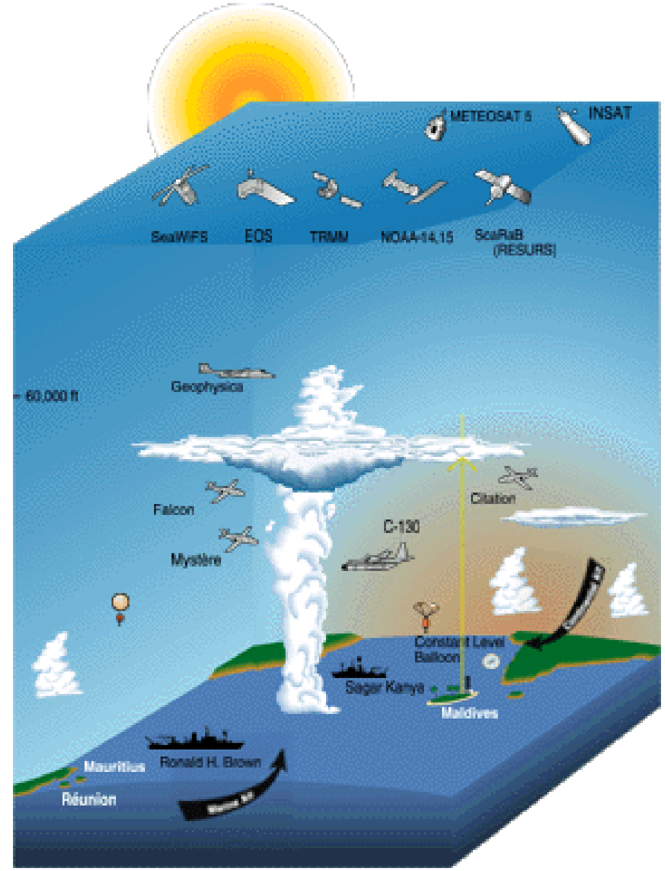
Air Quality in South Asia: INDOEX to TIGERZ



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"Changing Chemistry in a Changing Climate"
1-3 May 2013 at IITM Pune, India

What did we learn in INDOEX,1999?

- In the pre-monsoon season much of S Asia is covered with a heavy layer of aerosol that extends over the ocean to the ITCZ.
  - This aerosol is strongly absorbing.
  - It warms the atmosphere and dims the surface.
  - There is little ozone associated with this pollution.
- Adverse health effects.
- Impacts on clouds and hydrological cycle.

Questions raised by INDOEX

- Why do emissions inventories indicate much less BC than is observed?
- Why do composition and optical properties indicate that fossil fuel combustion dominates BC emission while emissions inventories suggest that biofuels dominate?
- Why are pollution levels and solar radiation high, but ozone concentrations low?
- How can we use remote sensing to improve our understanding of air quality and climate forcing?

How much climate forcing from black carbon?
Science April 23, 2013

CLIMATE CHANGE

Climate's Dark Forcings

Uncertainties about the properties and amounts of atmospheric black carbon complicate efforts to understand its regional and global effects on climate.

Meinrat O. Andreae[1,2] and V. Ramanathan[2,3]

The black soot coming out of the tailpipes of diesel trucks is a nuisance familiar to every highway traveler. Soot also endangers the health of untold numbers of women and their families exposed to smoke from traditional cookstoves burning biofuels and coal. But in addition to irritating our noses and lungs, this pollutant, also known as black carbon (BC), is the strongest absorber of solar radiation in the atmosphere. The magnitude of global warming from BC, as well as its regional effects, has been the subject of intense debate. In a recent comprehensive assessment, Bond *et al*. (*1*) have synthesized available model results and observations, and propose a "best estimate" for BC's global climate forcing. Their estimate is almost twice as high as values commonly discussed (*2*). What causes such large discrepancies between estimates, and what are the implications for the global and regional climate effects of BC?

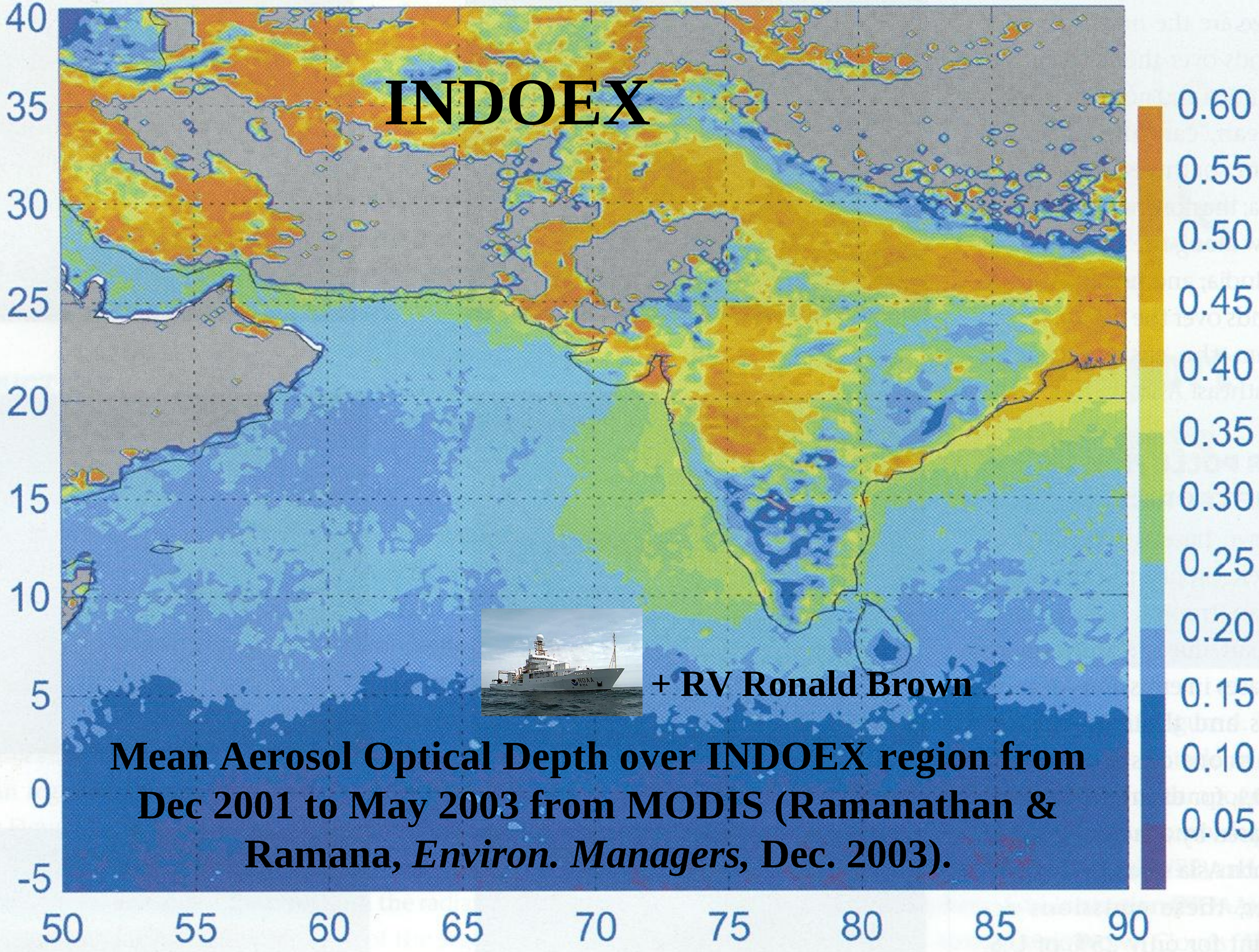
ules traditionally thought of as BC, the atmosphere contains light-absorbing organic or "brown" carbon (BrC) (*3*). BrC may account for 15 to 50% of light absorption in the atmosphere and in snow and ice (*1*, *4*, *5*) and has different optical properties and source and sink patterns from BC. In addition to combustion sources, especially biomass burning, BrC is also produced by atmospheric chemical reactions, a source not considered in emission inventories.

BrC is sometimes included implicitly in climate models constrained by BC measurements, because different BC measurement techniques may include some or all BrC. However, most models have ignored BrC absorption and, as a result, concluded that the combination of BC and nonabsorbing organic carbon leads to net cooling. This has been challenged by two recent studies (*5*, *6*). It is essential to improve measurement techniques for BrC and to include it explicitly all mechanisms. Because most earlier studies have included only a subset of mechanisms, one must be very careful when making comparisons.

Bond *et al*.'s "all mechanisms" forcing estimate of +1.1 W m^{-2} (with a large uncertainty) is about twice as high as that of UNEP/WMO (*2*), mostly because of higher values for the absorption by BC in the atmosphere. Yet, their estimate of 0.88 W m^{-2} for the forcing from light absorption by present-day BC is almost identical to that from a previous study (0.9 W m^{-2}) (*8*). This agreement is instructive, because the two studies use atmospheric models, but are otherwise based on very different approaches.

Ramanathan and Carmichael's estimate (*8*) is based on satellite and ground-based light absorption data from the AERONET network of more than 140 sites around the world. In contrast, Bond *et al*. derive absorption estimates from emission inventories and

INDOEX



+ RV Ronald Brown

Mean Aerosol Optical Depth over INDOEX region from Dec 2001 to May 2003 from MODIS (Ramanathan & Ramana, *Environ. Managers*, Dec. 2003).

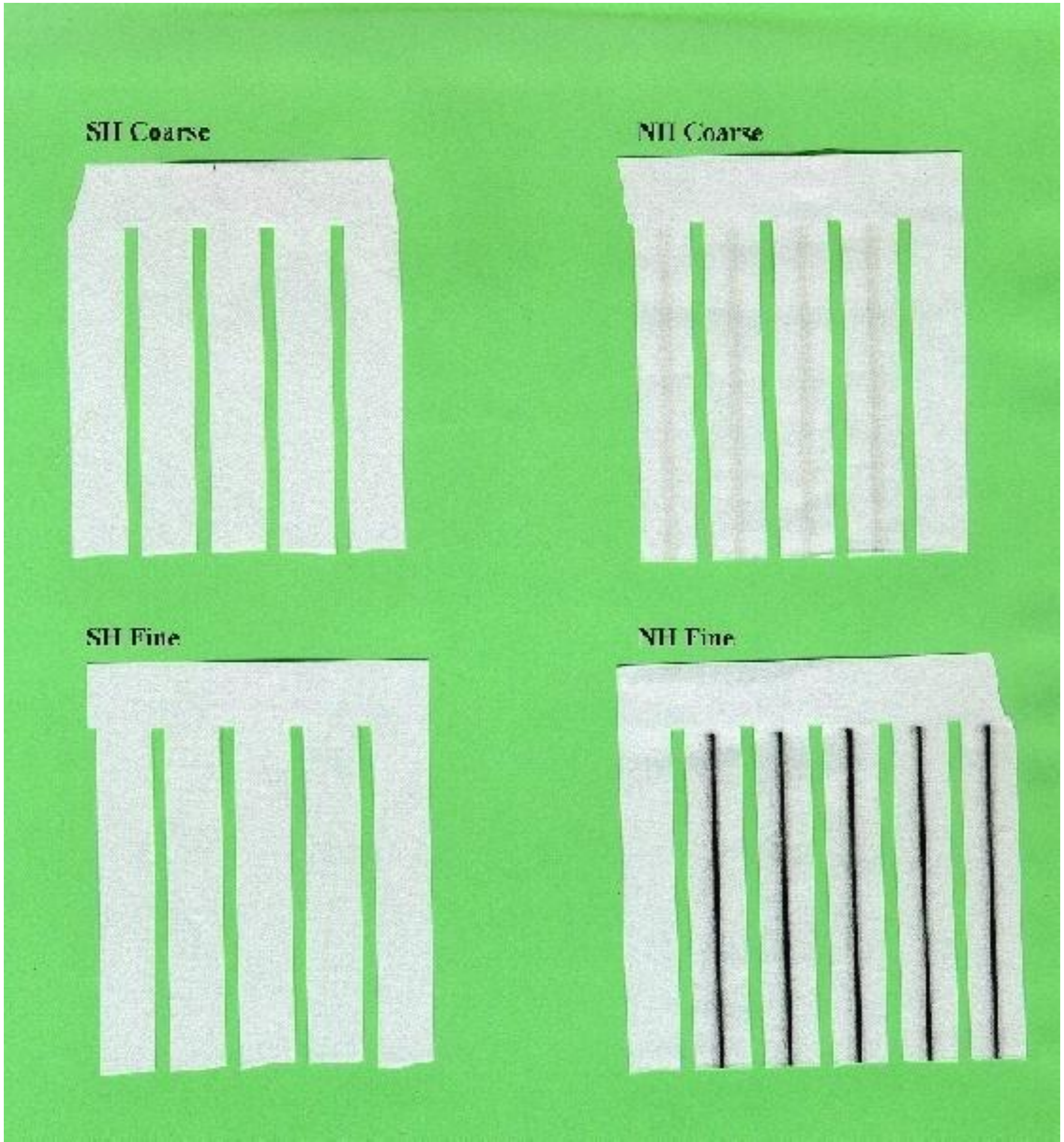
From an INDOEX proposal review

“Even if high concentrations of BC are found over South Asia it is highly unlikely that these aerosols will be transported as far as the ITCZ.”

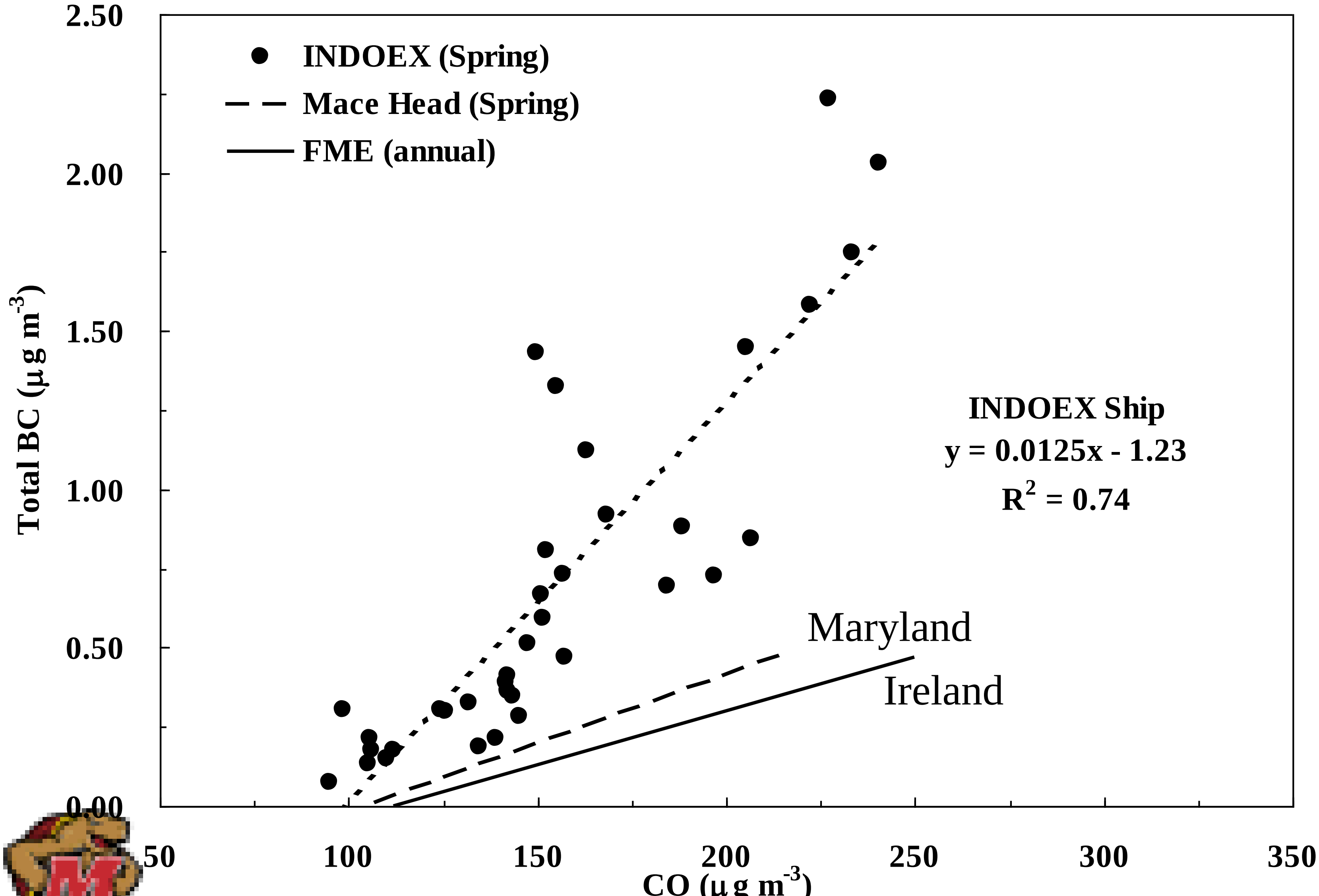
NOAA R/V Ronald Brown

Impactor Sample from INDOEX

South of ITCZ North of ITCZ



CO vs BC (total) from Ship During INDOEX



Emissions Inventories
Gg yr^{-1} Black Carbon from South Asia
High Estimate for 1999

Industry	Domestic	Mobile Sources	Power Generation	Field Combustion	Total
263	550	139	2.7	37	1009

From Dave Streets, Argonne

Estimate of BC Emission from Ambient Measurements

(CO is well behaved and well modeled)

$E_{BC} = E_{CO}$*[BC]/[CO]

Fort Meade, Maryland, USA

E_{BC} = 90 Tg(CO)/yr * 0.0034

= 0.**31** Tg(BC)/yr for N America

(vs. 0.49 Tg(BC)/yr from inventories)

INDOEX

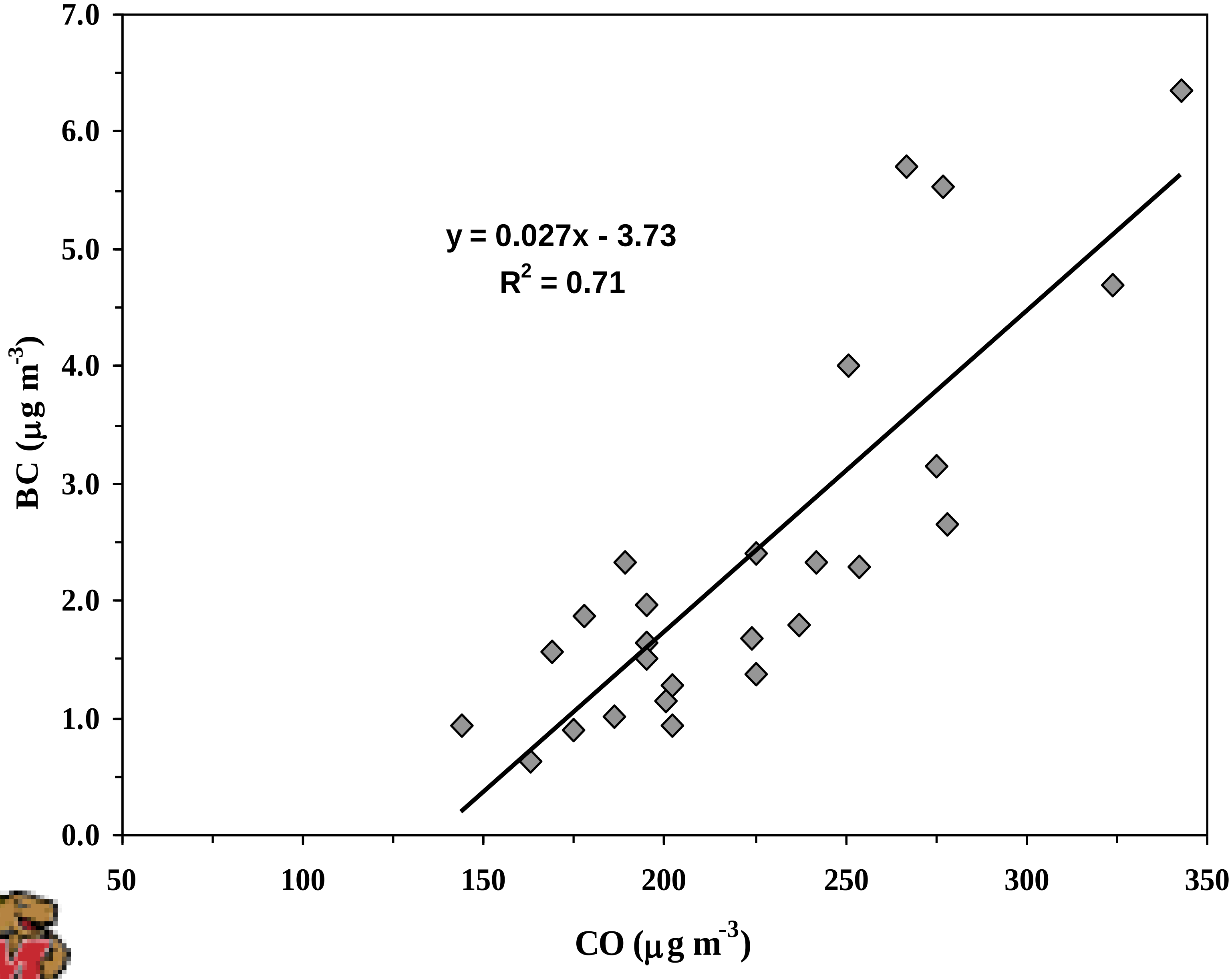
E_{BC} = 87 Tg(CO)/yr * 0.0125/0.5

= 2.2 Tg(BC)/yr for South Asia

(vs. 0.5 to 1 Tg(BC)/yr from bottom up)

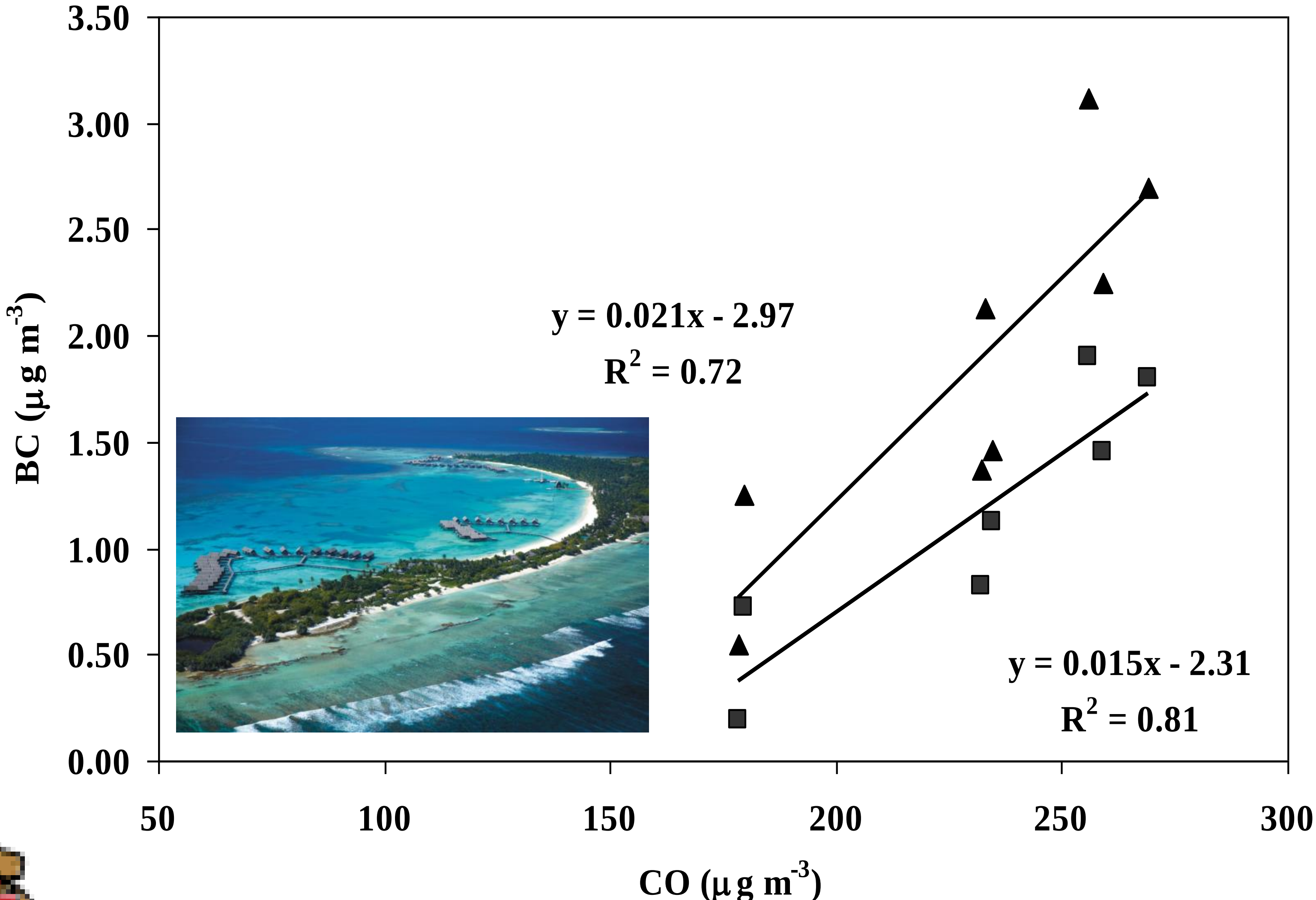
NCAR C130 on low pass over R/V Ronald Brown over Indian Ocean during INDOEX 1999

CO vs BC from C130 During INDOEX



Similar results from the island site in the Maldives

CO vs. BC from KCO During INDOEX



So there is lots of BC and BrC from South Asia
Where does the it come from?

- Emissions inventories indicate <u>12-45% fossil C.</u>
  - Dickerson et al., 2002; Reddy et al., 2002; Bond et al., 2004; Venkataraman et al., 2005.
- Chemical and optical properties indicate <u>40-90% fossil C.</u>
  - Novakov et al., 2000; Mayol-Bracero et al., 2002; Stone et al., 2007.

Where does the BC and BrC come from?

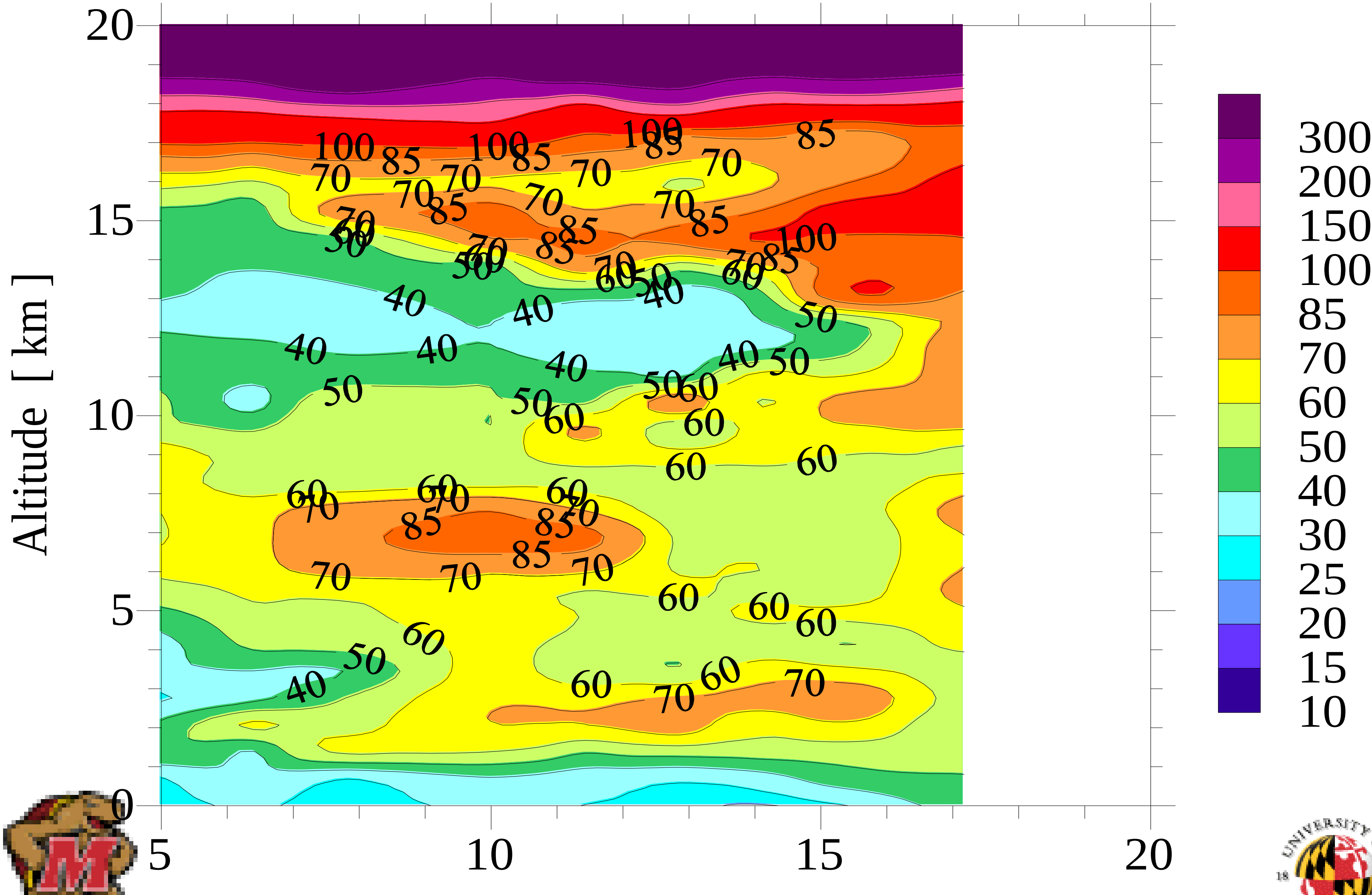
Brown Clouds over South Asia: Biomass or Fossil Fuel Combustion?

Örjan Gustafsson,[1]* Martin Kruså,[1] Zdenek Zencak,[1] Rebecca J. Sheesley,[1] Lennart Granat,[2] Erik Engström,[2] P. S. Praveen,[3] P. S. P. Rao,[4] Caroline Leck,[2] Henning Rodhe[2]

Carbonaceous aerosols cause strong atmospheric heating and large surface cooling that is as important to South Asian climate forcing as greenhouse gases, yet the aerosol sources are poorly understood. Emission inventory models suggest that biofuel burning accounts for 50 to 90% of emissions, whereas the elemental composition of ambient aerosols points to fossil fuel combustion. We used radiocarbon measurements of winter monsoon aerosols from western India and the Indian Ocean to determine that biomass combustion produced two-thirds of the bulk carbonaceous aerosols, as well as one-half and two-thirds of two black carbon subfractions, respectively. These constraints show that both biomass combustion (such as residential cooking and agricultural burning) and fossil fuel combustion should be targeted to mitigate climate effects and improve air quality.

- Radiocarbon 30-60% Fossil C.
  - Gustafsson et al., *Science* 2009.
  - Absorbing aerosols in South Asia are different from those previously observed.
  - Need to control emissions from both fossil and biofuels.

INDOEX-99: Ozone [ppbv] Cross Section Leg 2-A (05-10 March1999)
Obtained from Ozone/Humidity Soundings from RV "Ronald Brown"



File: IXMO32A1.SRF
By H.G.J. Smit / Research Centre Jülich (ICG-2)

INDOEX Interim Update

- **India and much of N Indian Ocean is (was) heavily polluted with soot, but not ozone.**
- **Why so little ozone?**
  - **NOx relatively low in 1999 (more on this later)**
  - **VOC/NOx too high (NOx tied up in organic compounds)**
  - **multiphase chemistry**
  - **reduced j(NO_2).**
- **Inventories did not include emissions of brown carbon and in situ reactions.**
- **Ambient measurements in 1999 indicate 2-3 Tg(BC) a^{-1}.**
- **Interactions of soot and dust?**

TIGERZ

Derived Aerosol Absorption and Size Properties from AERONET

Giles (NASA) et al. JGR, 2011, 2012

Aerosol Absorption

- Spectral Single Scattering Albedo (SSA)
- Absorption Angstrom Exponent (AAE)
  AAE = $-d\ln(\tau_{abs})/d\ln(\lambda)$, 440-870nm inclusive range

Aerosol Size

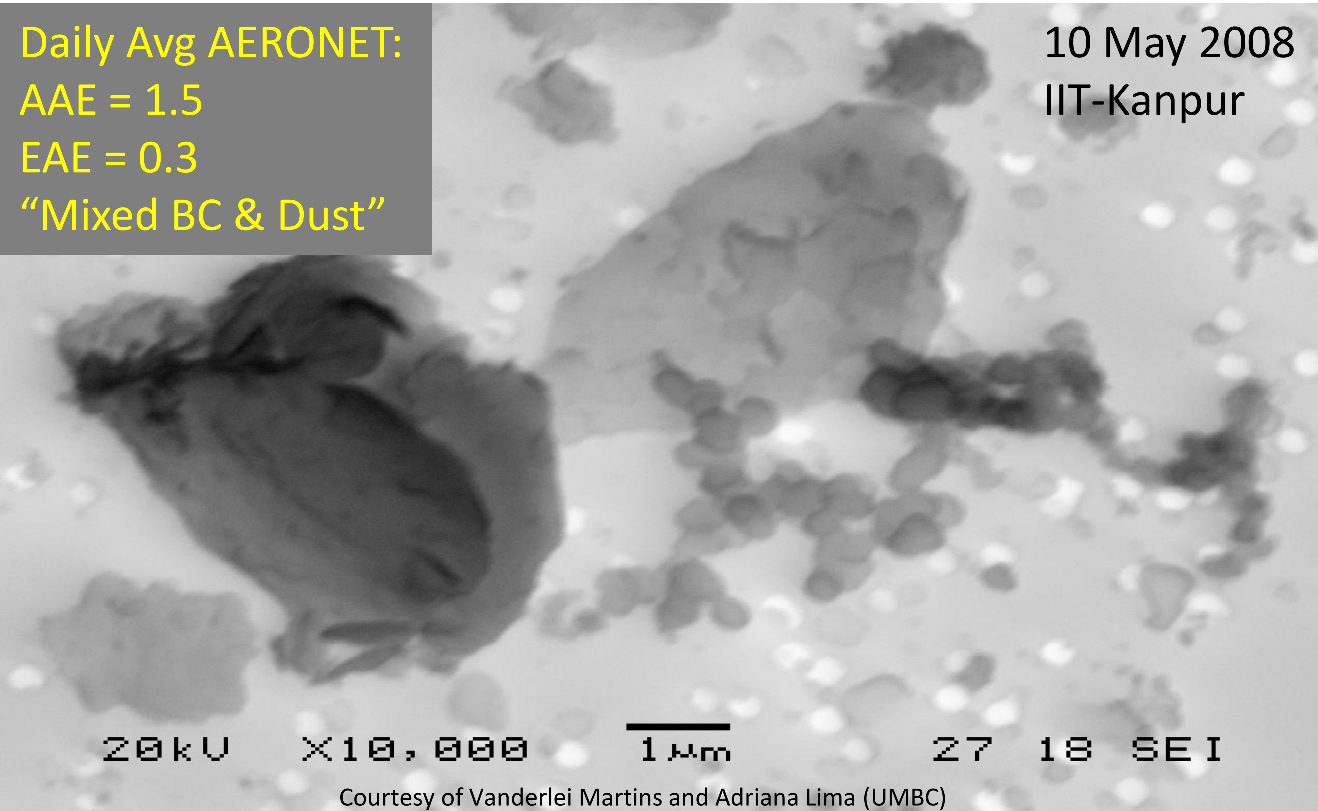
- Fine Mode Fraction (FMF) of AOD
  $FMF(\lambda) = \tau_{fine}(\lambda)/ [\tau_{fine}(\lambda)+\tau_{coarse}(\lambda)]$
- Extinction Angstrom Exponent (EAE)
  EAE = $-d\ln[\tau(\lambda)]/d\ln(\lambda)$, 440-870nm inclusive range

Data Set

- **λ=440, 675, 870 nm** (interpolated to **550 nm for FMF**)
- **τ(440nm) > 0.4** for Version 2, Level 2.0 retrievals
- Instrument collimator consistency checks to remove artifacts

Aerosol Robotic Network (AERONET)

Dust and Black Carbon Particles



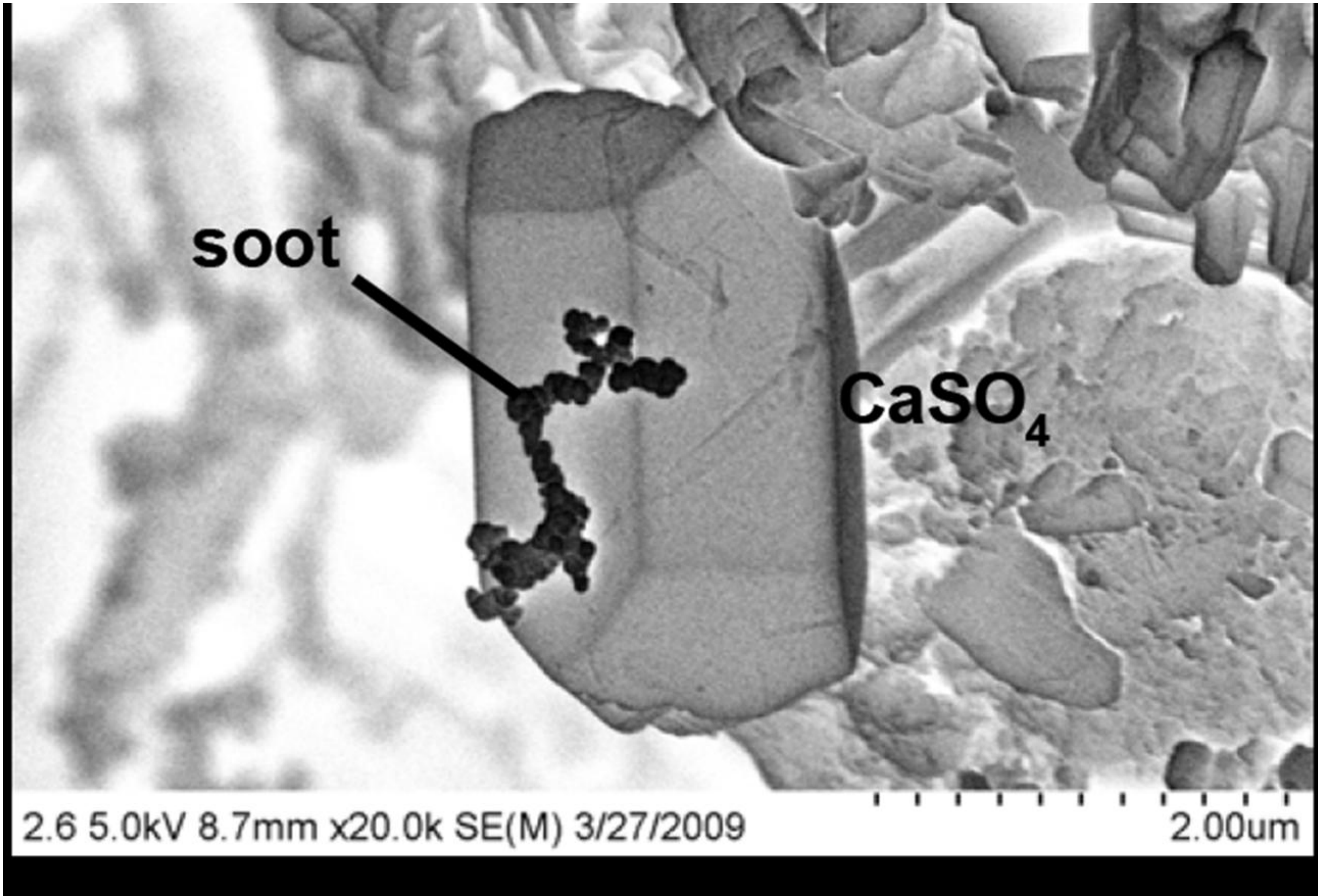
Courtesy of Vanderlei Martins and Adriana Lima (UMBC)

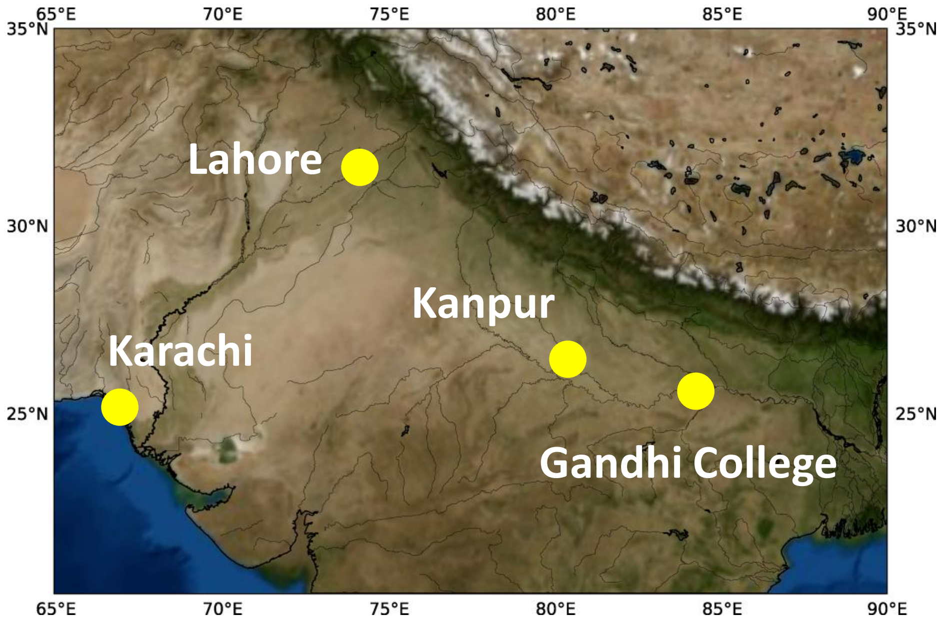
Courtesy of Sheng-Hsiang Wang

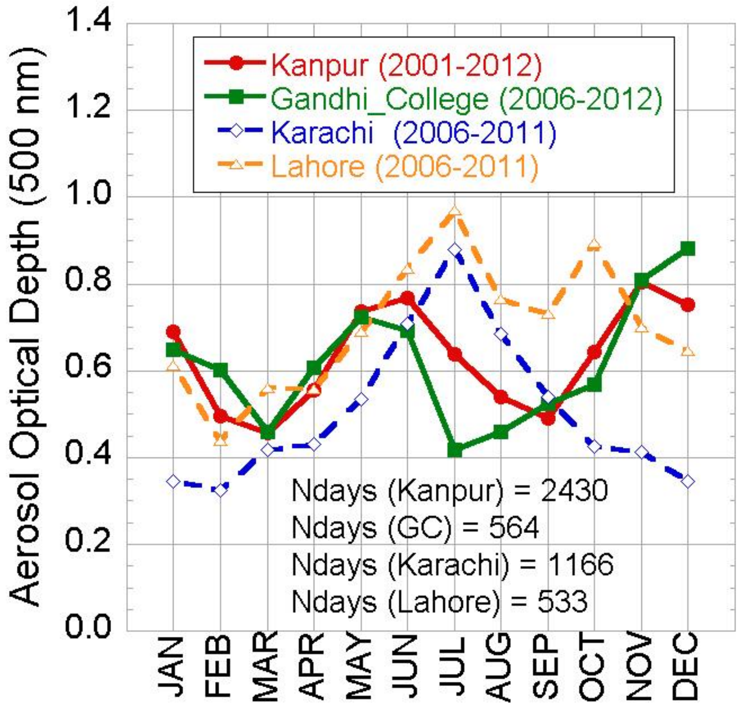
Courtesy of Sheng-Hsiang Wang

From Giles 2012,
Ph.D. University of Maryland

Scanning electron microscope image of particles collected in Xianghe, E of Beijing.



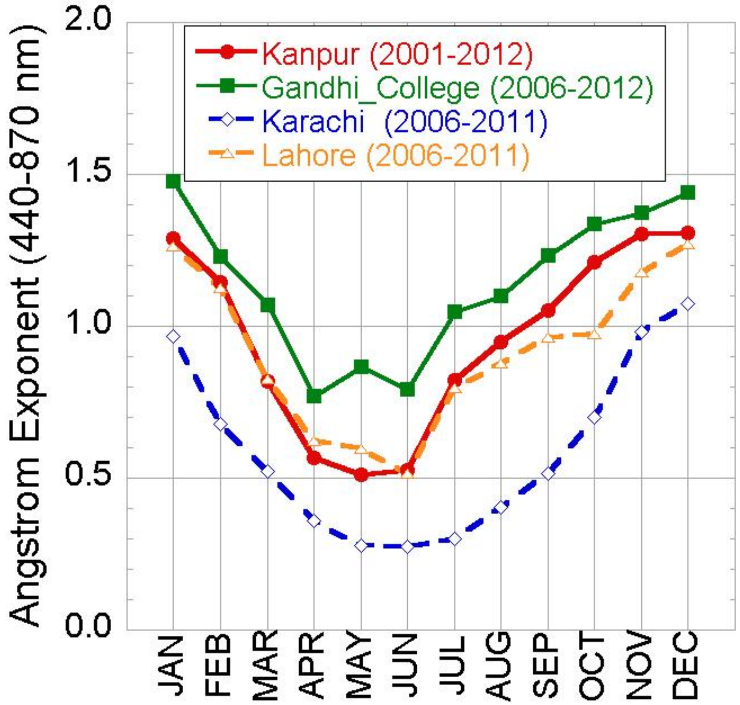




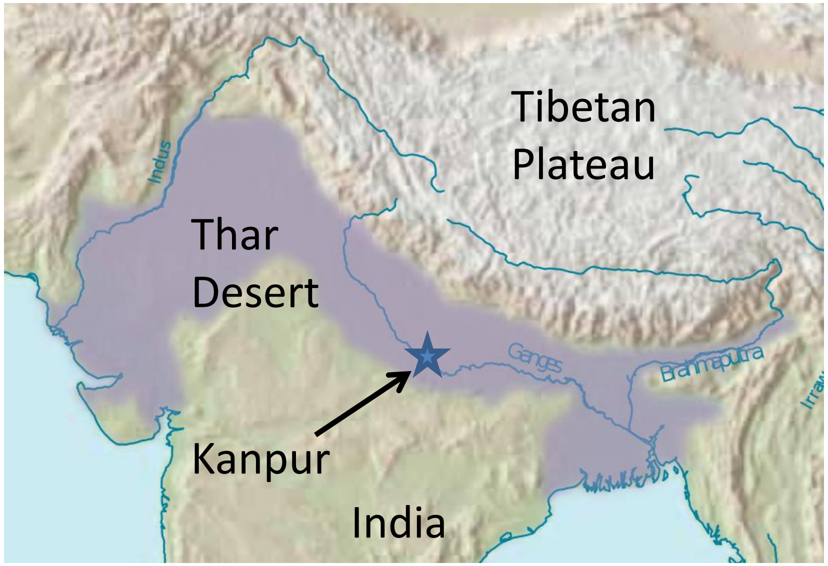
- AOD maxima for sites in Pakistan occur in July.

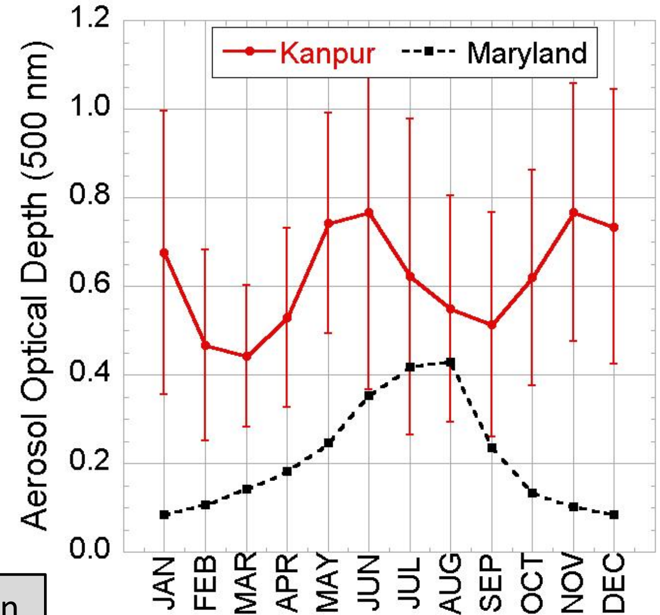
- Larger AE at GC indicates fewer large particles – less dust.

- Smaller AE at Karachi – more dust.

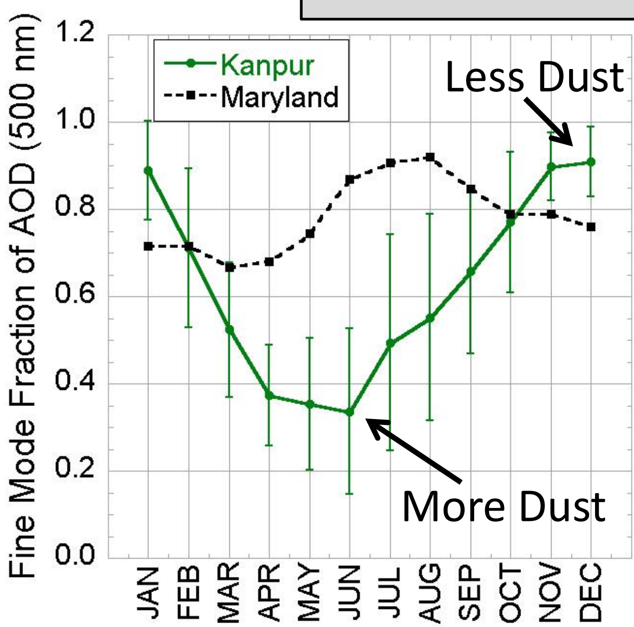


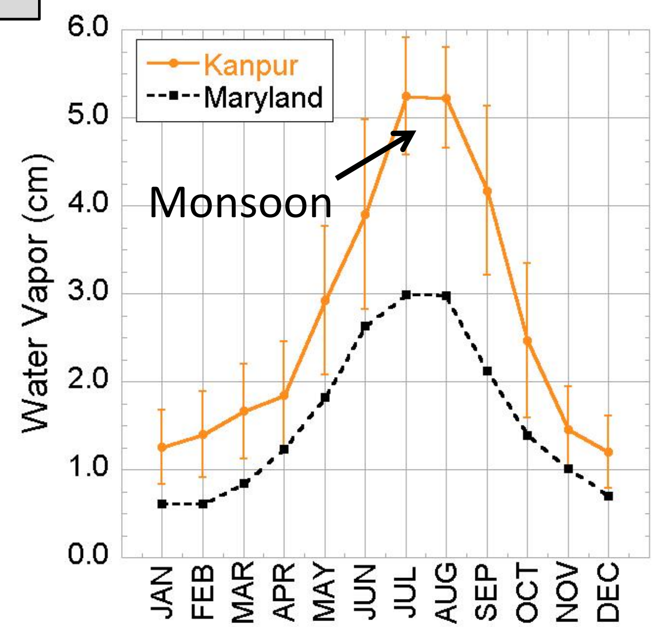
Kanpur, India Climatology (2001-2009)





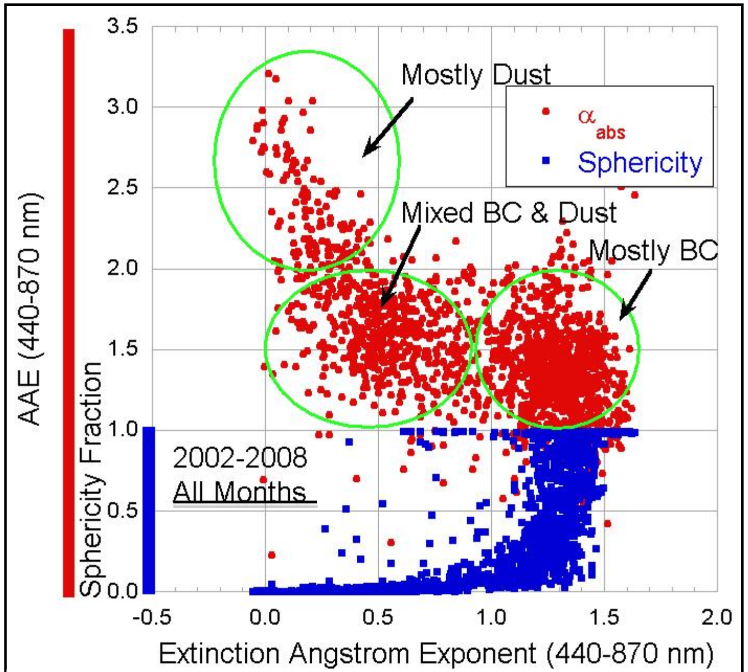
Error bars indicate standard deviation

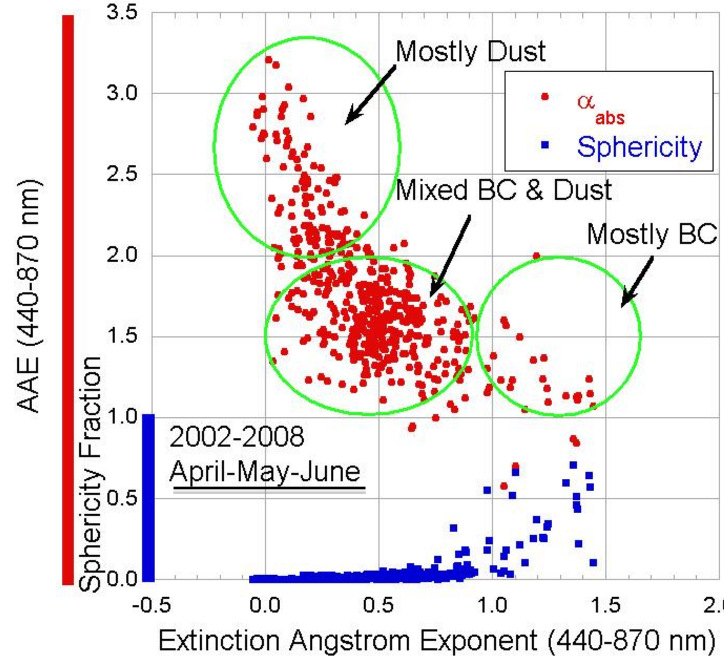


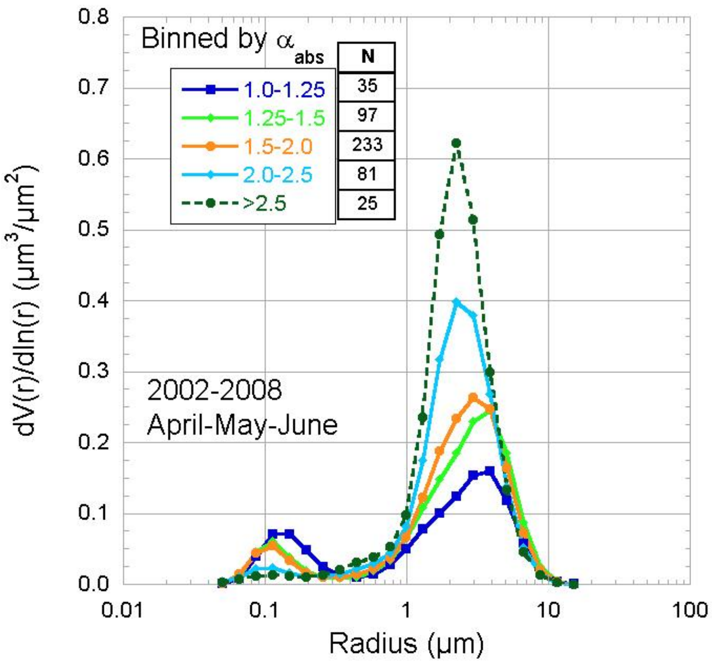


Derived from Giles et al. 2011, *J. Geophys. Res.*, *116*, D18203, doi:10.1029/2011JD015809

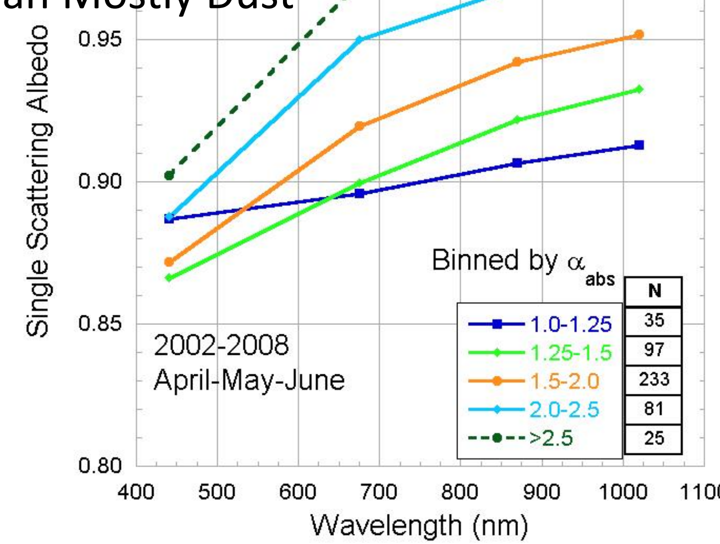
Dominant Absorbing Aerosols over Kanpur







*Mixture more absorbing than Mostly Dust



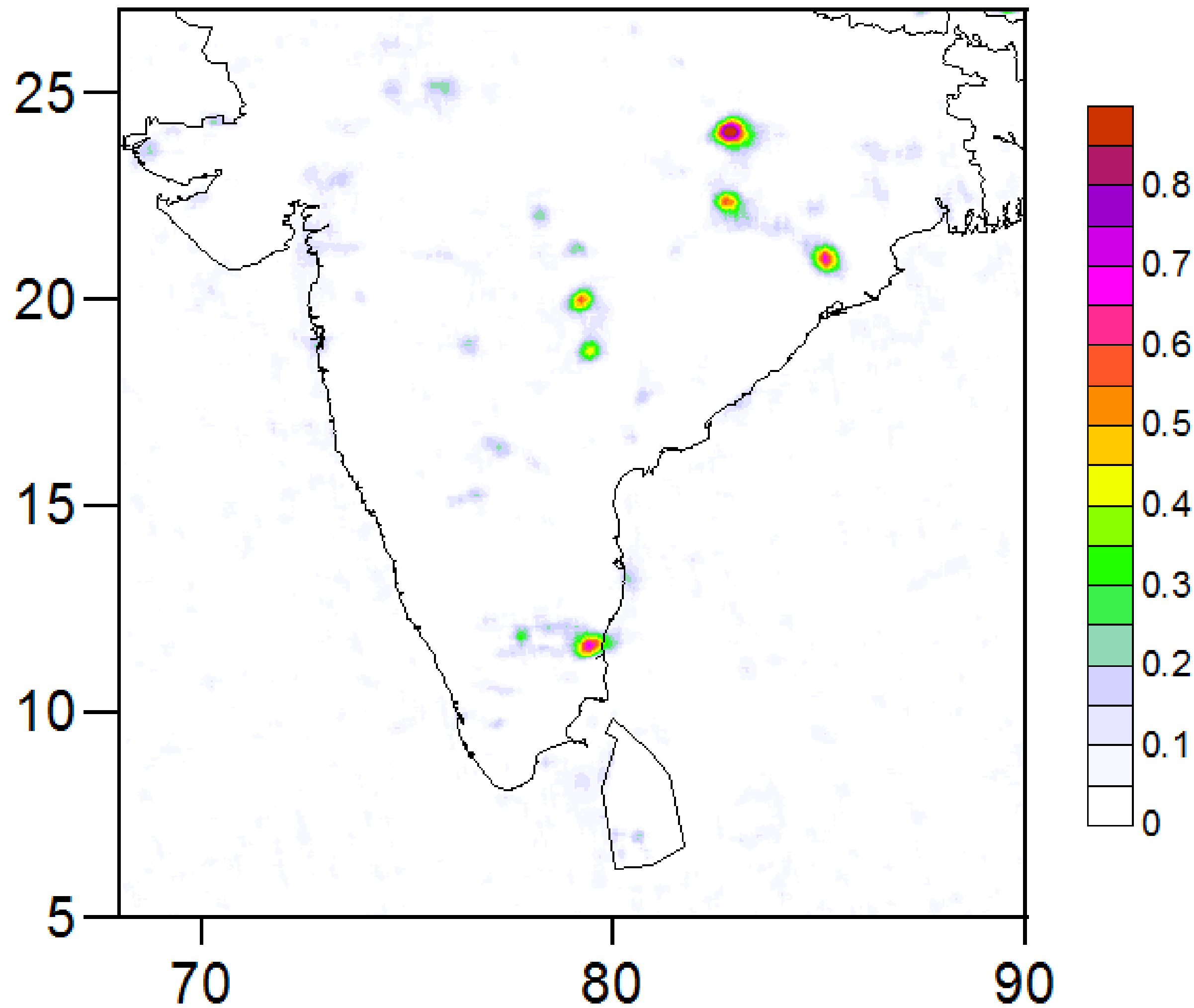
Derived from Giles et al. 2011, *J. Geophys. Res.*, *116*, D18203, doi:10.1029/2011JD015809

TIGERZ conclusions

- Mixtures of dust and BC and dust (or BrC and dust) absorb more radiation (lower SSA) than individual components.
- AERONET observations using Angstrom Absorption Exponent and Extinction Angstrom Exponent can help quantify MODIS observations over bright surfaces.

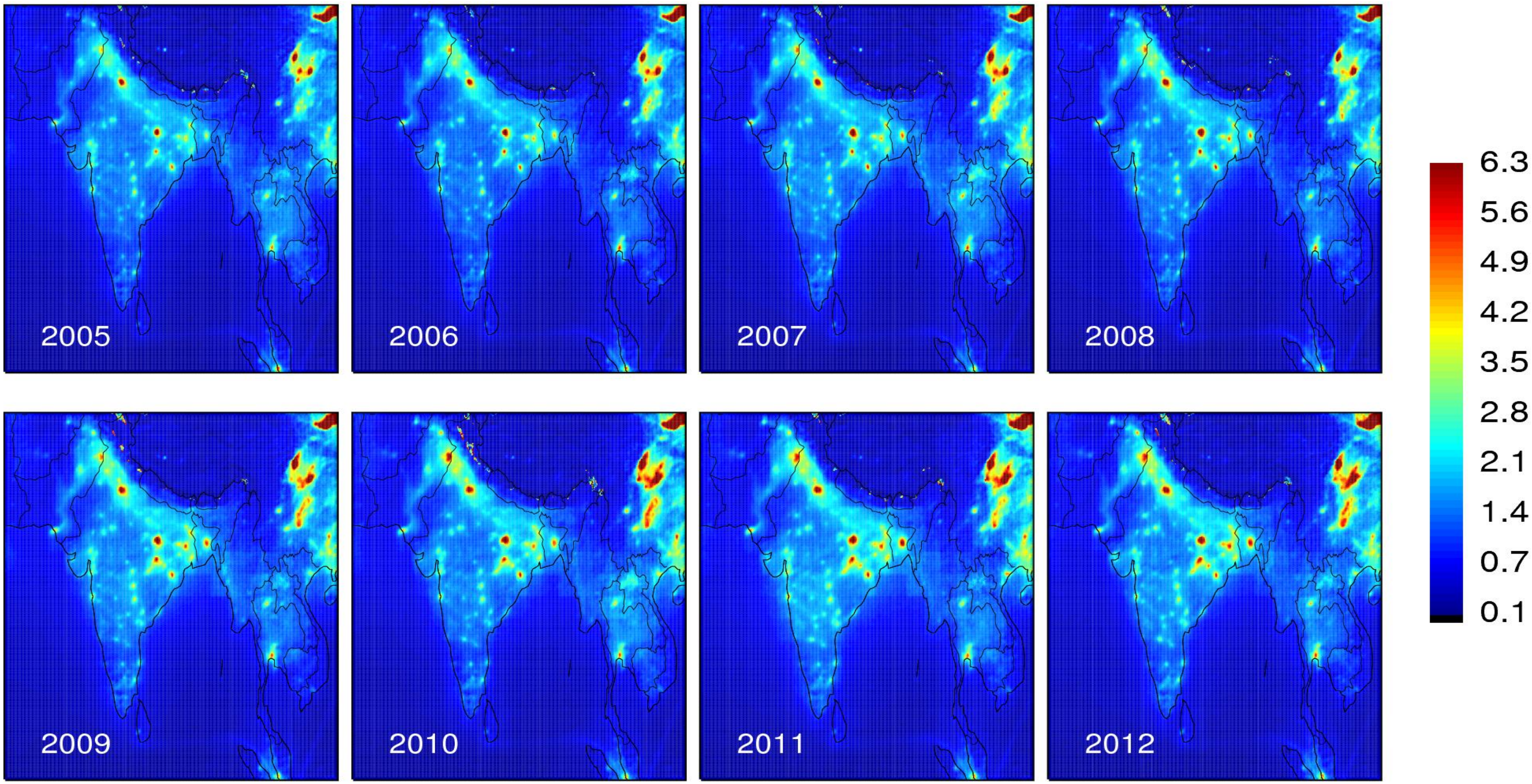
What can we learn about South Asia from OMI?

OMI SO_2 (DU) 2005-2007



Small compared to China but measurable now. Thanks Fioletov & Krotkov

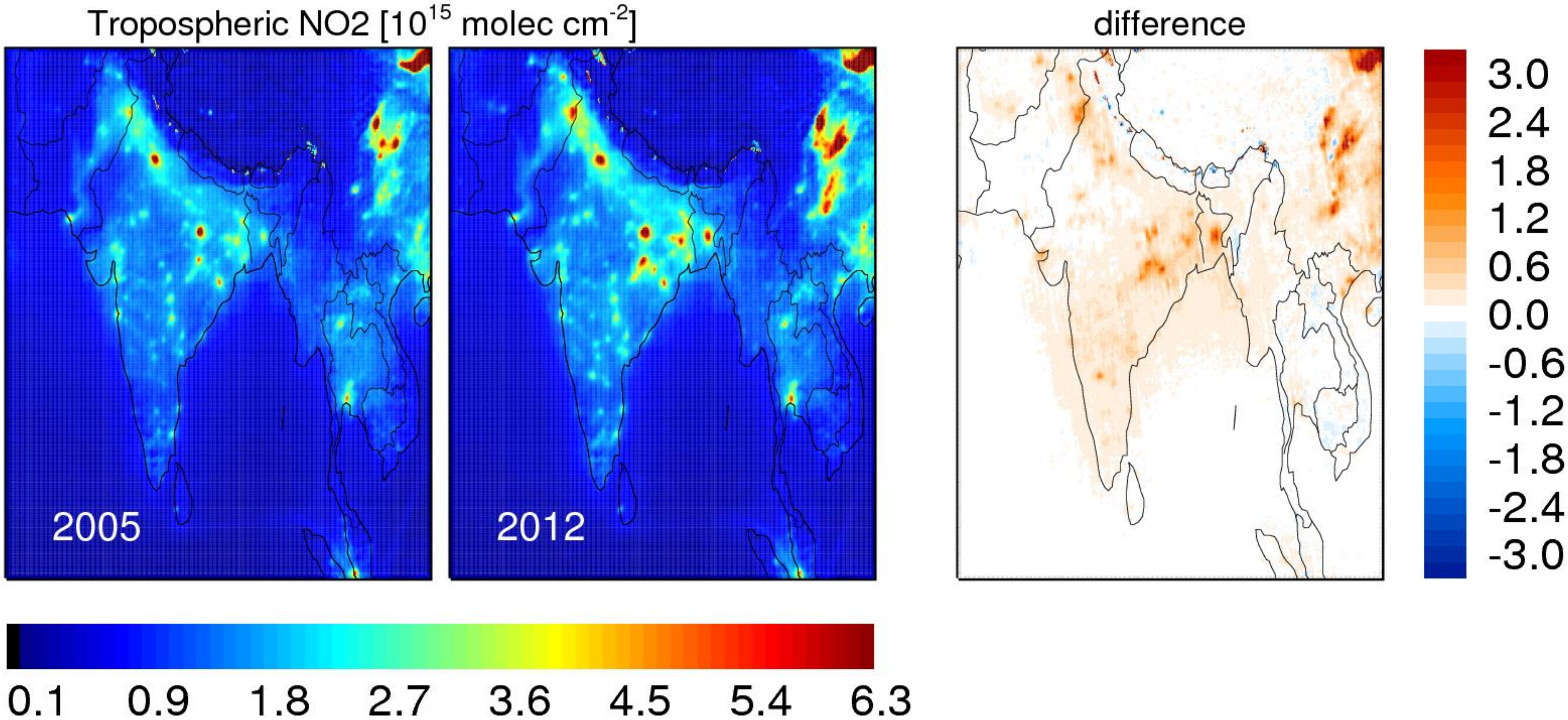
OMI NO_2 Columns
(Lamsal, Krotkov, Yang)



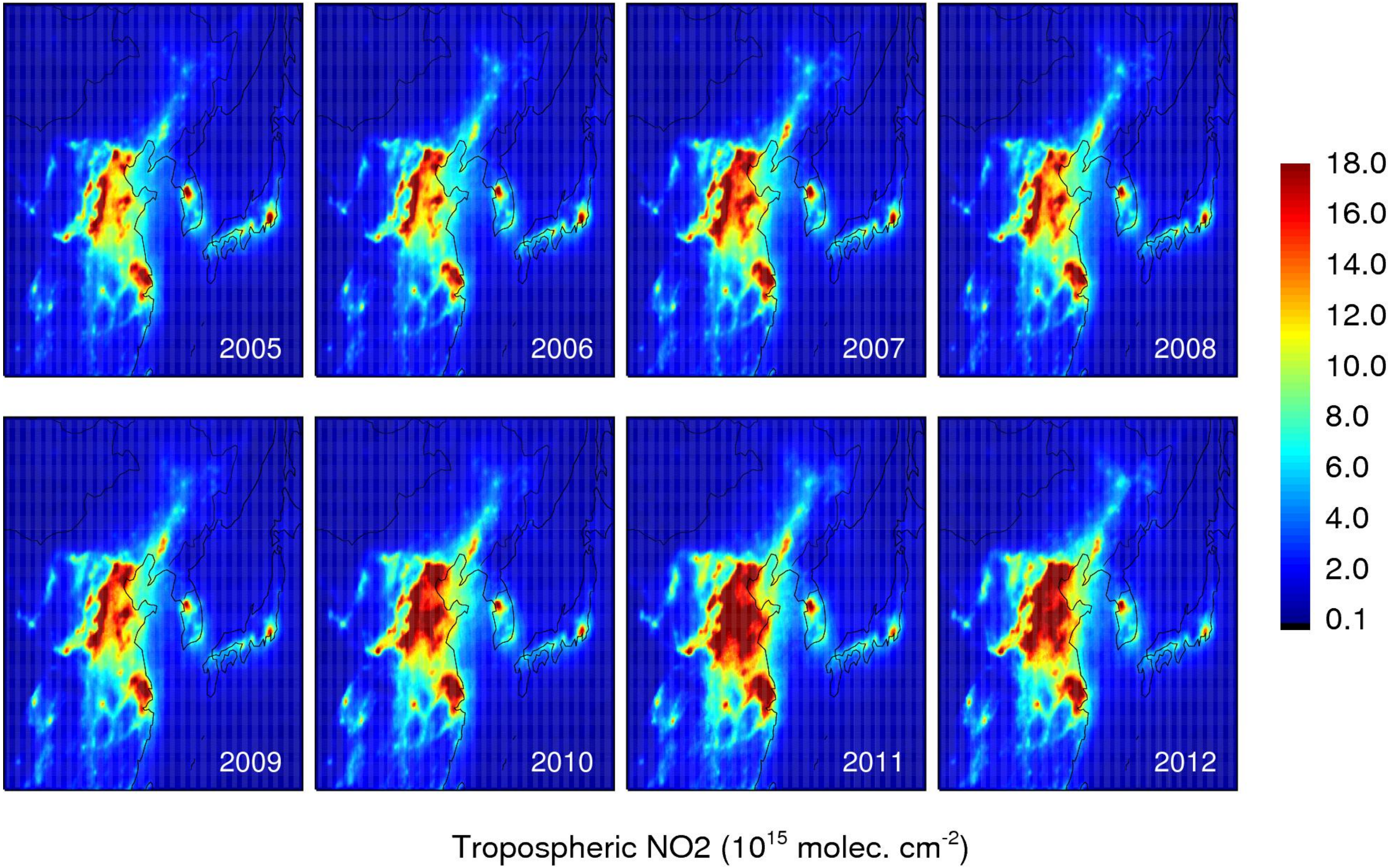
Tropospheric NO2 (10^{15} molec. cm^{-2})

“As South Asia develops technologically and converts from two-stroke motorcycles to four-stroke
automobiles the ratio of VOC to NOx will decrease and may result in higher ozone levels

The trend is worrisome.



But still small compared to East Asia



Conclusions

- Measurements indicate greater <u>global</u> forcing than inventories; observations from S Asia support this.
- Absorbing aerosols are created *in situ* and aerosols can become darker with aging (BrC).
- Mixtures of dust and BC absorb more radiation than either alone.
- India has seen little Los Angeles-type smog (O_3) thus far, but development may change that.

Looking forward

- More *in situ* surface observations of trace gases aerosols, and meteorology –
  - coordinated and simultaneous to understand processes and evaluate emissions inventories
- Vertical profiles such as research aircraft both in source regions and downwind.
- Remote sensing – focused retrievals and ground truth.
- High resolution models tailored to local chemistry and meteorology.
- Science driven air quality and climate policy.

Thank You