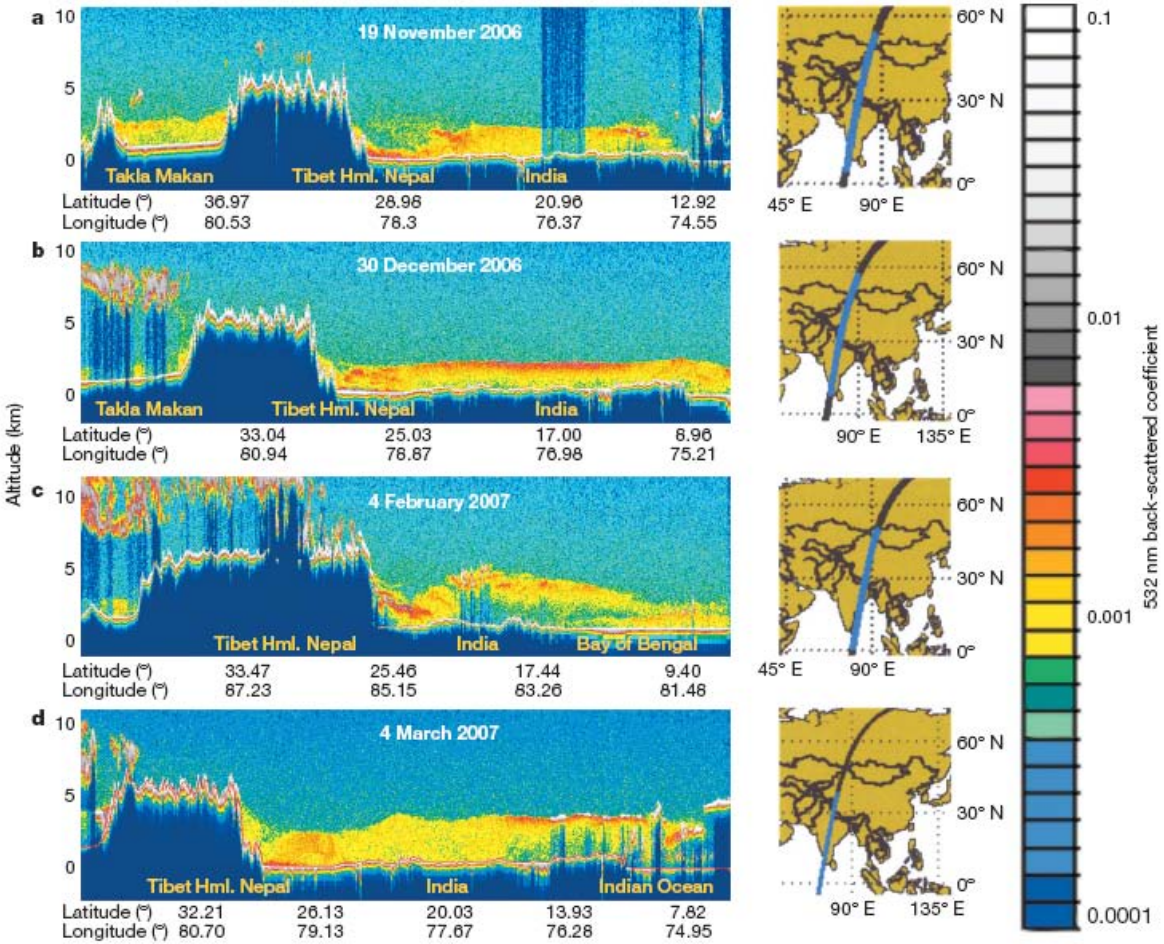
Veerabhadran Ramanathan[1], Muvva V. Ramana[1], Gregory Roberts[1], Dohyeong Kim[1], Craig Corrigan[1], Chul Chung[1] & David Winker[2]

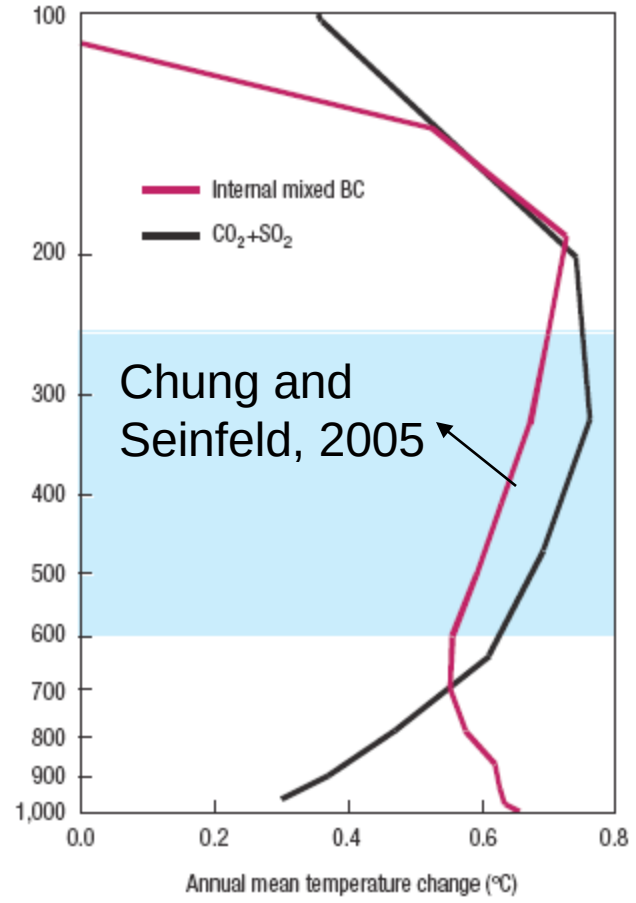


Warming trends in Asia amplified by brown cloud solar absorption

Nature Aug 2007

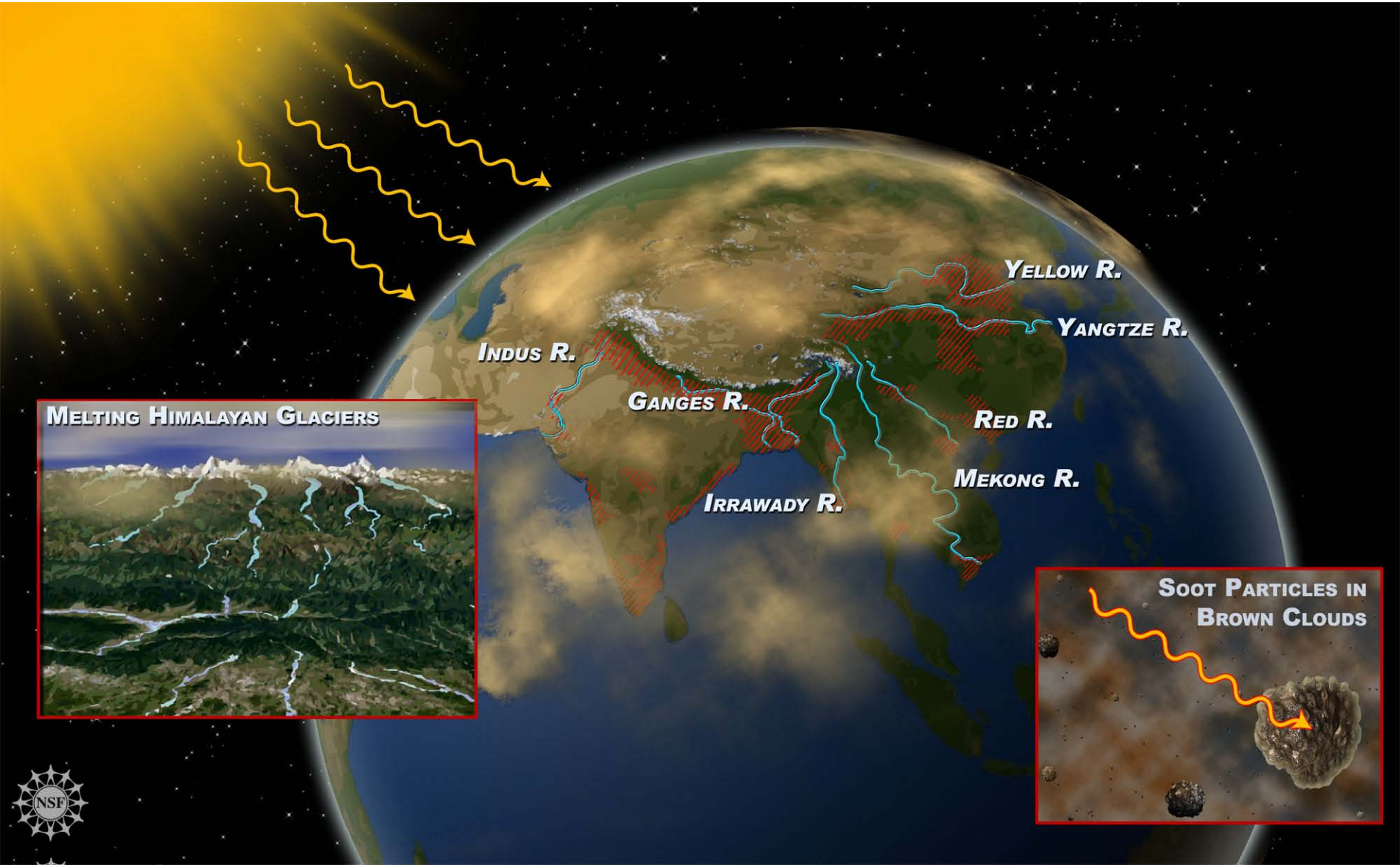
Veerabhadran Ramanathan[1], Muvva V. Ramana[1], Gregory Roberts[1], Dohyeong Kim[1], Craig Corrigan[1], Chul Chung[1] & David Winker[2]





Hindu Kush-Himalayan-Tibetan Glaciers:

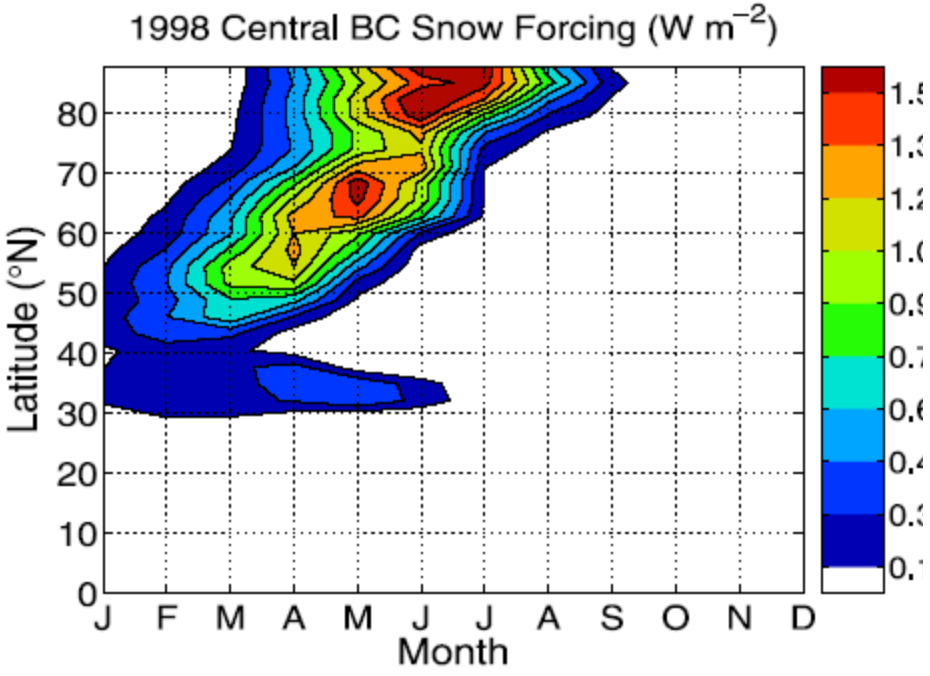
Water Fountain of Asia

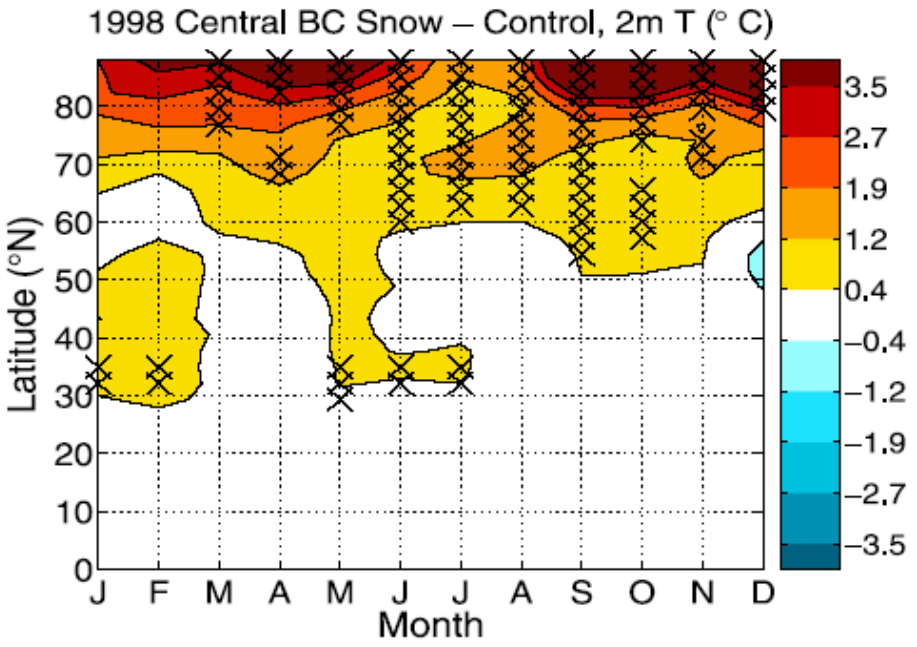


Black Carbon deposition on Snow is a major source for arctic sea Ice retreat

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. Rasch[2]



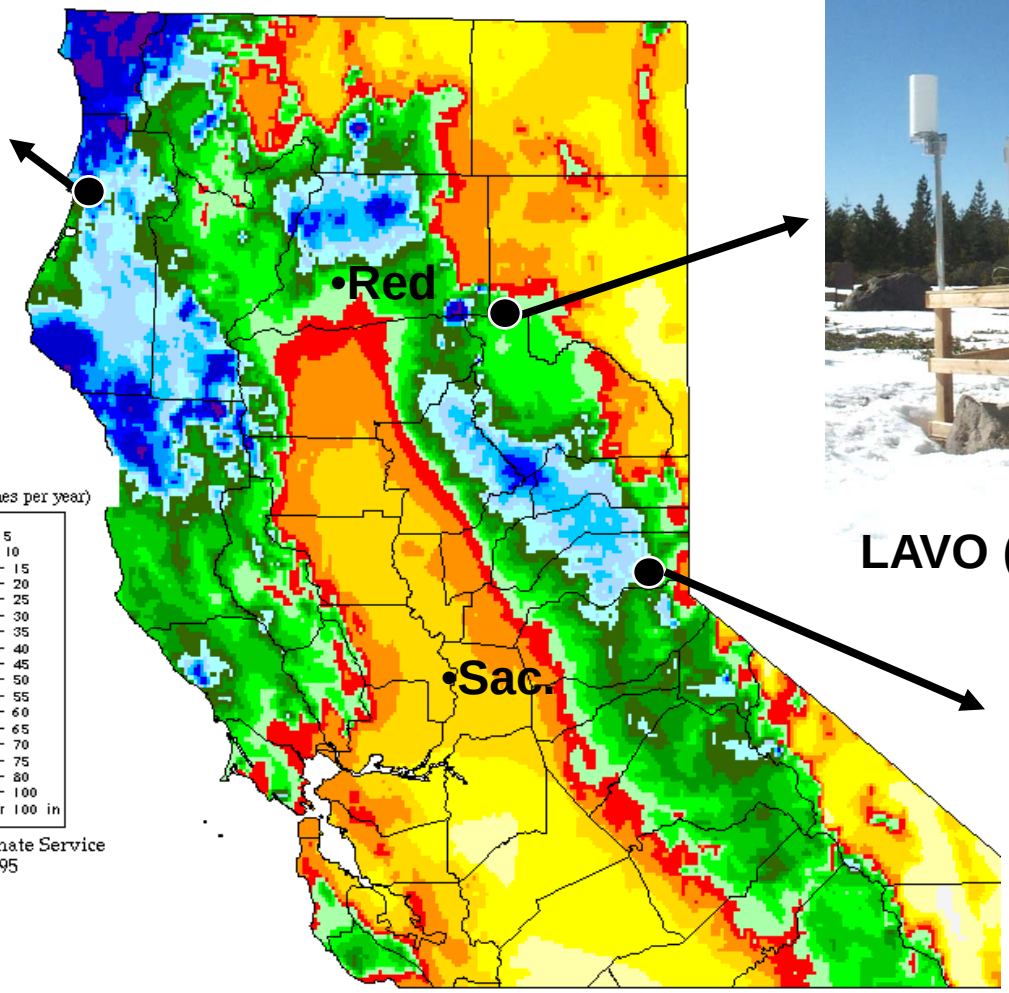


JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 112, D11202, doi:10.1029/2006JD008003, 2007

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

HD (107 m)

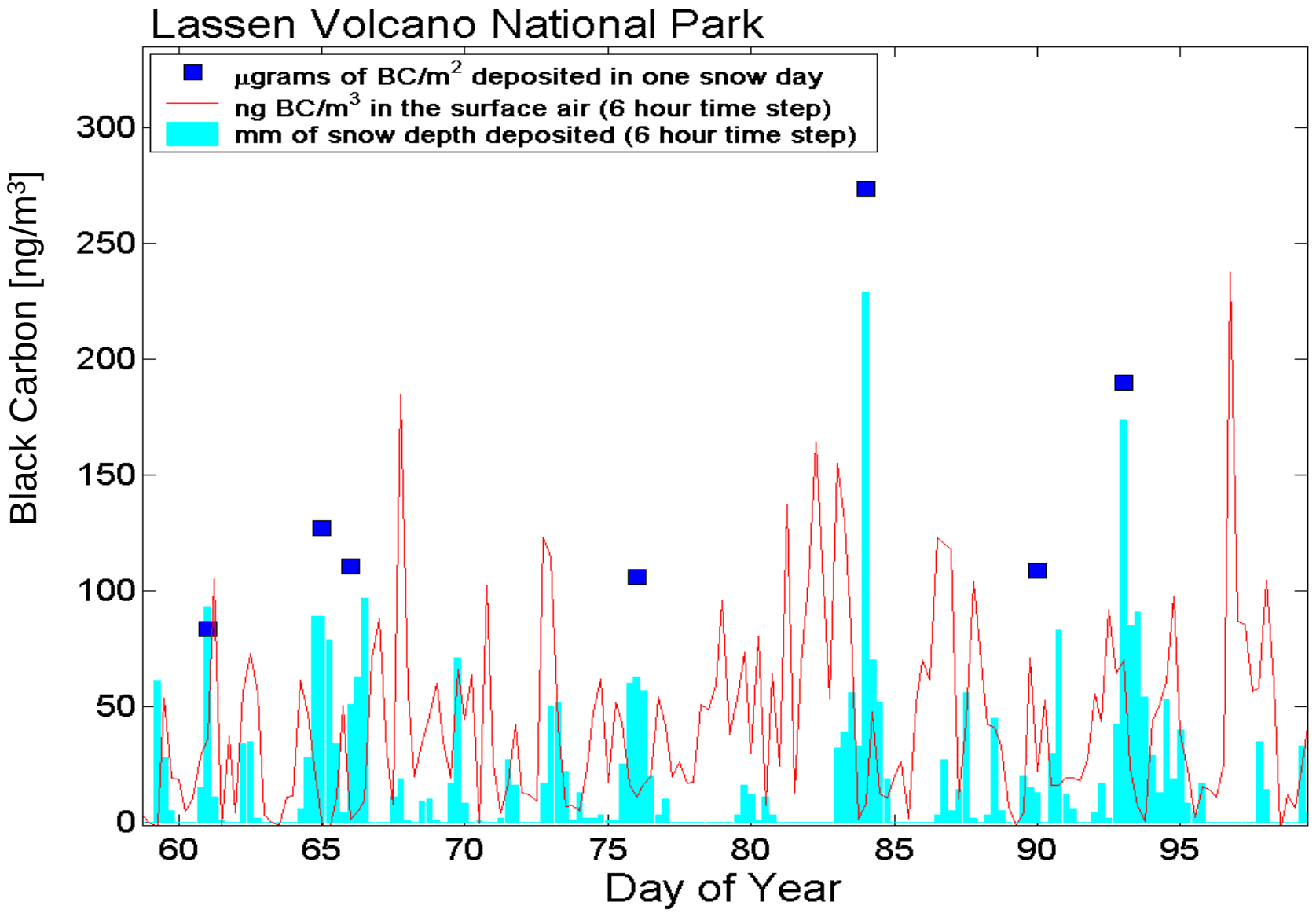


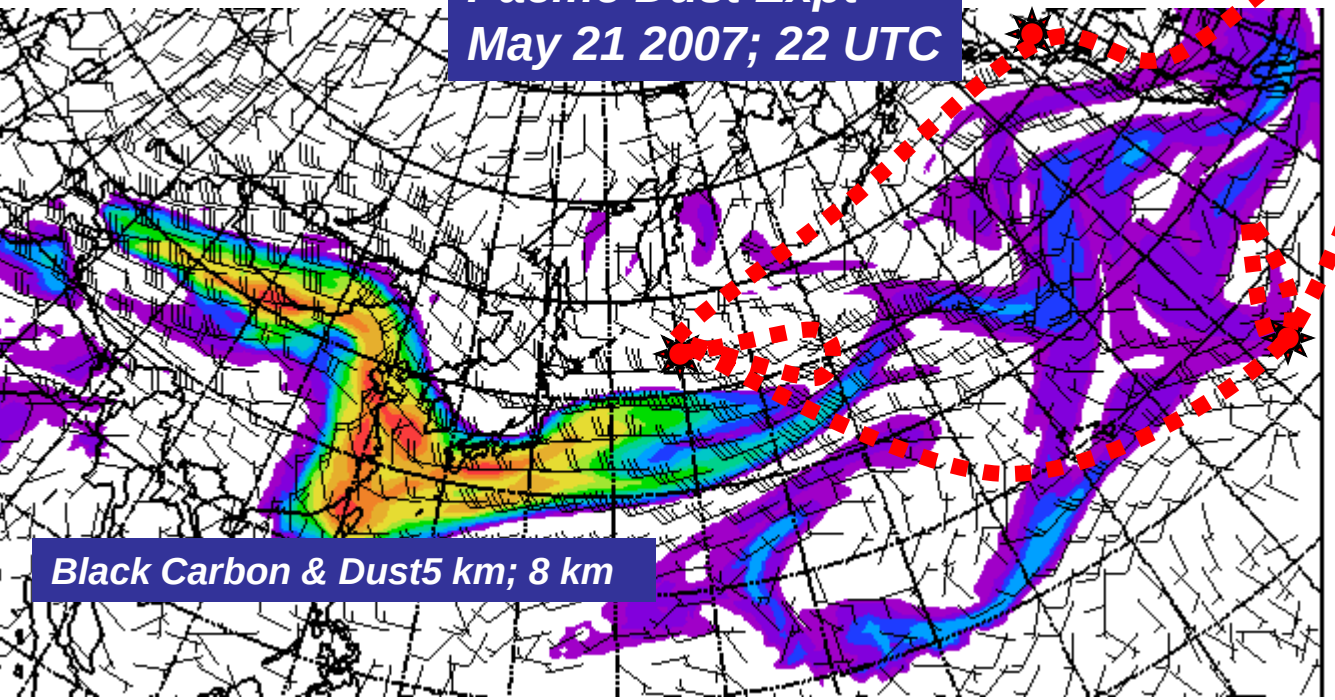
LAVO (1732 m)

HD (100 m)

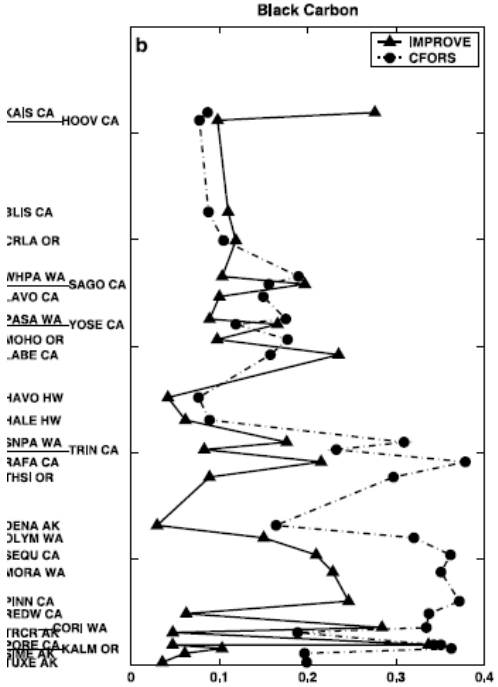
CSSL (2100 m)

Ambient vs. precipitation concentration





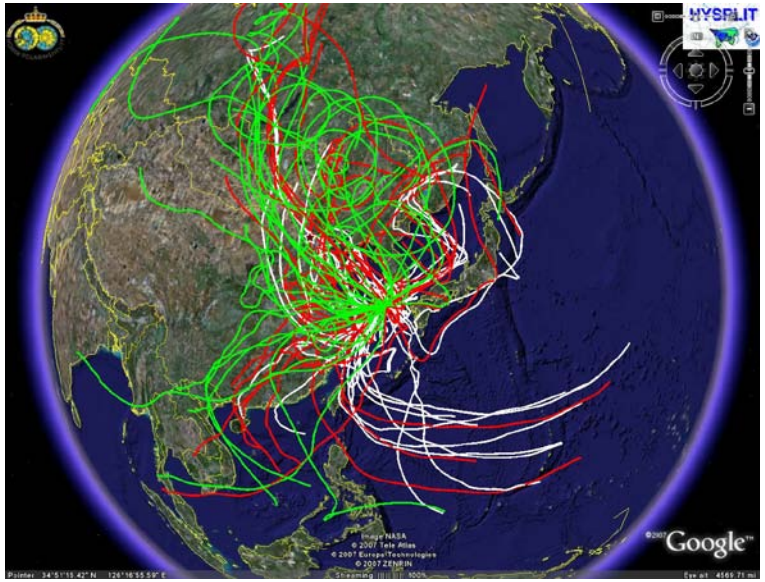
Stith and Ramanathan, 2006



Long Range Transport Of Black Carbon

CIFEX : N California
Hadley et al, 2006

Beijing Olympics Campaign (Aug and Sept 2008

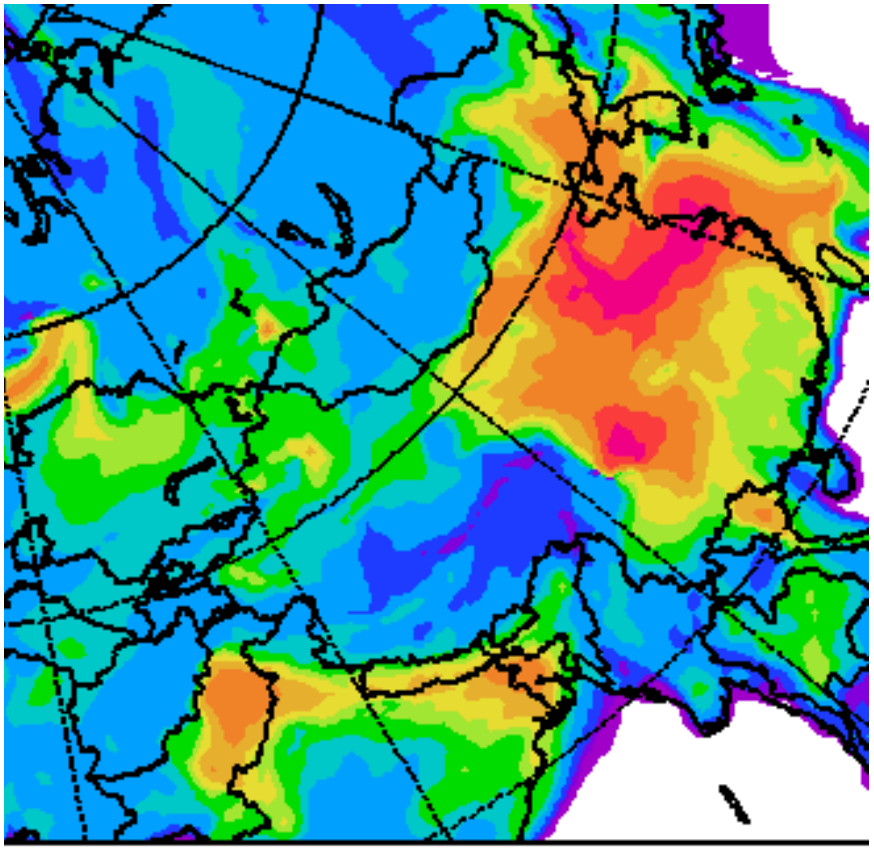


Ramanathan (SIO) & S-C Yoon (SNU)
Nguyen; Ramana;

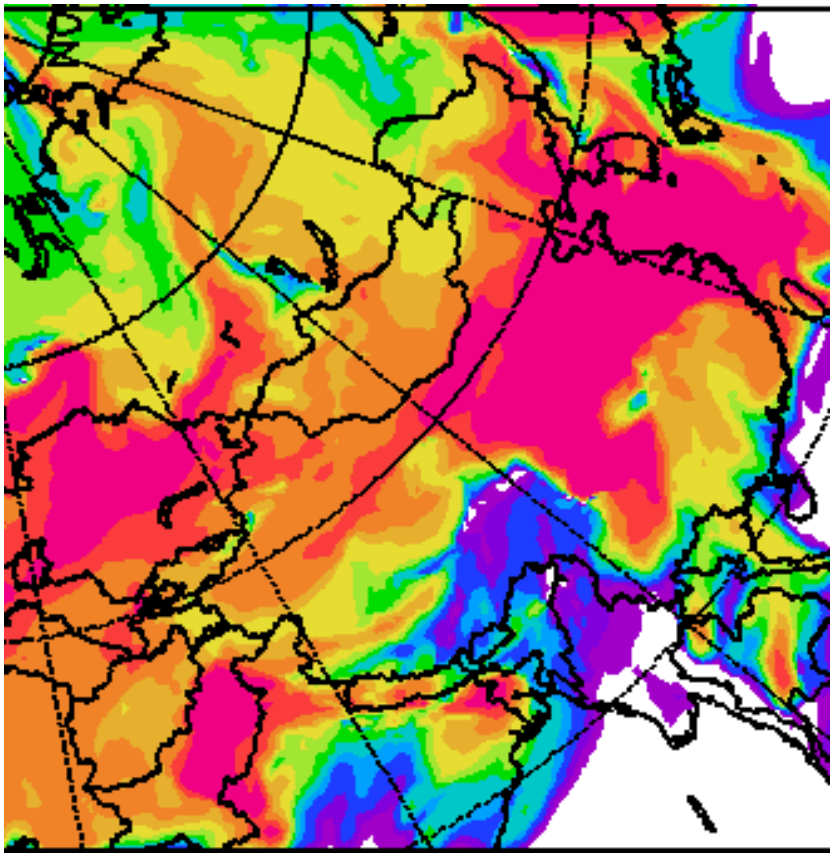
California Air Pollution and Climate Forcing Campaign
NASA Dryden; Antelope Valley, CA; May 08 to Marc 09

Corrigan, Nguyen, Lehmann, Ramana, Ramanathan

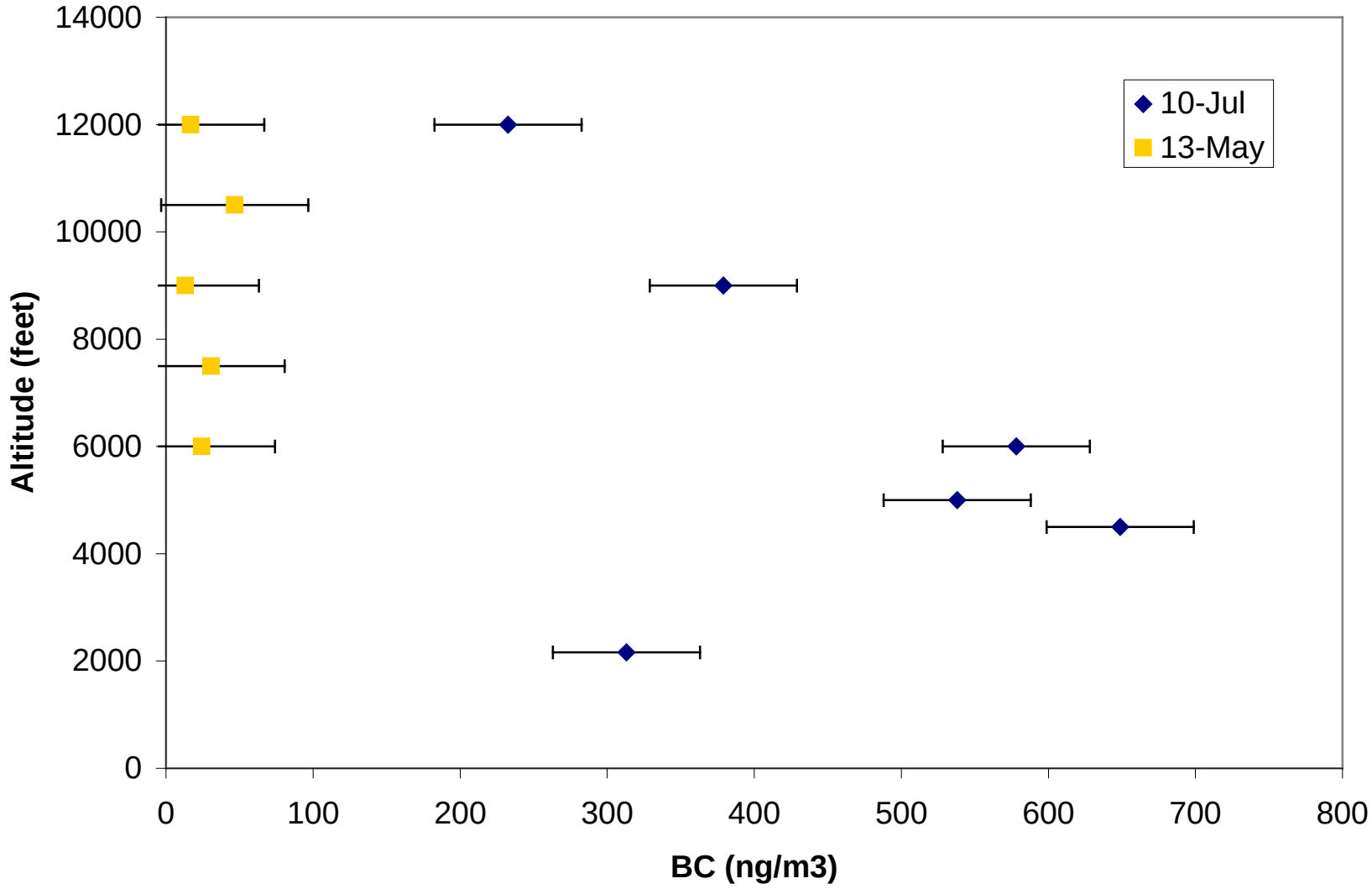
Simulated BC ($\mu g/m^3$) in the Lowest layer
at 0UTC, 08/14/2008

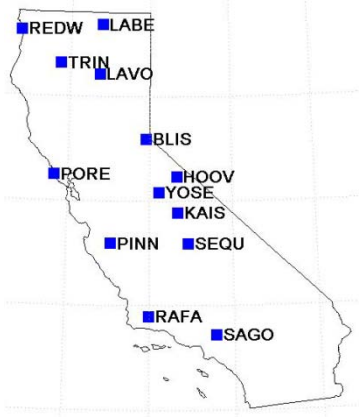


mulated Sulfate ($\mu g/m^3$) in the Lowest layer
at 0UTC, 08/14/2008



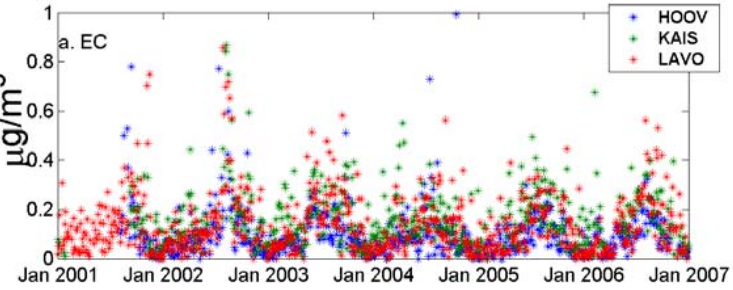
Black Carbon over NASA Dryden

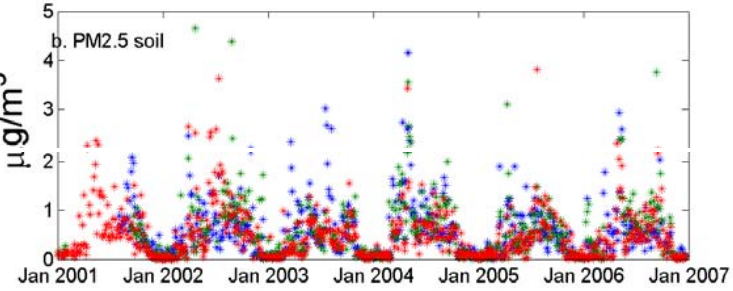


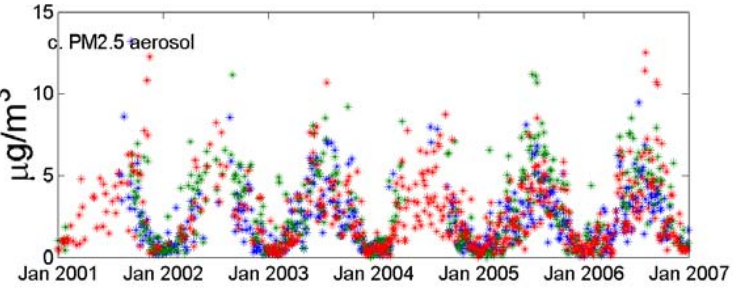


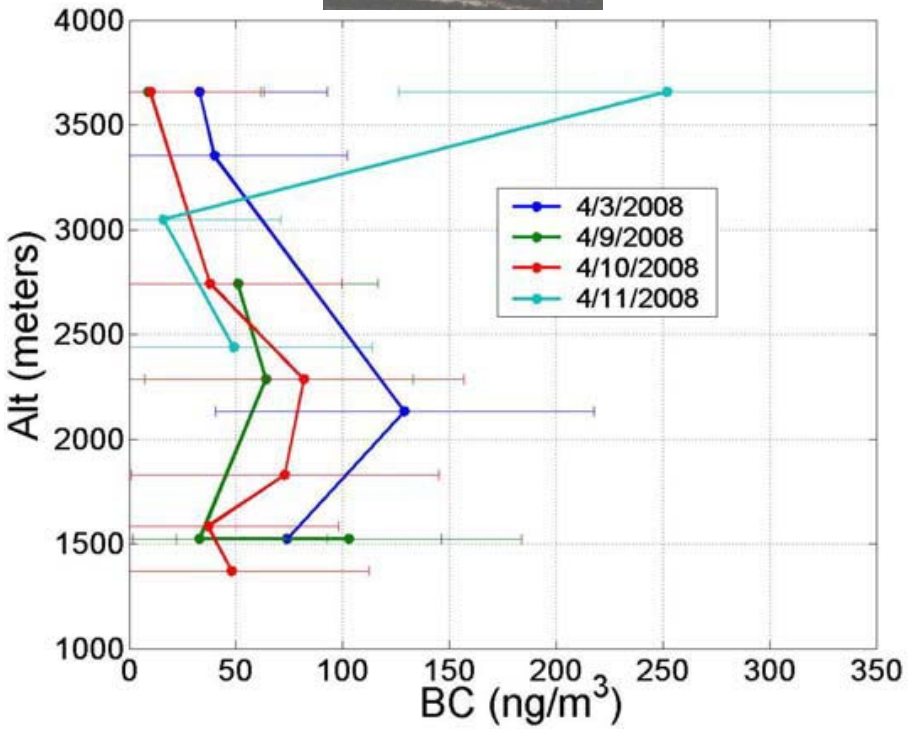
IMPROVE SITES

UAV-BC profile
CEC funded
Corrigan et al, 2008





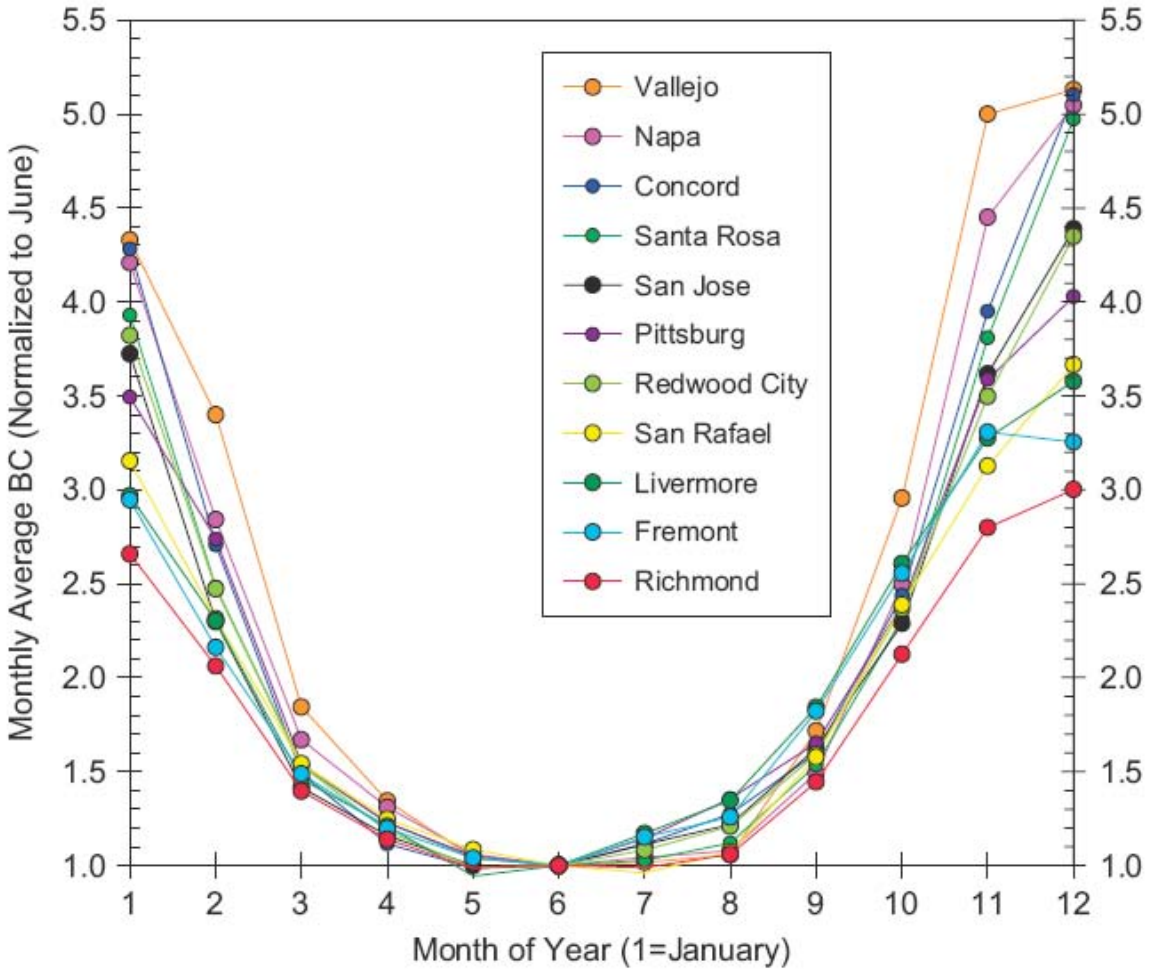




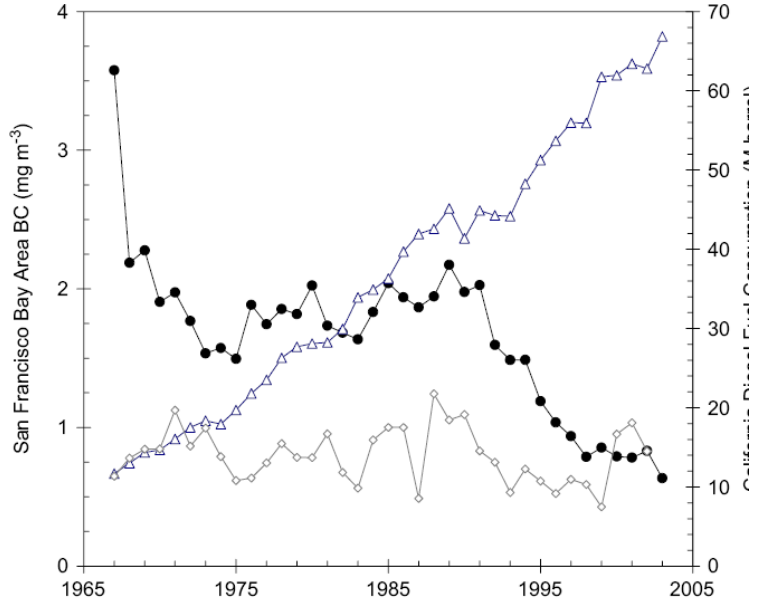
Black carbon concentrations and diesel vehicle emission factors derived from coefficient of haze measurements in California: 1967–2003

Thomas W. Kirchstetter[a,*], Jeffery Aguiar[a], Shaheen Tonse[a], David Fairley[b], T. Novakov[a]

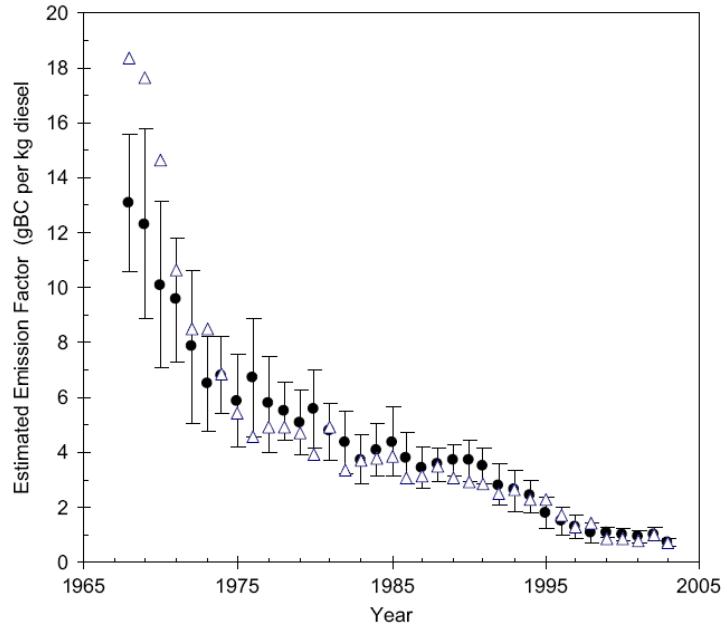
b



a

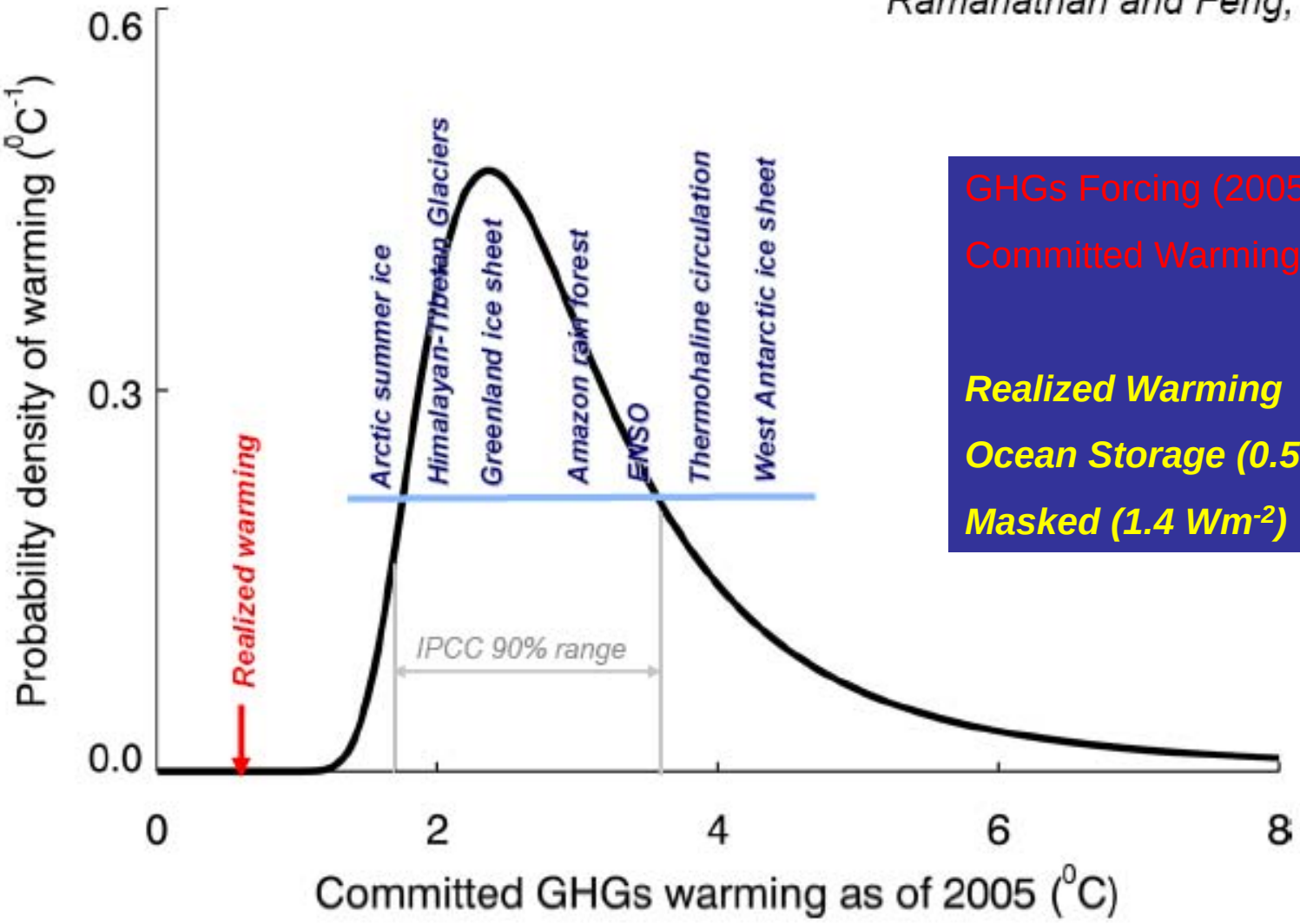

San Francisco Bay Area BC (mg m-3)
0
1
2
3
4
0
10
20
30
40
50
60
70
1965
1975
1985
1995
2005

b


Estimated Emission Factor (gBC per kg diesel
0
2
4
6
8
10
12
14
16
18
20
1965
1975
1985
1995
2005
Year

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

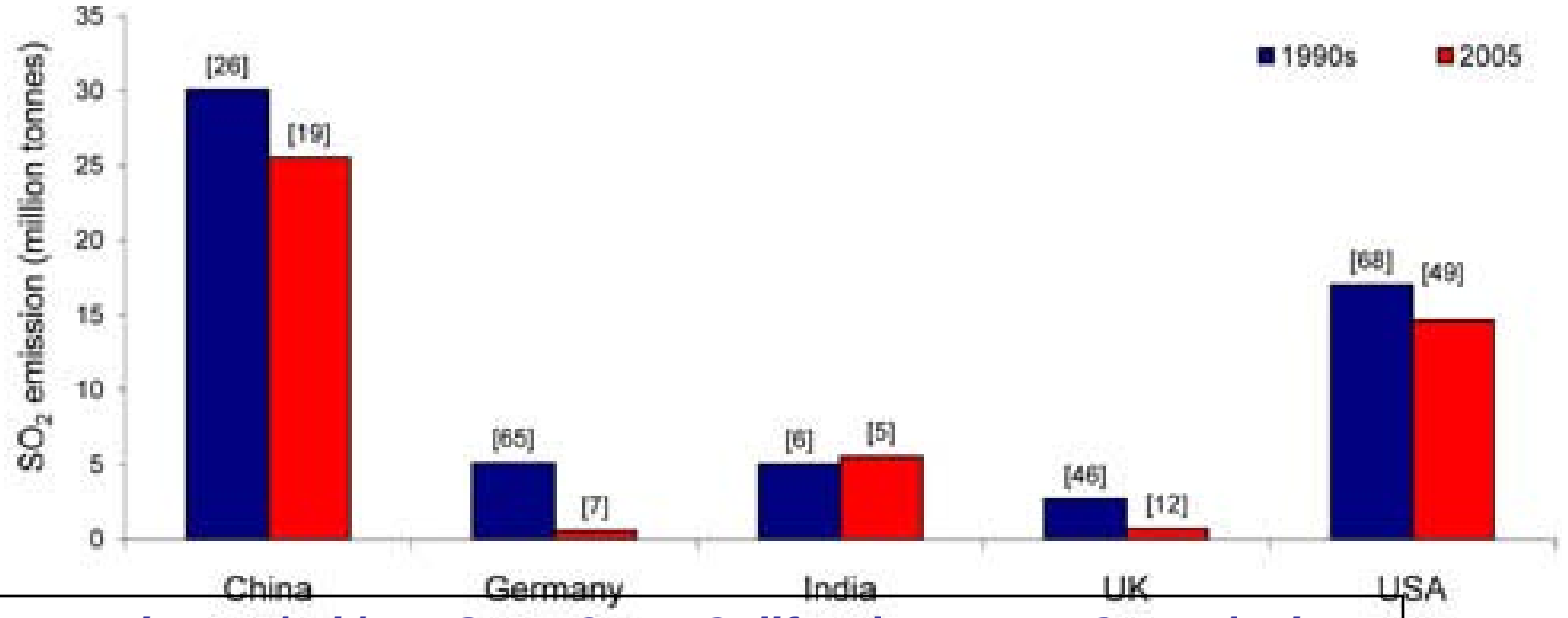
Masked (1.4 Wm^{-2}) = 1.2 C

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

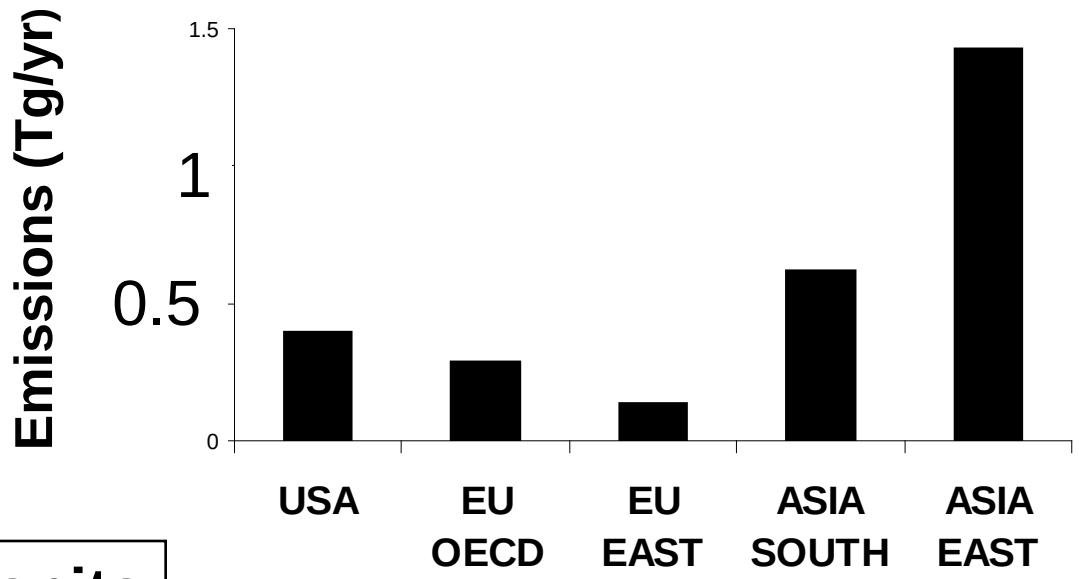
SO_2 Emissions



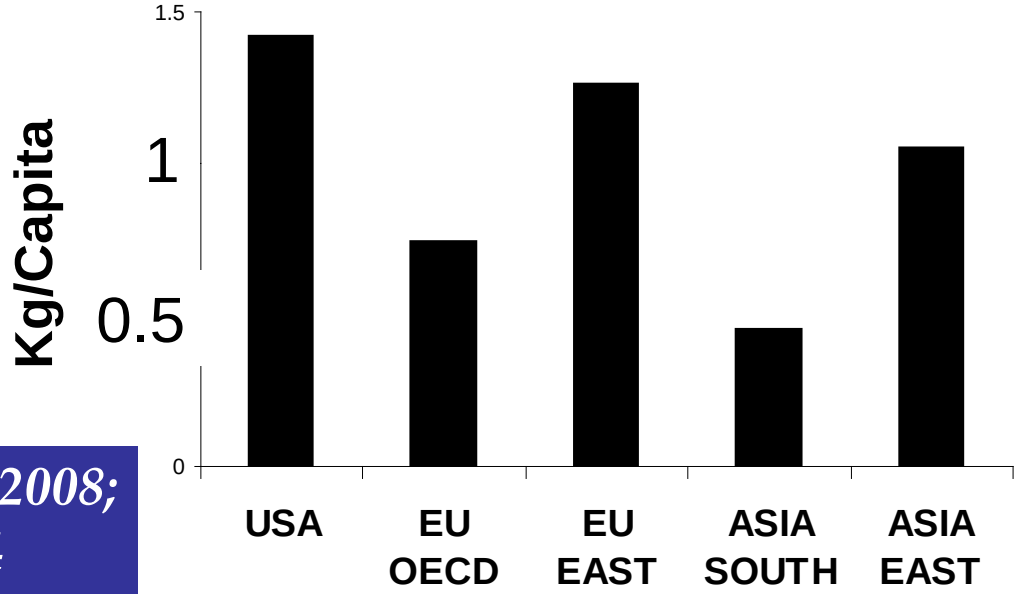
Research Funded by NSF; NOAA; California Energy Commission; Vetlesen Fndn

Ramanathan 2007

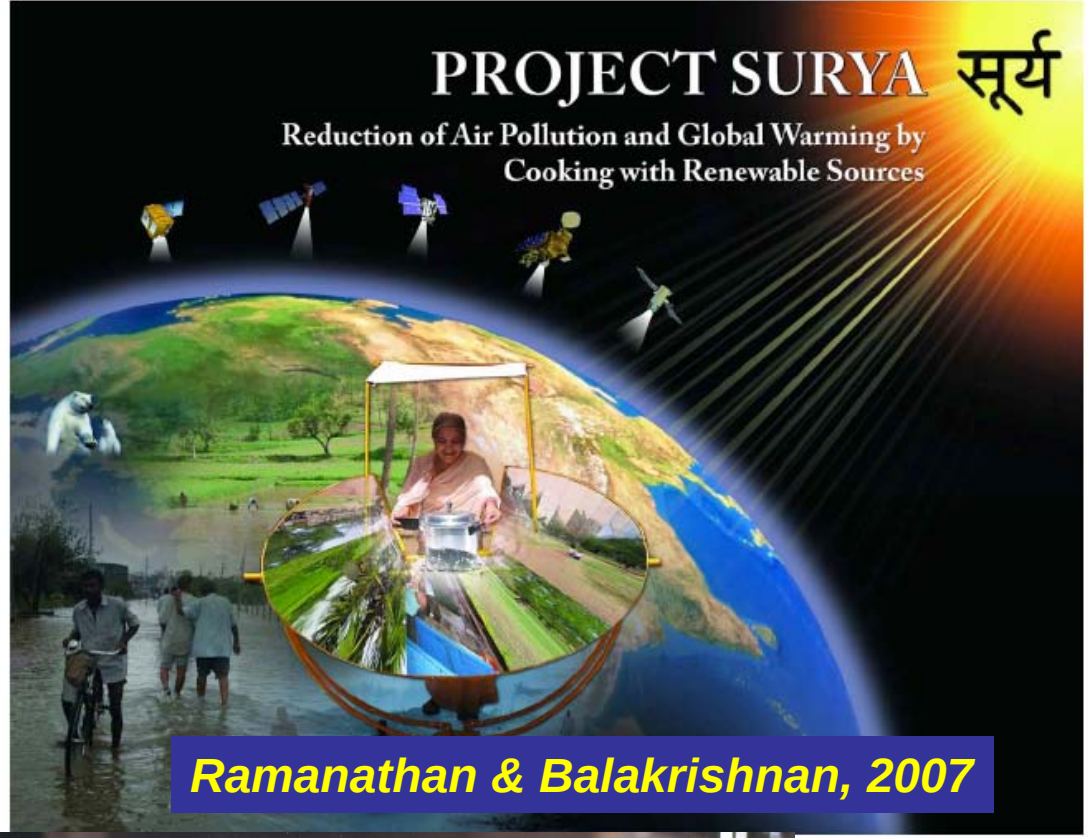
BC emission

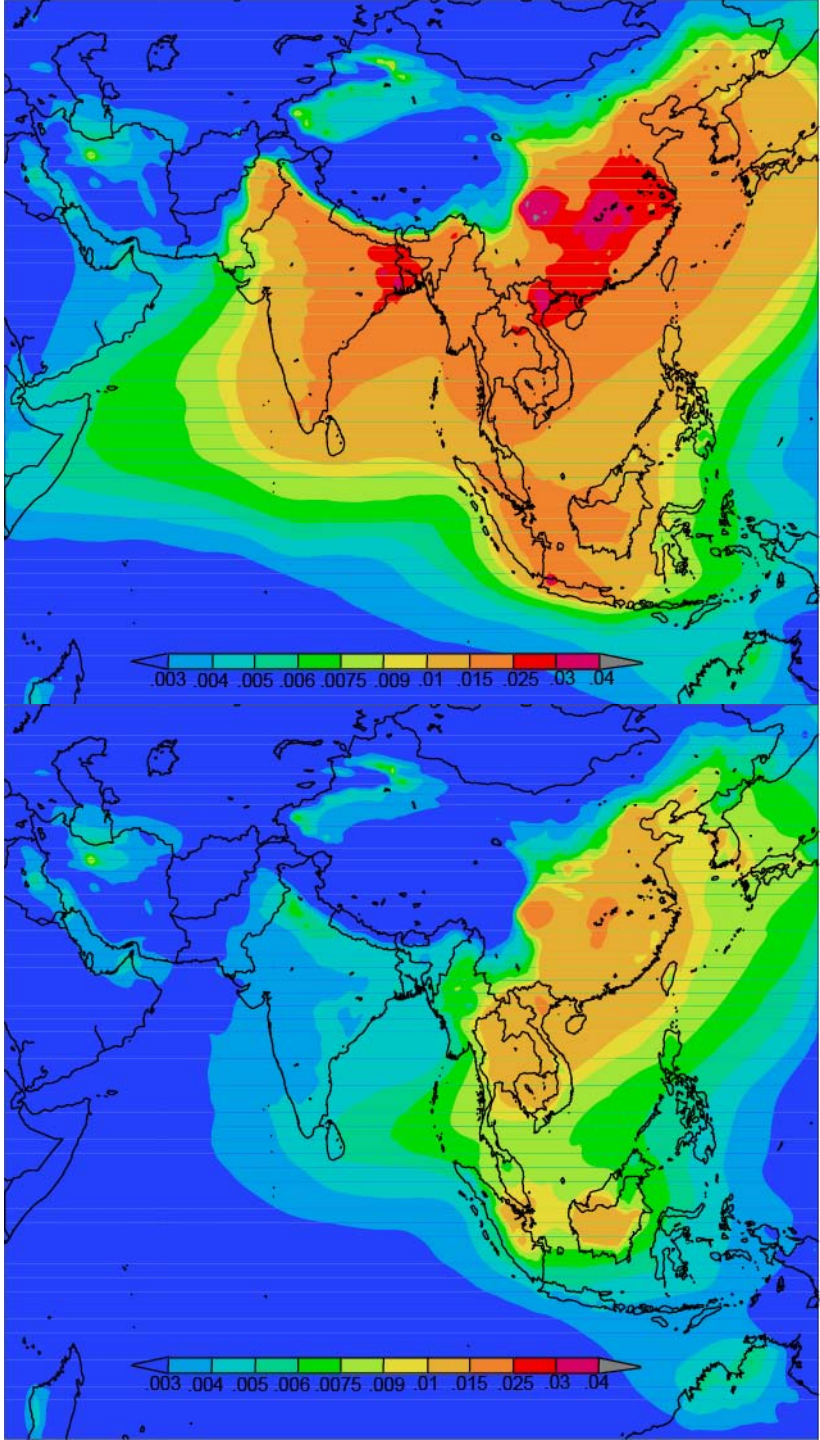


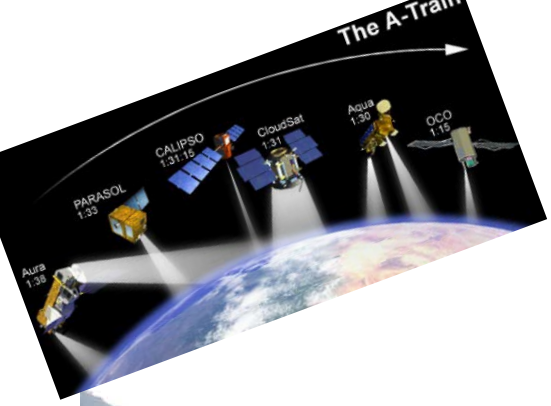
BC Emission/Capita



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


.003 .004 .005 .006 .0075 .009 .01 .015 .025 .03 .04
.003 .004 .005 .006 .0075 .009 .01 .015 .025 .03 .04



Surya Observing System

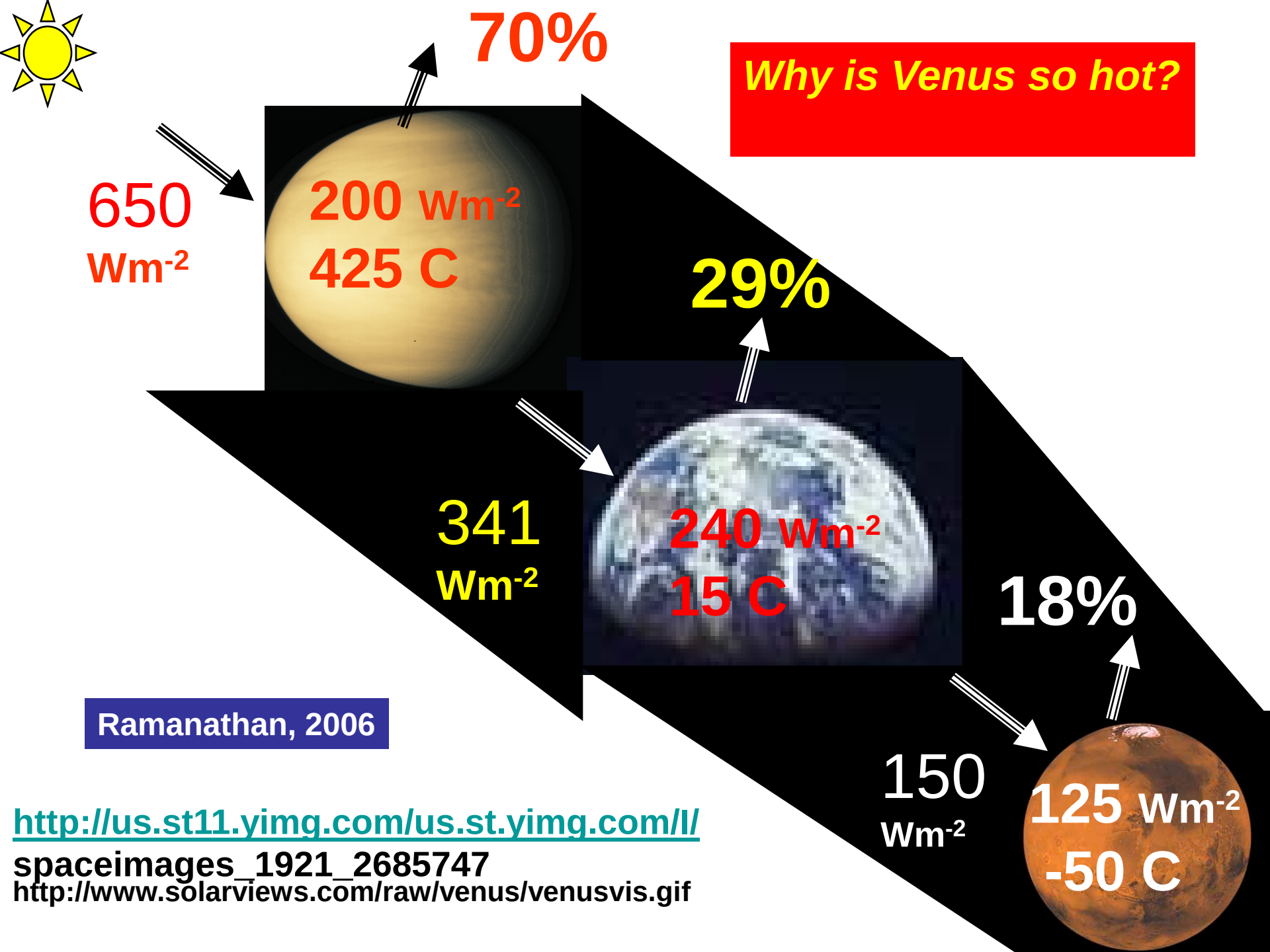
ABC Observatories

Indoor cheap sensors: 2000 sensors

Traveling Laboratory

Physicians

Ramanathan and Balakrishnan, 2007


70%
Why is Venus so hot?
650
Wm-2
200 Wm-2
425 C
29%
341
Wm-2
240 Wm-2
15 C
18%
150
Wm-2
125 Wm-2
-50 C
Ramanathan, 2006
http://us.st11.yimg.com/us.st.yimg.com/I/
spaceimages_1921_2685747
http://www.solarviews.com/raw/venus/venusvis.gif