Atmospheric Brown Clouds (ABC)

: Regional Assessment Report with Focus on Asia

Sang-Woo Kim

Seoul National University, Republic of Korea

UNEP

ATMOSPHERIC BROWN CLOUDS

UNEP Project Atmospheric Brown Cloud (ABC)

Definition of ABCs: regional-scale plumes of air pollution, that consist of copious amount of tiny particles of BC, sulphates, nitrates, fly ash and many other pollutants (e.g., O_3 and its precusors), in the middle and lower troposphere.

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ATMOSPHERIC BROWN CLOUDS

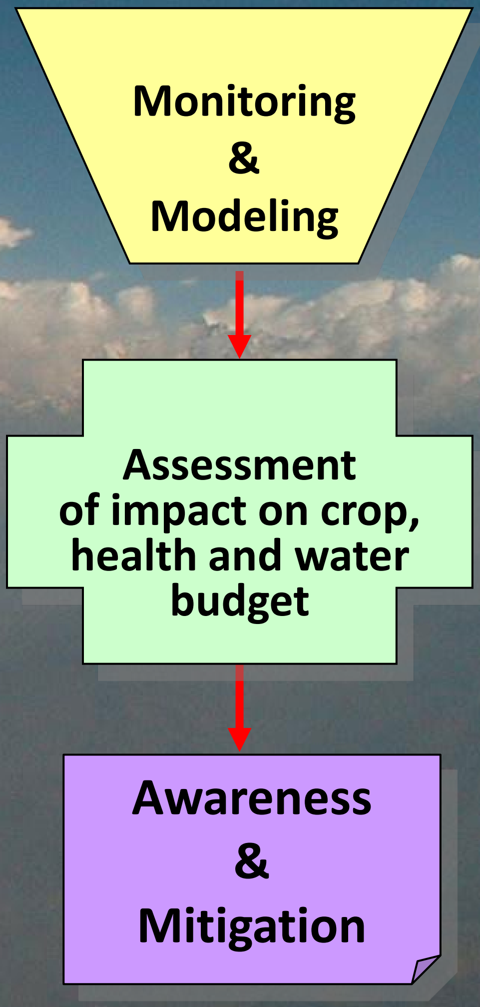
Major Components of Project ABC

The project ABC comprised of 3 major programs:

Observation and modeling: establishment of a network of ground based monitoring stations across the Asia and Pacific region and providing inputs to the assessments of impacts.

Impact assessment: assessment of the potential impacts of ABC on climate, agriculture, water, and health, etc.

Awareness and mitigation: provide science-based information for policy makers to mitigate atmospheric pollution.



Expanded UNEP/ABC Science Team

ABC International

Coordinate the 3 regions and implement activities on cross cutting areas. Facilitate the implementation of adaptation and mitigation programmes

V. Ramanathan (Chair), Chair ABC-Asia, Chair ABC-Africa, Chair ABC-Latin America

ABC-Asia

Coordinate the scientific activities in Asia. Facilitate the Implementation of ABC observatory programme and impact assessment programme

T. Nakajima (Chair); A. Jayaraman, S. C. Yoon, and Z. Yuanhang (Vice Chairs); V. Ramanathan, P. J. Crutzen, G. R. Carmichael, S. Fuzzi, H. Rodhe, K. R. Kim, M. G. Lawrence, G. Y. Shi, J. Srinivasan. Y. Kondo (Members);

Ex-officio members: IPCC (R. K. Pachauri), and WMO (L. Jalkanen)

Started from 2003

ABC-Africa

Coordinate the scientific activities in Africa. Facilitate the development of feasibility study on the establishment of ABC-Africa, and implementation of ABC observatory programme and impact assessment programme

Chair, Vice Chair, and Team members will be identified in consultation with the scientists from Africa

Started from 2010

ABC-Latin America

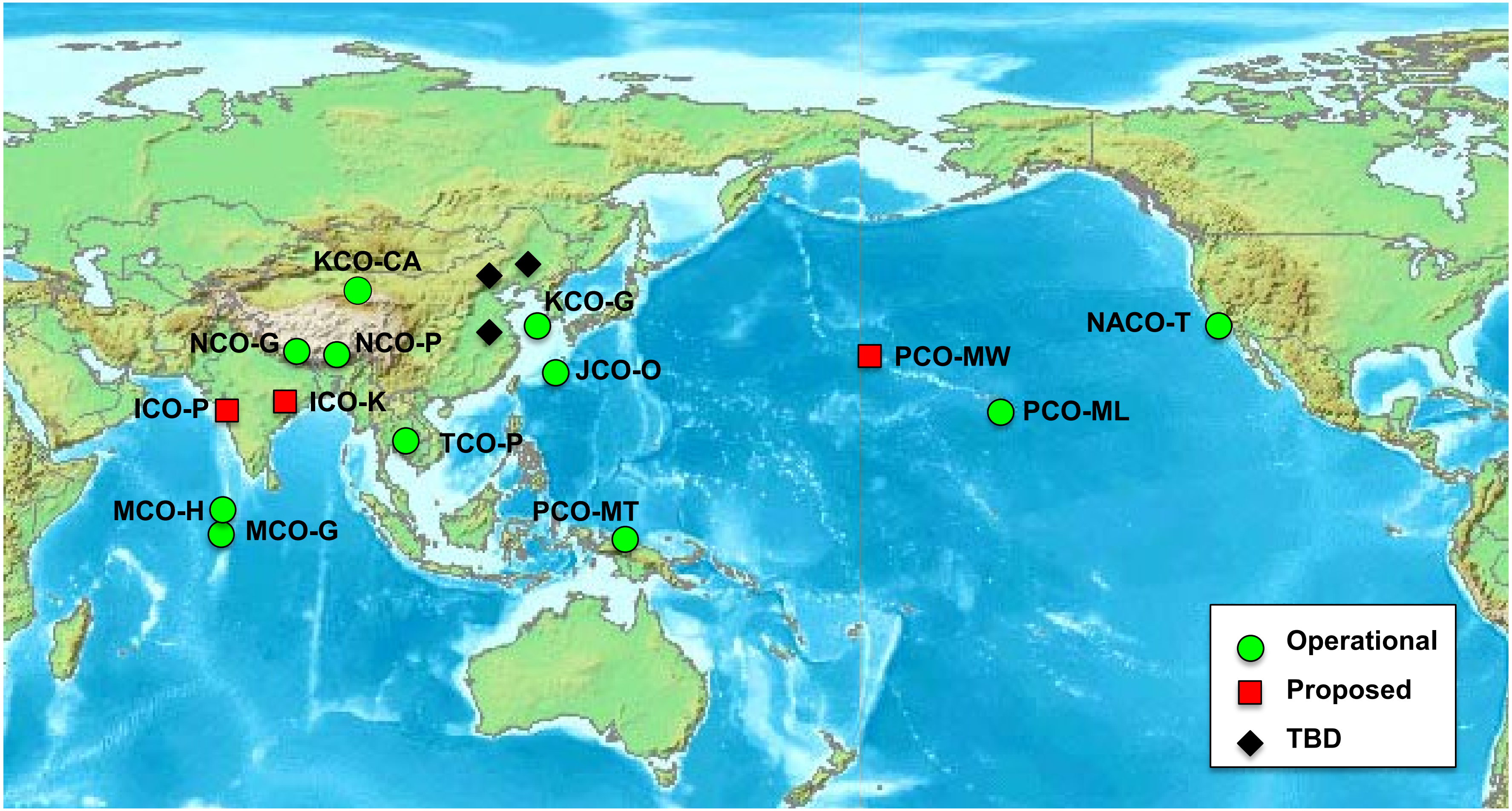
Coordinate the scientific activities in Latin America. Facilitate development of feasibility study on the establishment of ABC- Latin America, and implementation of ABC observatory programme and impact assessment programme

Chair, Vice Chair, and Team members will be identified in consultation with the scientists from Latin America

Started from 2010

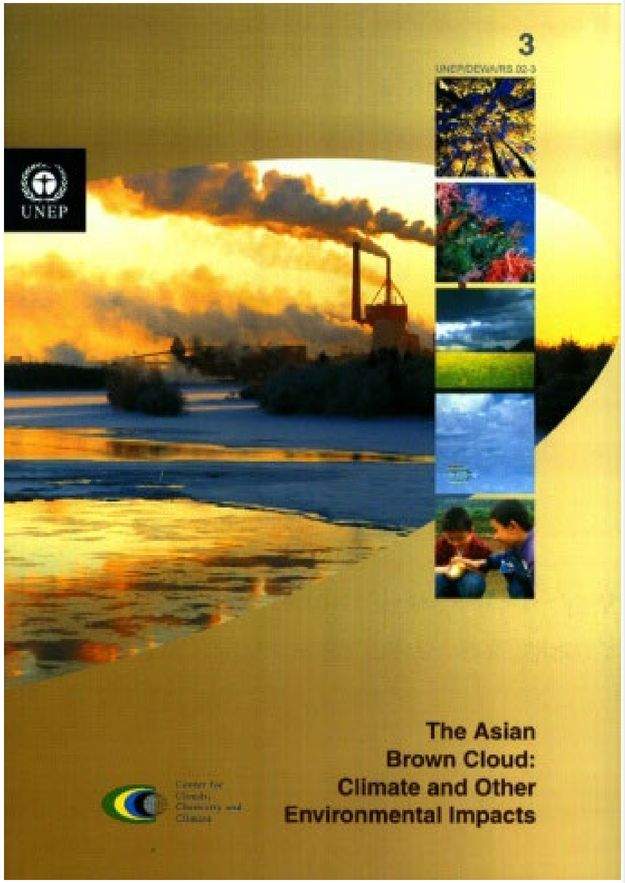
- ABC-Phase I : 2003 – 2007, ABC-Phase II : 2008 - Present

ABC Climate Observatories in Asia and the Pacific

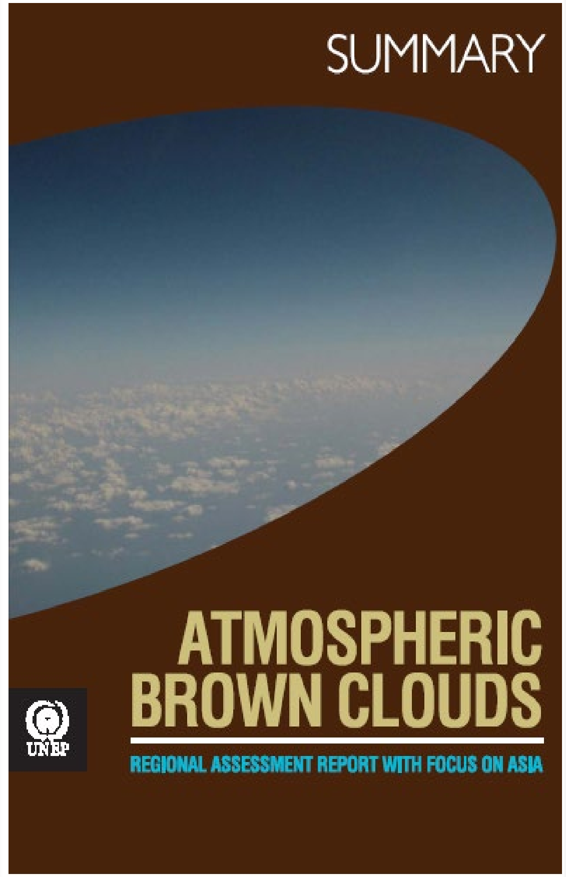


- Establishment of an integrated network of 12 strategically located state-of-the-art ABC surface climate observatories throughout the Indo-Asia-Pacific region → **Strengthening capacity to monitor ABC.**
- In addition, the measurements carried out during intensive field campaigns utilizing various platforms (ground, ships, aircrafts and UAVs, satellites) add valuable data and findings to that from regular routine monitoring at the observatories.

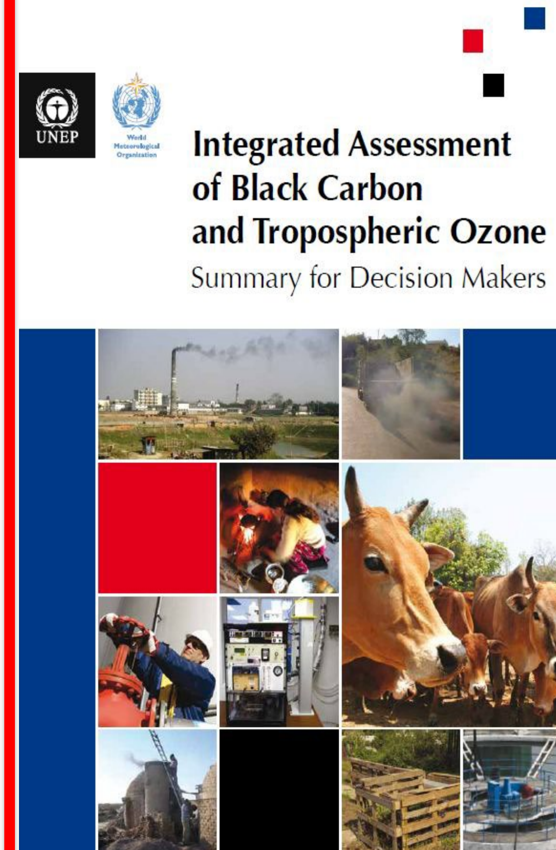
Atmospheric Brown Clouds (ABC):
A Climate Mitigation Journey that began in 2000



Preliminary Assessment Report (Aug 2002)



The First Impact Assessment Report (Nov 2008)



Integrated Assessment of Black Carbon and Tropospheric Ozone (Feb 2011)

First Impact Assessment Report with Focus on Asia

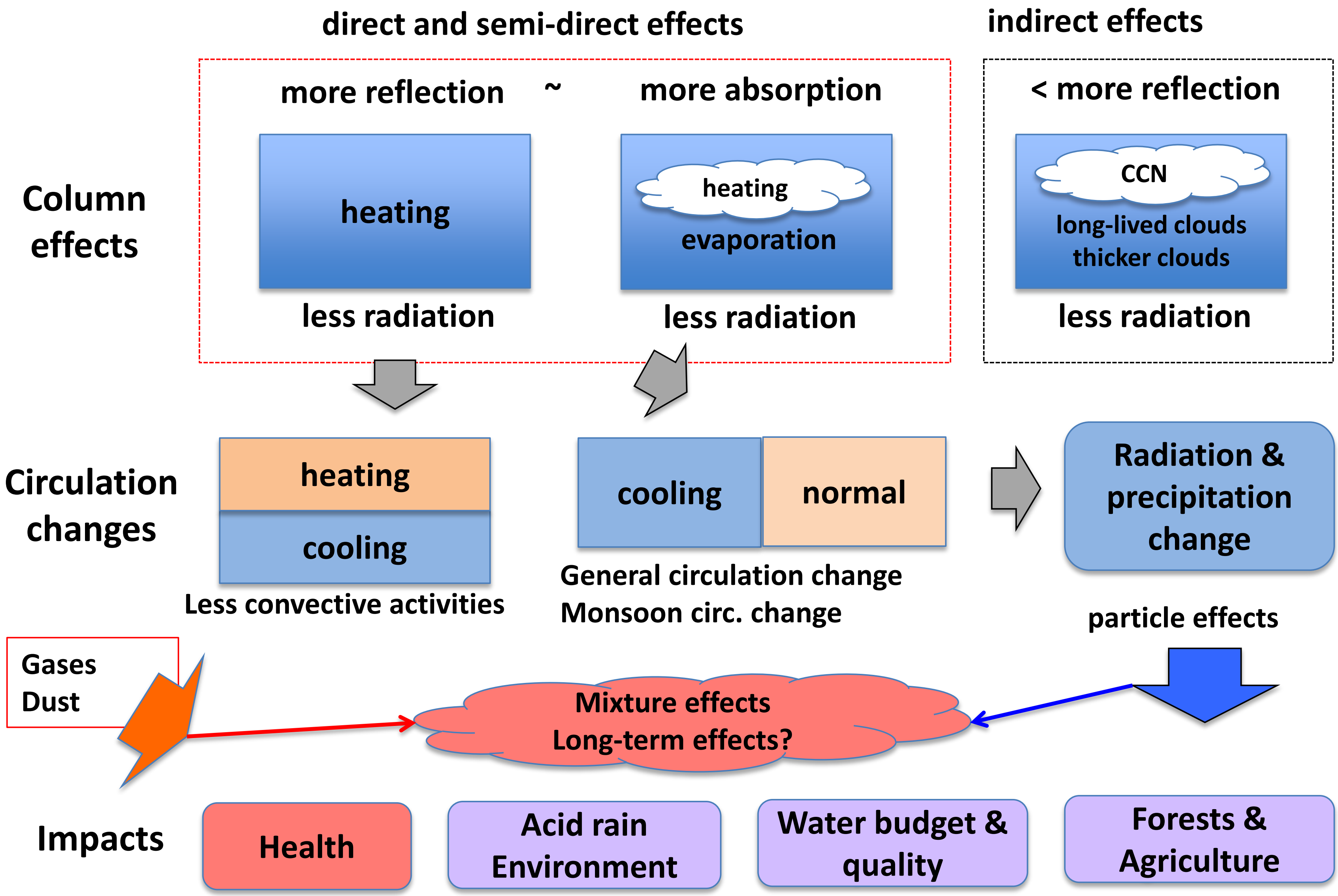
Source: *http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=550&ArticleID=5978&l=en*

→ Published on 13 November 2008 in Beijing

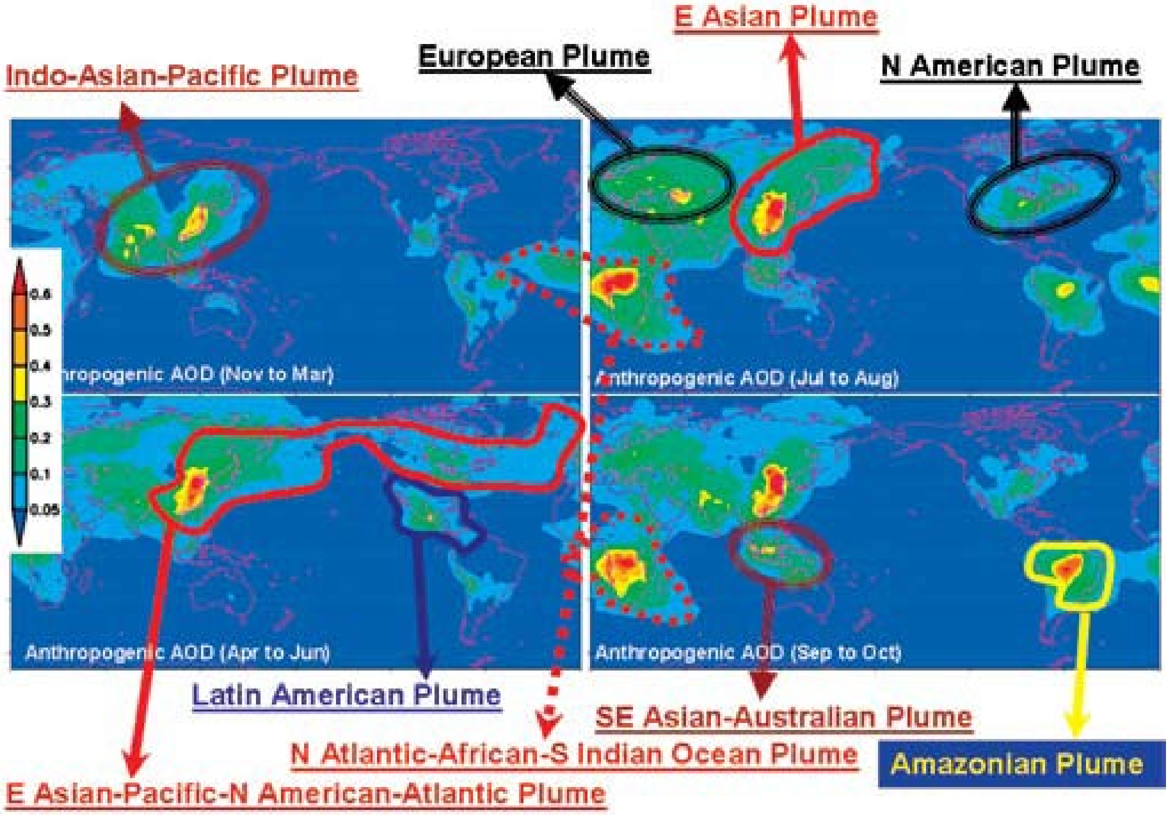
→ The starting point of this report was an earlier preliminary assessment report on human health, food security and the water budget in 2002 that was based on the findings of Indian Ocean Experiment (INDOEX).

→ ABC Impacts on Regional Climate, Water Resources, Agriculture and Human Health

Various effects of ABCs and BC



1. Identification of Regional ABC Hotspots

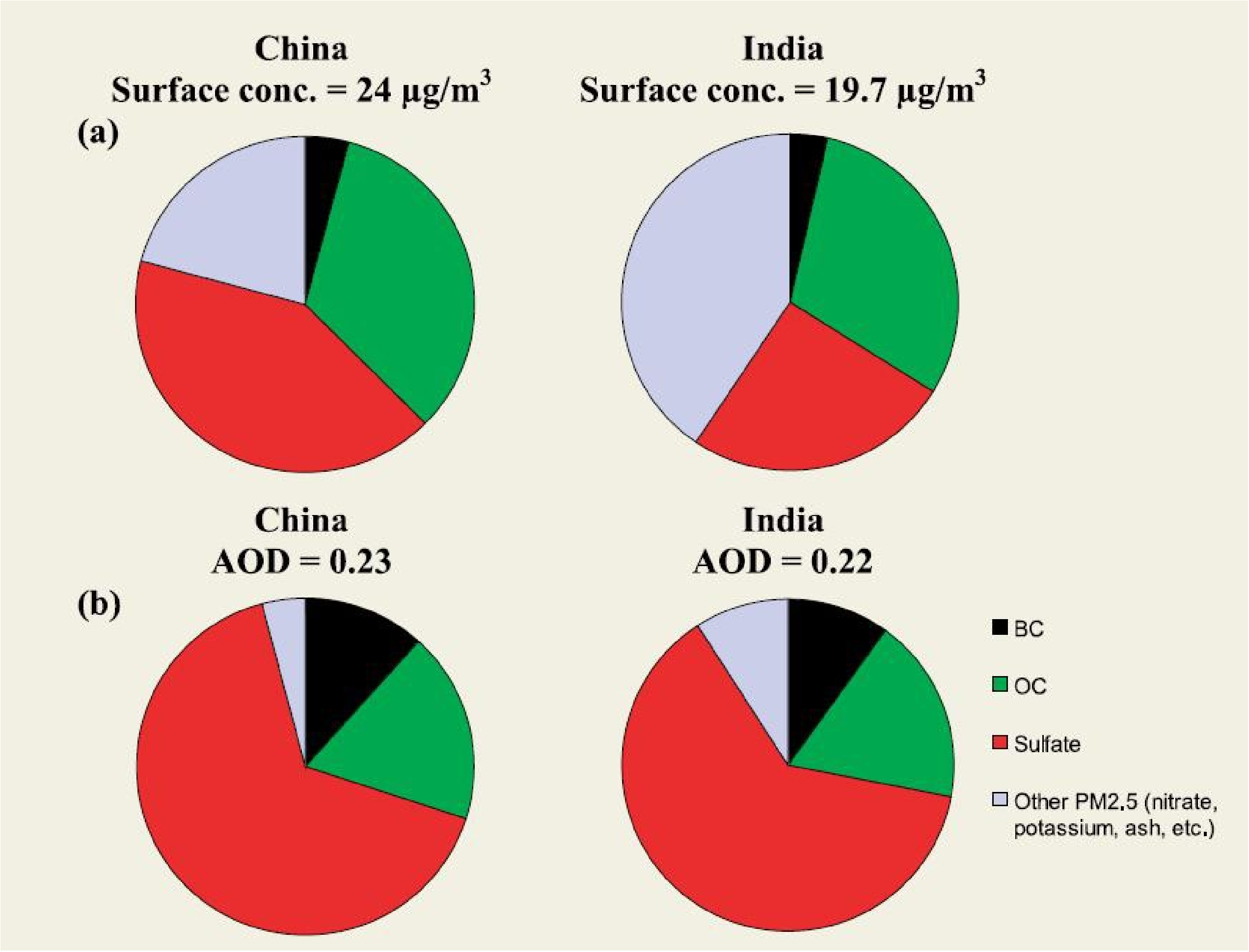


• By integrating and assimilating ABC surface observations with satellite observations and chemistry transport model (CTM), five regional ABC hotspots around the world have been identified:

i) East Asia
ii) Indo-Gangetic Plain in S. Asia
iii) Southeast Asia
iv) Southern Africa
v) the Amazon Basin

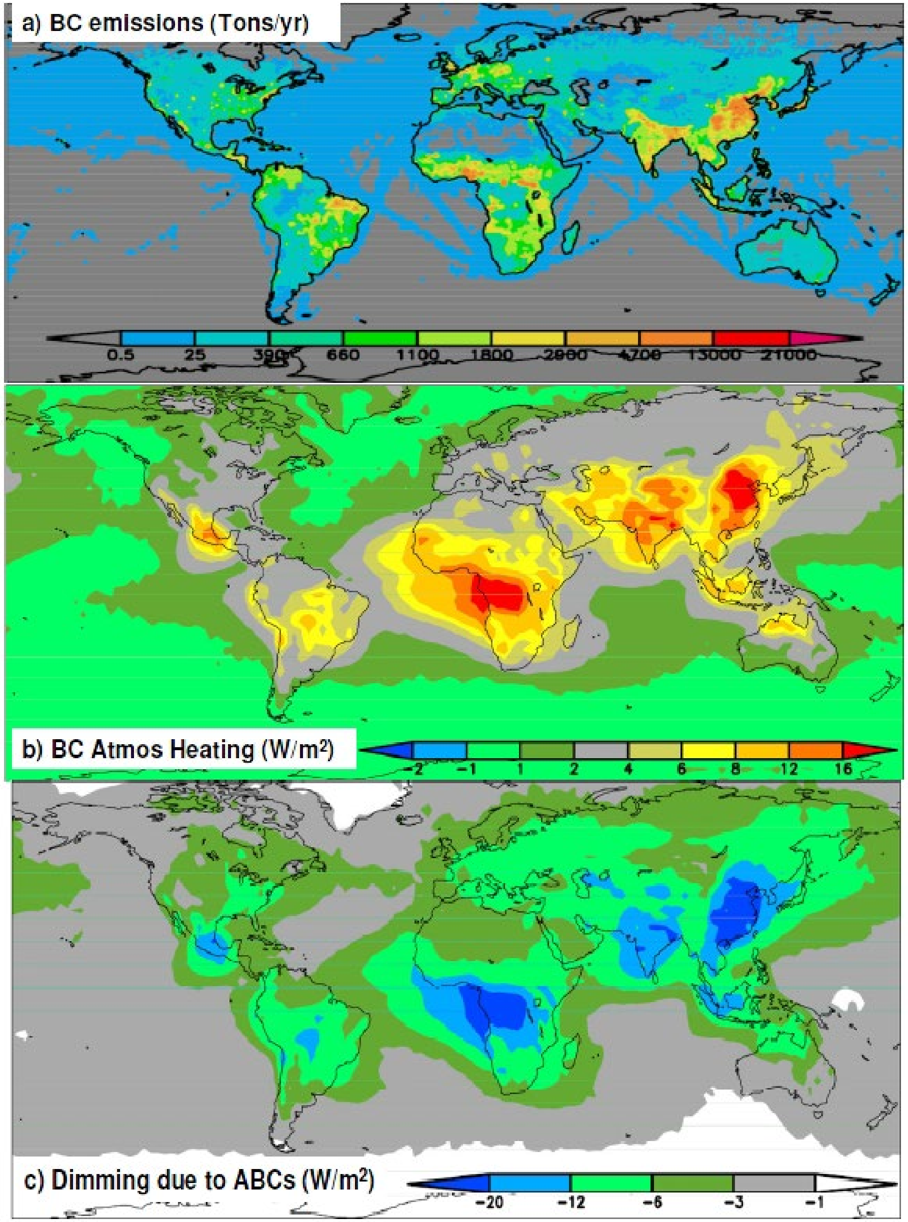
• **The following 13 mega-city ABC hotspots in Asia have been identified:** Bangkok, Beijing, Cairo, Dhaka, Karachi, Kolkata, Lagos, Mumbai, New Delhi, Seoul, Shanghai, Shenzhen and Tehran.

Chemical Composition of Aerosols in ABCs



- Using satellite data and regional assimilation models, the chemical composition of aerosols in ABCs and how their chemistry contributes to the AOD have been characterized for the first time for China and India.

2. ABCs Radiative Forcing



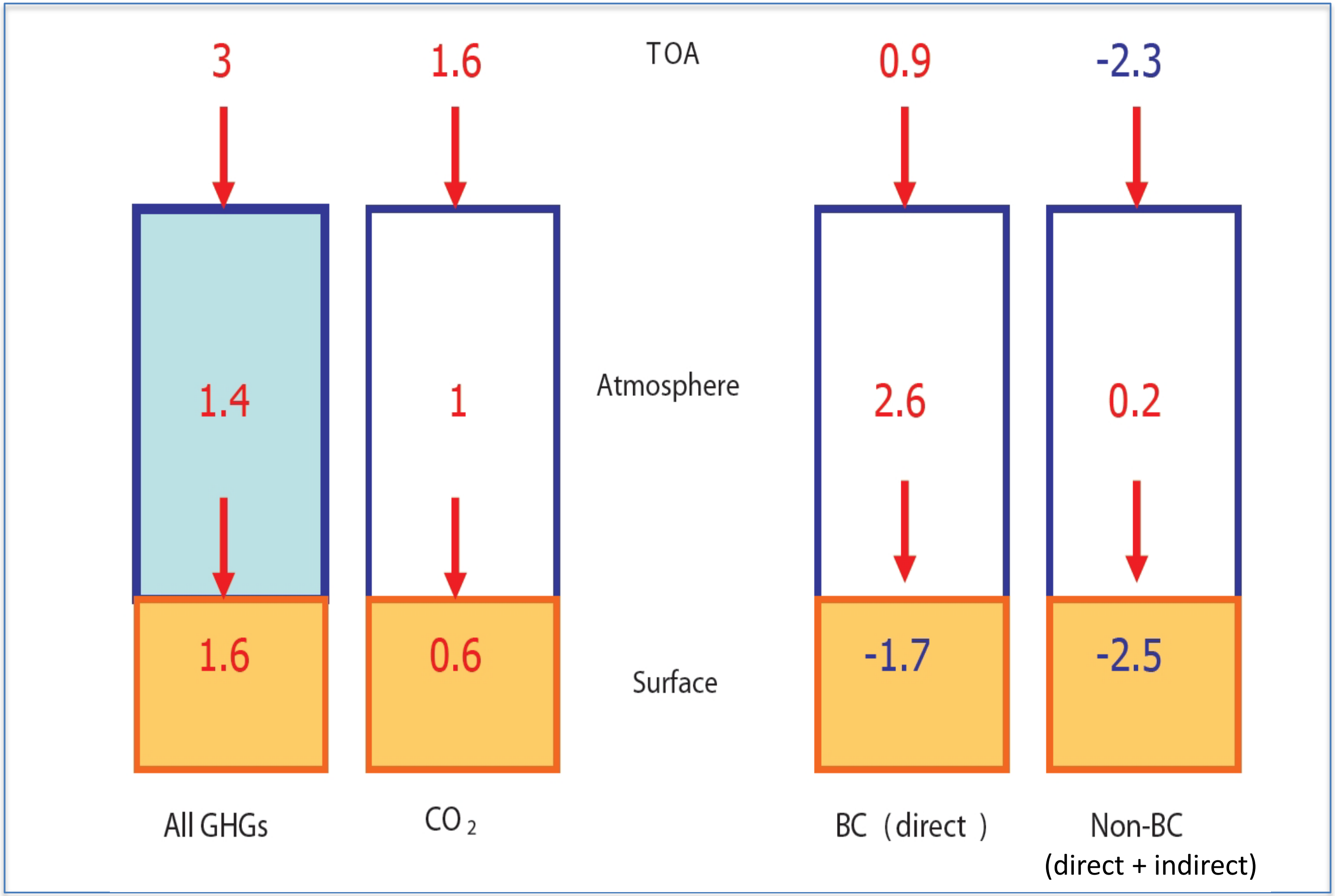
- Life time of ABCs (and BC) is of the order of few days to few weeks

- Fossil fuel combustion, bio fuel cooking and biomass burning are the sources of ABCs (BC).

- ABCs (BC) adds solar heating to the atmosphere and causes dimming at the surface

- Unlike GHGs, ABCs (BC) concentrations and forcing are unevenly distributed, with the largest values concentrated in and downwind of the strongest source regions.

2. ABCs Radiative Forcing



Unit: W/m^2

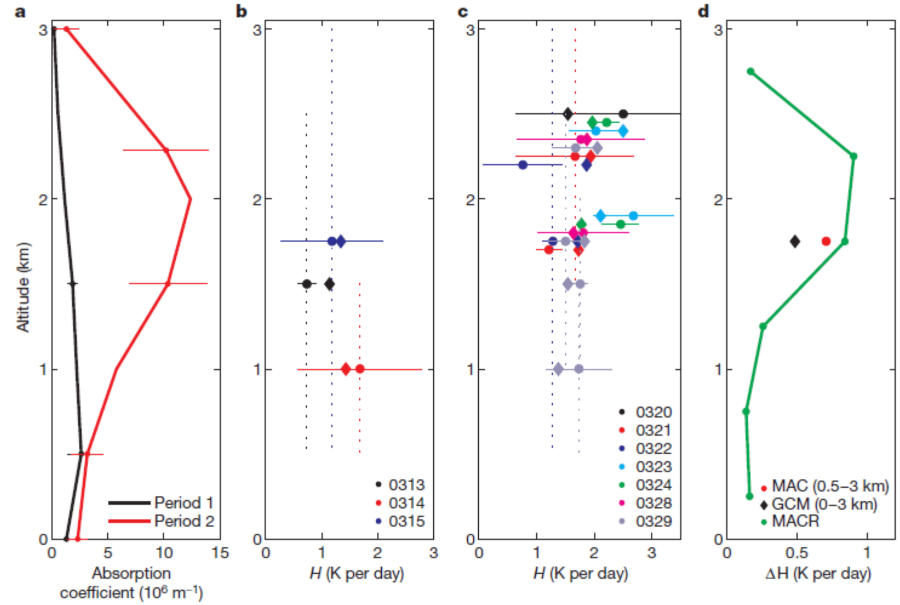
- It is highly likely that black carbon (BC) in ABCs has increased the vertically averaged annual mean solar absorption in the troposphere (from the surface up to 14 km in altitude) by about 15% (about 14 W m^{-2}) and the solar heating at elevated levels (1 - 4 km) over India and China by as much as 20 - 50% (6 - 20 W m^{-2}).

MAC: Maldives Autonomous UAV campaign - 2006

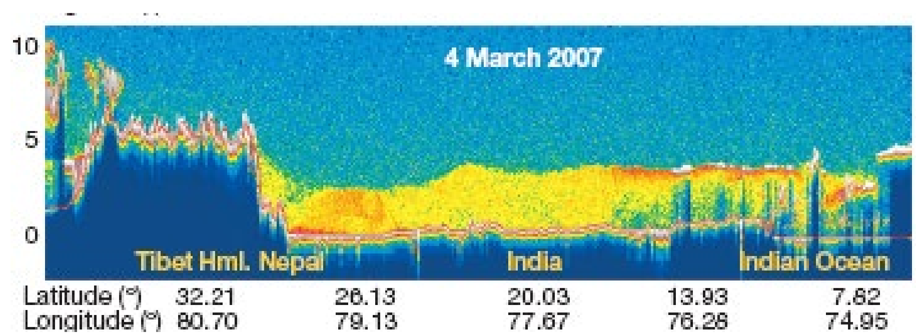
Ramanathan V., M.V. Ramana, G. Roberts, D. Kim, C.E. Corrigan, C.E. Chung & D. Winker (2007). Warming trends in Asia amplified by brown cloud solar absorption. *Nature*, 448, 575-578, doi:10.1038/nature 06019.

Corrigan, C.E., G.C. Roberts, M.V. Ramana, D. Kim and V. Ramanathan (2008). Capturing vertical profiles of aerosols and black carbon over the Indian Ocean using autonomous unmanned aerial vehicles. *Atmos. Chem. & Phys., 8*, 737-747.

Roberts G.C., M.V. Ramana, C. Corrigan, D. Kim, and V. Ramanathan (2008). Simultaneous observations of aerosol-cloud-albedo interactions with three stacked unmanned aerial vehicles. PNAS., 105, 7370-7375.



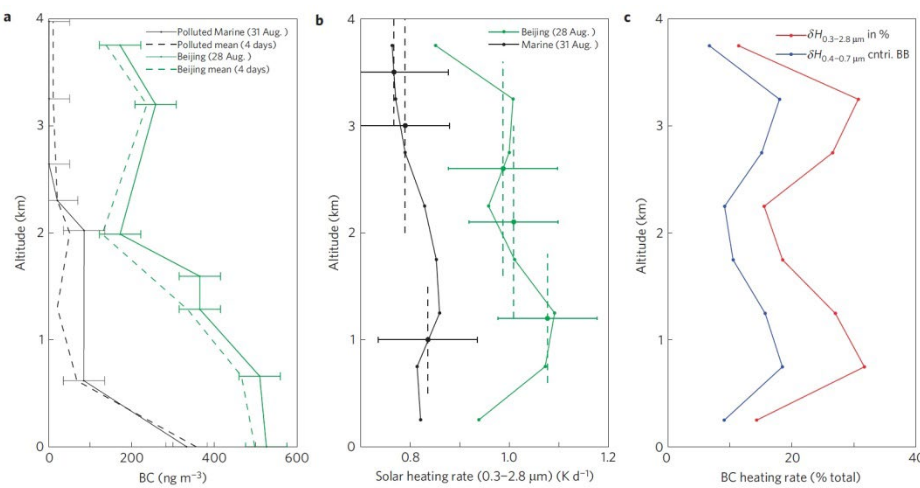
Vertical distribution of UAV observations.
H: Solar heating rate. (Ramanathan et al., 2007)



CALIPSO lidar showing the vertical distribution of ABCs. (Ramanathan et al., 2007)

UAV experiment: CAPMEX

August 9 - September 30, 2008



Vertical profiles determined from the UAV data. **a**, BC concentration profiles for the Marine plumes and the Beijing plumes. **b**, Broadband (0:3–2:8 m) diurnal averaged solar-heating rate (*H*) profiles for the Marine and the Beijing plumes. **c**, The percentage contribution by BC to *H* (*H*0:3–2:8 m in %) and the percentage contribution by solar absorption in the visible range (0:4–0:7 m) to *H* (*H*0:4–0:7 m cntri. BB).

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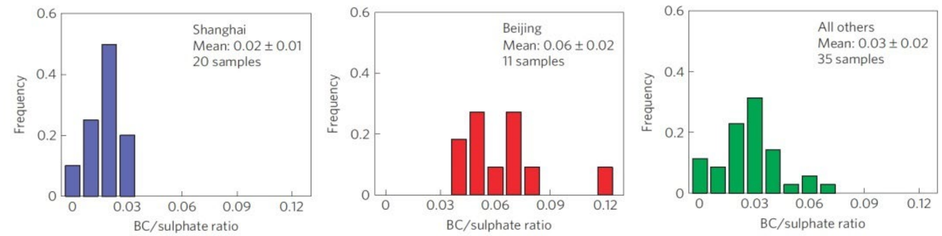
Warming influenced by the ratio of black carbon to sulphate and the black-carbon source

M. V. Ramana[1], V. Ramanathan[1]*, Y. Feng[1], S-C. Yoon[2], S-W. Kim[2], G. R. Carmichael[3] and J. J. Schauer[4]



Frequency distribution of the BC-to-sulphate mass-concentration ratio for the Shanghai plumes, the Beijing plumes and the 'all-others' plumes measured at the Gosan climate observatory.

backstory

Olympic atmosphere

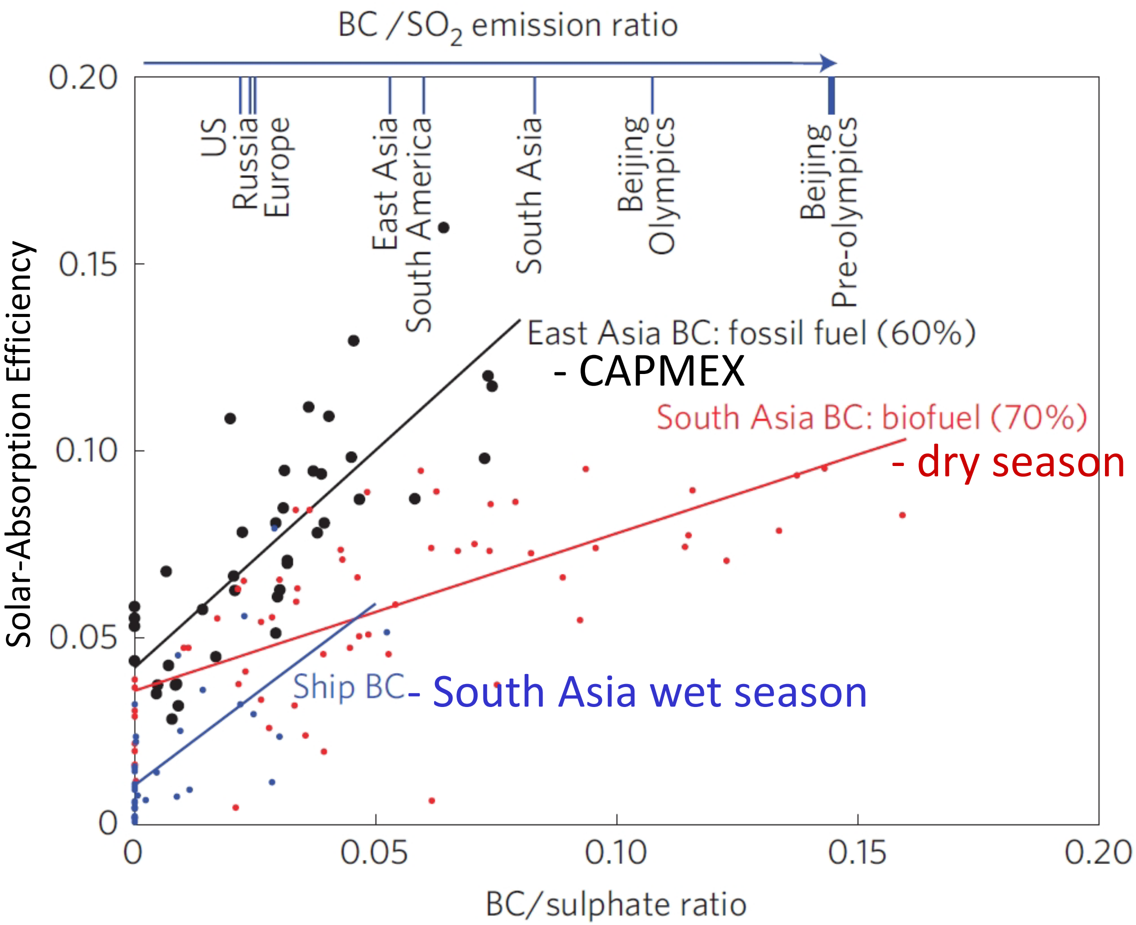
Veerabhadran Ramanathan, James Schauer, Hung Nguyen and colleagues found the Beijing Olympics to be conducive to international collaboration in science, as well as sport, as they attempted to assess the effect of emission restrictions on climate forcing.

What was the objective of the work?
During the 2008 Beijing Summer Olympics, the Chinese government achieved a massive reduction in the emission of atmospheric pollutants. This provided a unique opportunity to assess the uncertainties associated with the role of aerosols in climate change forcing. We wanted to directly assess the heating of black carbon in the atmosphere and to estimate the changes in this heating resulting from the air pollution controls put in place for the Olympics.

Why did you choose this particular location?
The Gosan sampling site, on the Korean island of Jeju, is a climate observatory for the United Nations Environment Programme

The team prepares an unmanned aerial vehicle for take-off on a makeshift landing strip on

Measured BC-to-sulphate mass-concentration ratio versus aerosol solar-absorption efficiency (α) at 550 nm

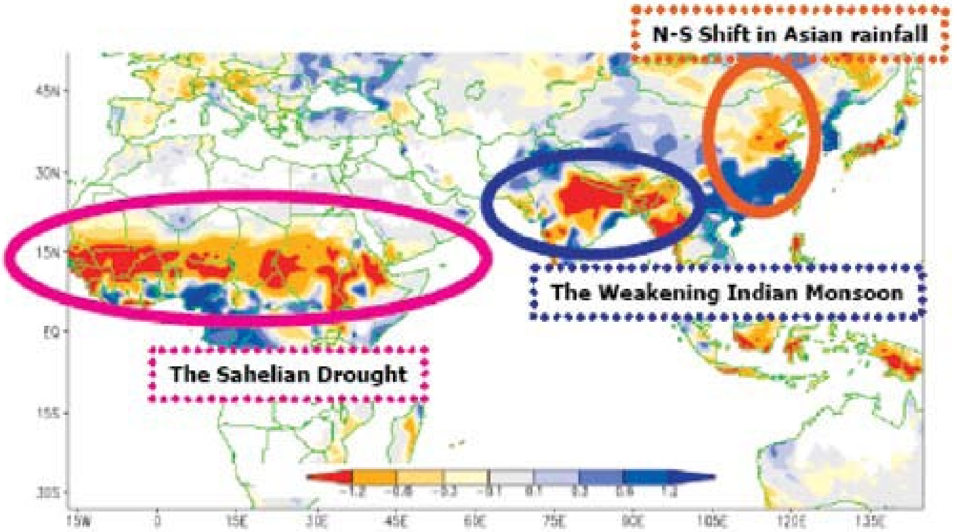


- Fossil-fuel combustion is the main source for BC in East Asia, whereas biomass-fuel BC is the main source in South Asia.
- The slope of 1.17($\pm$0.28) for the East Asia aerosols is a factor of 2.5 larger than that of the South Asia aerosols [0.42($\pm$0.13)].
- For the same BC-to-sulphate ratio, values for the East Asia aerosols are about **a factor of two (i.e., 100%)** larger than those for the South Asia aerosols.

- Another result that supports the larger absorption efficiency of fossil-fuel plumes containing BC is that the slope for the ship BC (0.97$\pm$0.38) is similar to the East Asia aerosol slope (1.17$\pm$0.28).
- **Fossil-fuel BC is more effective as a warming agent compared with BC from biomass fuels.**

2. ABCs Radiative Forcing

Observed trends in summer rainfall: 1950 - 2002.



• Rainfall over the northern half of India has decreased, while the rainfall pattern in China has shifted. The southern parts of Eastern China have been receiving more rainfall since the 1950s, while the northern parts are experiencing a negative trend.

• The number of rainy days for all India is also decreasing, although the frequency of intense rainfall is increasing, leading to more frequent floods. The heavily populated Indo-Gangetic Plain is especially vulnerable.

• ABC-induced dimming is considered as the major causal factor for the rainfall decrease in India and for the north to south shift of the summer monsoon in Eastern China. However, many uncertainties in modelling regional climate remain.

• Atmospheric solar heating combined with sot deposition on the snow/ice can add to greenhouse warming and accelerate the retreat of glaciers and snow packs in Hindu-Kush-Himalayan (HKH) Mountains.

doi:10.1038/nature10552

Arabian Sea tropical cyclones intensified by emissions of black carbon and other aerosols

Amato T. Evan[1], James P. Kossin[2,3], Chul 'Eddy' Chung[4] & V. Ramanathan[5]

Throughout the year, average sea surface temperatures in the Arabian Sea are warm enough to support the development of tropical cyclones[1], but the atmospheric monsoon circulation and associated strong vertical wind shear limits cyclone development and intensification, only permitting a pre-monsoon and post-monsoon period for cyclogenesis[1–4]. Thus a recent increase in the intensity of tropical cyclones over the northern Indian Ocean[5] is thought to be related to the weakening of the climatological vertical wind shear[3,4]. At the same time, anthropogenic emissions of aerosols have increased sixfold since the 1930s, leading to a weakening of the southwesterly lower-level and easterly upper-level winds that define the monsoonal circulation over the Arabian Sea[6–9]. In principle, this aerosol-driven circulation modification could affect tropical cyclone intensity over the Arabian Sea, but so far no such linkage has been shown. Here we report an increase in the intensity of pre-monsoon Arabian Sea tropical cyclones during the period 1979–2010, and show that this change in storm strength is a consequence of a simultaneous upward trend in anthropogenic black carbon and sulphate emissions. We use a combination of observational, reanalysis and model data to demonstrate that the anomalous circulation, which is radiatively forced by these anthropogenic aerosols, reduces the basin-wide vertical wind shear, creating an environment more favourable for tropical cyclone intensification. Because most Arabian Sea tropical cyclones make landfall[1], our results suggest an additional impact on human health from regional air pollution.

The South Asian atmospheric brown cloud (ABC) is a 3-km-thick layer of pollution over the northern Indian Ocean (NIO) and Indian subcontinent that results from human emission of aerosols such as black and organic carbon and sulfates[9]. When over water the dominant surface-radiative effect of the ABC is a decrease in solar insolation, which is enhanced significantly by black and organic carbon aerosols[7–11]. There is a northward gradient of fine-mode aerosol optical depth over the Arabian Sea (Fig. 1a) and therefore a southward gradient in aerosol surface forcing[7,9,10,12] (that is, negative surface forcing is greater in magnitude to the north). Positive forcing associated with greenhouse gases is offset in the NIO by the sixfold increase in emissions since 1930 (ref. 9), resulting in a southward gradient in sea surface temperature (SST) trends (Fig. 1b) and a decrease in the climatological summertime northward SST gradient[7]. The atmospheric response to this anomalous SST gradient is a weakening of the southerly cross-equatorial surface flow and upper-level tropical easterly jet, which define the Indian monsoon circulation, through anomalously high sea-level pressure to the north and low sea-level pressure to the south[7,8].

Once the monsoon onset occurs, very strong vertical wind shear develops across the Arabian Sea, the main factor prohibiting tropical cyclone development during July and August[1,2]. Thus, despite clima-

For a tropical cyclone to intensify, net heat transfer from the ocean to the near-surface air must be sufficient to overcome the frictional drag acting on the cyclone winds in the boundary layer[13]. In the absence of large-scale kinematic forces that would disrupt the physical structure of a cyclone, such as vertical wind shear[14], storm intensity is limited largely by the thermodynamic environment, as described by potential intensity theory[15]. As atmospheric kinematic conditions become more favourable for cyclones to develop, those that do form are more likely to achieve maximum intensities close to their potential intensity. Note that the ABC can affect the mean thermodynamic environment by stabilizing regional atmospheric lapse rates and decreasing potential intensity, but this effect is small relative to the regionally high absolute values of potential intensity[1].

One way to evaluate temporal changes in the intensity of tropical cyclones is to examine cyclone lifetime maximum intensity (LMI), defined as the maximum intensity achieved in the lifetime of a storm[16]. We calculate LMI for each storm from historical estimates of cyclone wind speeds[17] and then separate the data into the 1979–1996 and 1997–2010 periods, because ten pre-monsoon tropical cyclones formed during

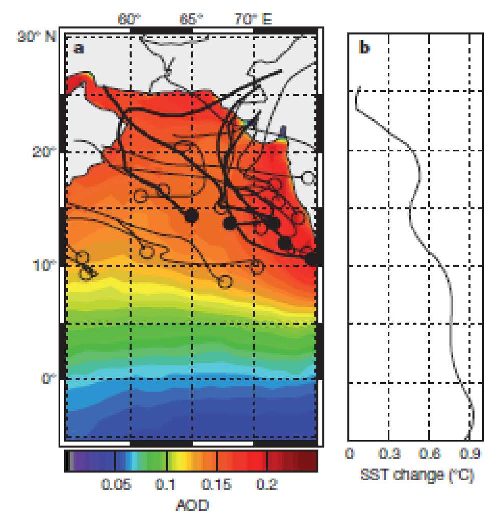


Figure 1 | Tropical cyclone tracks, aerosol optical depth and meridional SST trends in the Arabian Sea. **a**, Genesis points (circles) and tracks (solid lines) of pre-monsoon tropical cyclones during the period 1979–2010. Storms with an lifetime maximum intensity (LMI) of more than 50 m s^{-1} are indicated with a filled circle at the genesis point and thick track lines. Shaded contours represent

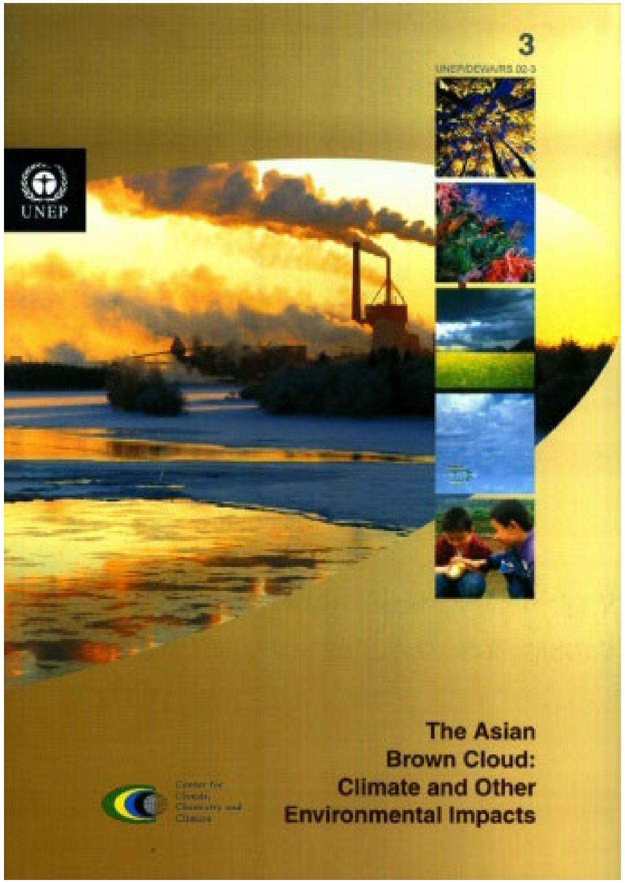
3. Improvement in understanding on impacts of ABCs: agriculture and health

• Formation of international teams of experts from within and outside Asia to carry out comprehensive scientific assessment studies on the impacts of ABCs on agriculture, water budgets and human health in Asia

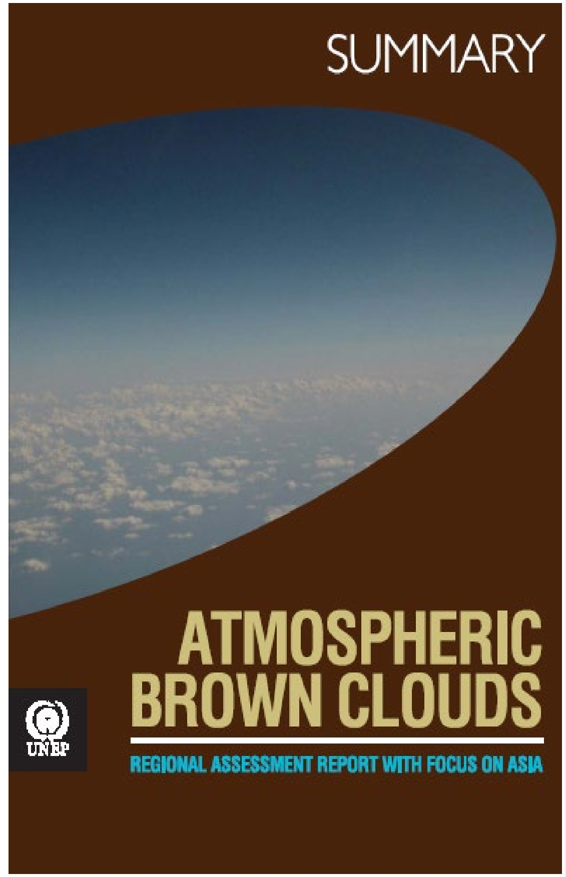
- Indian Agriculture Research Institute (India) as lead regional institution for coordinating agriculture impact study
- Nanyang Technological University(Singapore) for water impacts
- Chulabhorn Research Institute (Thailand) for Health impacts

• Capacity of Asian researchers has been significantly enhanced regarding the understanding of the ABC issue and carries out impact assessment studies

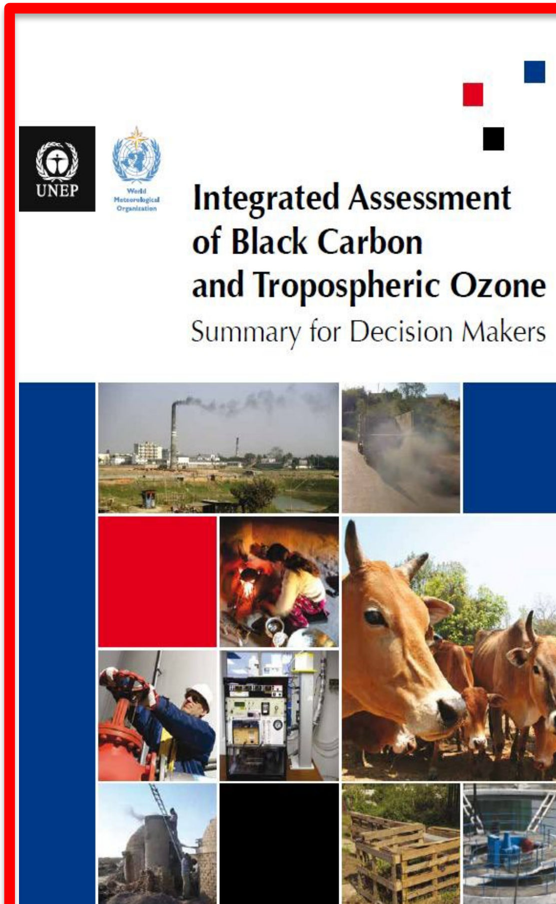
Atmospheric Brown Clouds (ABC):
A Climate Mitigation Journey that began in 2000



Preliminary Assessment Report (Aug 2002)

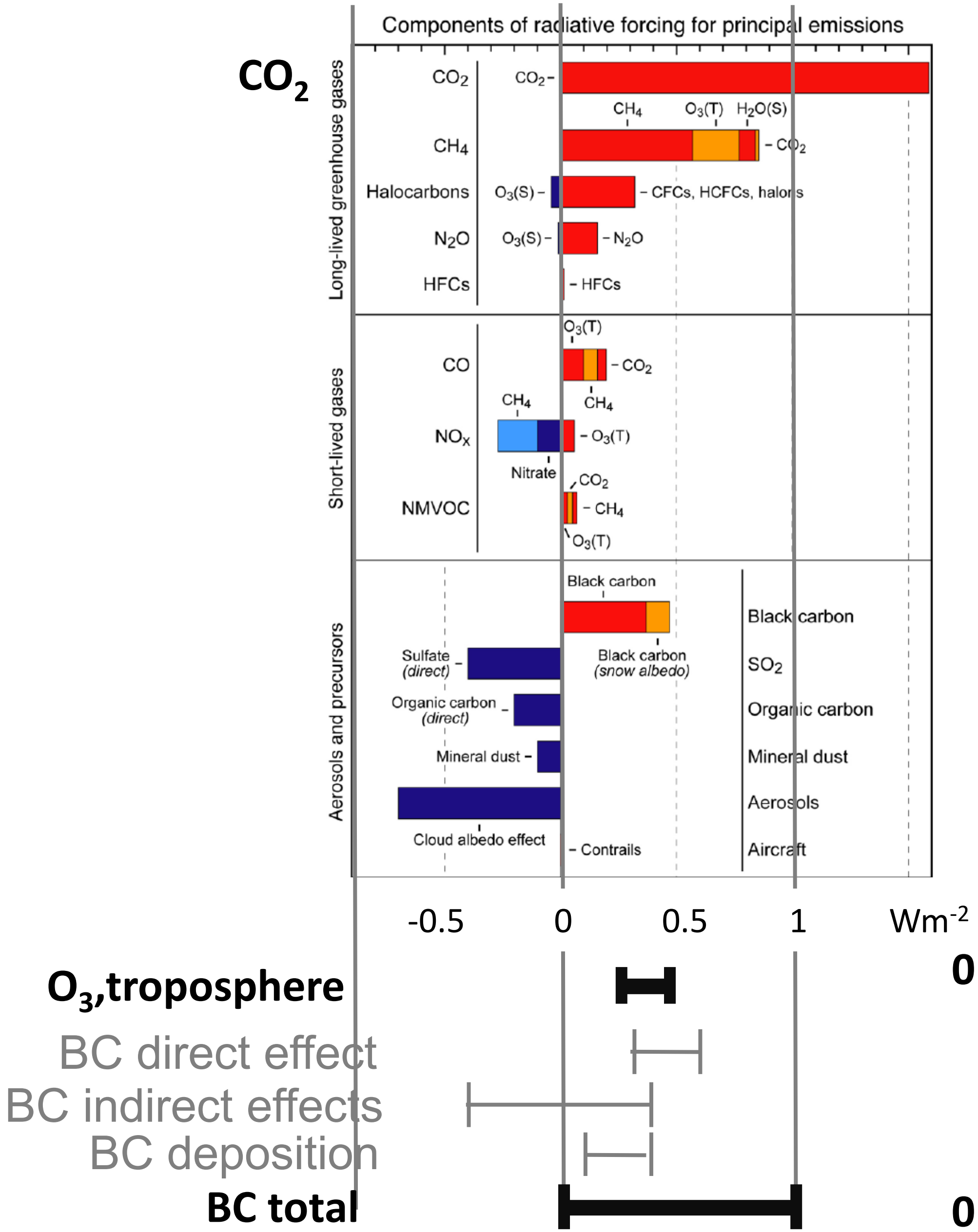


The First Impact Assessment Report (Nov 2008)



Integrated Assessment of Black Carbon and Tropospheric Ozone (Feb 2011)

present day TOA radiatve forcing by past emissions



1.5 - 1.7 Wm^{-2} ⇒ 1.2 – 1.4 °C

0.35(0.25 - 0.45) Wm^{-2} ⇒ 0.2 °C
(0.1 – 0.4 °)C

0.5 (0.0 – 1.0) Wm^{-2} ⇒ 0.4 °C
(0.0 – 0.8 °C)

IPCC 4AR, 2007

UNEP, 2011

present impacts of BC and tropospheric ozone

On air quality!

Black carbon, a component of PM, leads to premature deaths worldwide.

Ozone is the main responsible for reducing crop yields, and thus affects food security.

On global climate

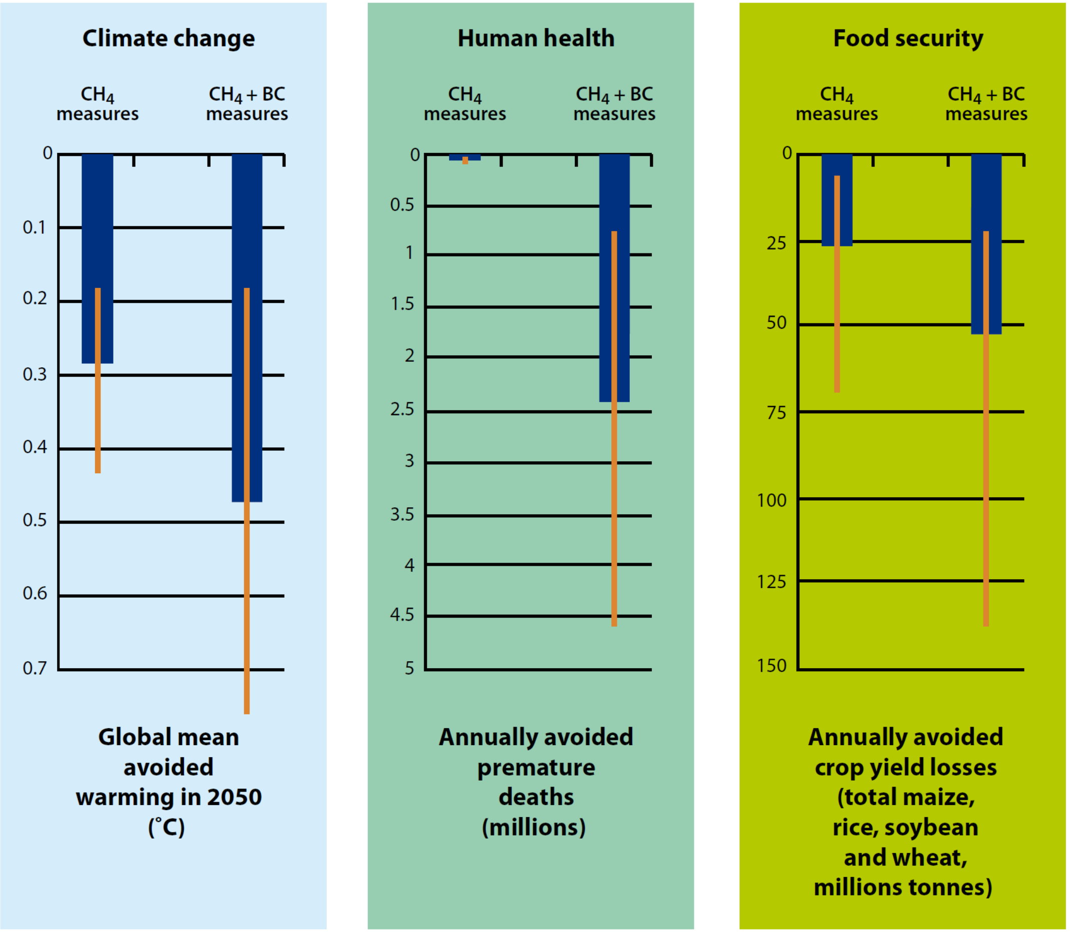
Changes in their burdens over the 20th Century results in a global warming *potentially* similar to that of CO_2

On regional climate !

Atmospheric heating by BC disturbs tropical rainfall and regional circulation patterns such as the Asian monsoon.

Black carbon deposition on snow, along with atmospheric heating, leads to faster melting of snow and ice (e.g., in the Arctic and the Himalayas).

Impact of the Measures on Health, Crop yields and Climate



- Identified measures, implemented by 2030, would reduce global warming by 0.5°C (0.2-0.7°C) in 2050 – half the warming projected -and would improve the chance of not exceeding 2°C target, but only if CO_2 is also aggressively addressed.
- Health and crop benefits are substantial – could avoid 2.4 million premature deaths (0.7-4.6 million) and loss of 52 million tones (30-140 million) of maize, rice, wheat and soybean, each year.

- The identified measures are all currently in use in different regions around the world to achieve a variety of environment and development objectives (case studies).
- Much wider and more rapid implementation is required to achieve the full benefits identified in this Assessment.

ABC Phase II Objectives

- To increase capacity and understanding of aerosol properties, radiation, aerosol radiative forcing on regional climate change.

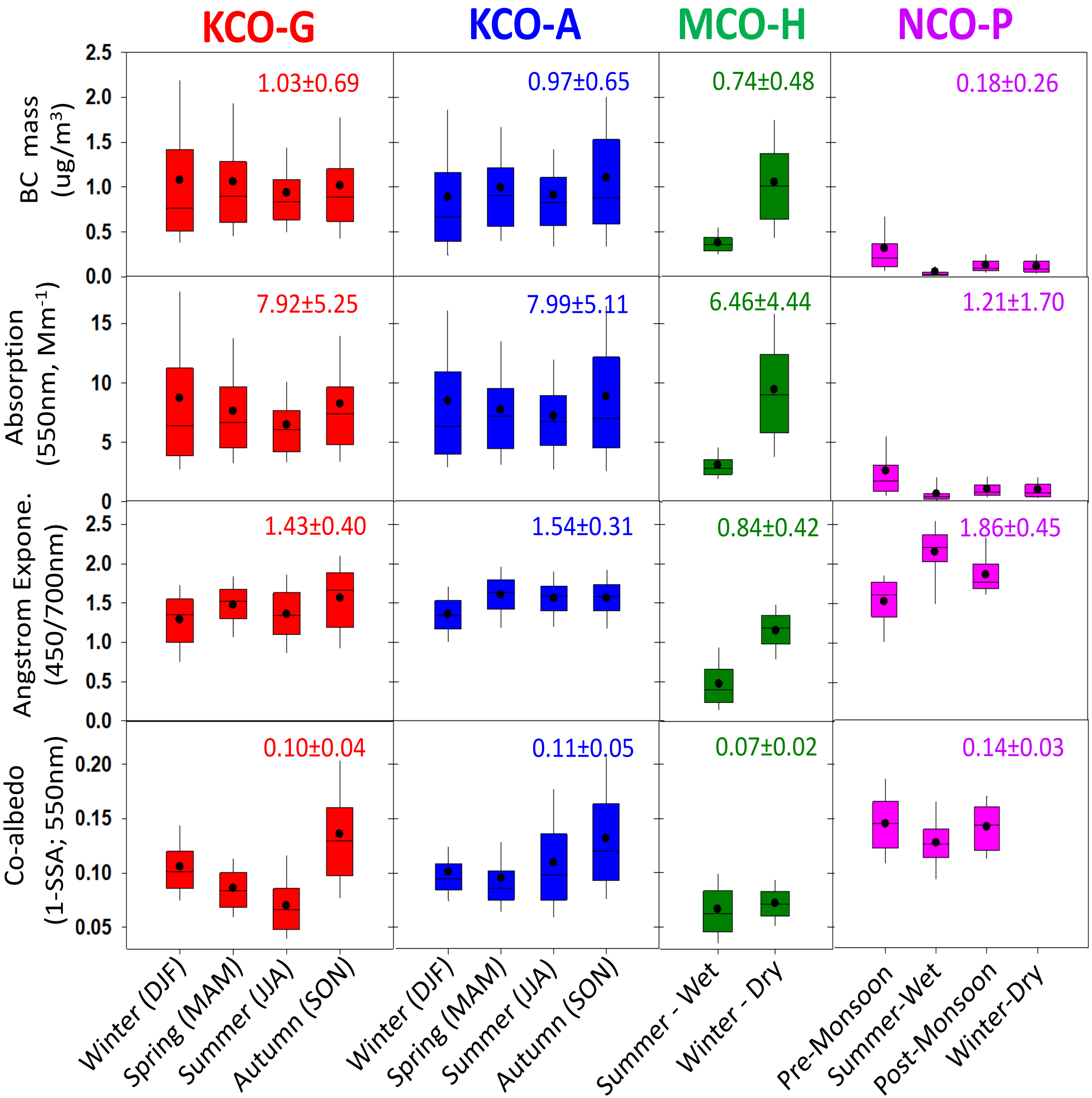
- To increase understanding of the impacts of atmospheric brown clouds on regional climate, water resources, agriculture and human health and increases capacity to carry out impact assessment.

- To develop and effectively communicate the knowledge concerning mitigation and adaptation measures to decision-makers and general public.

- To establish Policy Forum at the regional level to make possible development of effective cooperation programs on ABC.

Thank you for your attention!

(Next ABC meeting is planned to be held on March or April 2012)


KCO-G
KCO-A
MCO-H
NCO-P
BC mass
(ug/m³)
Absorption
(550nm, Mm⁻¹)
Angstrom Expone.
(450/700nm)
Co-albedo
(1-SSA; 550nm)
1.03±0.69
0.97±0.65
0.74±0.48
0.18±0.26
7.92±5.25
7.99±5.11
6.46±4.44
1.21±1.70
1.43±0.40
1.54±0.31
0.84±0.42
1.86±0.45
0.10±0.04
0.11±0.05
0.07±0.02
0.14±0.03
Winter (DJF)
Spring (MAM)
Summer (JJA)
Autumn (SON)
Winter (DJF)
Spring (MAM)
Summer (JJA)
Autumn (SON)
Summer - Wet
Winter - Dry
Pre-Monsoon
Summer-Wet
Post-Monsoon
Winter-Dry