The Indian Ocean Experiment and the Asian Brown Cloud

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The Indian Ocean Experiment (INDOEX) was sponsored by research agencies within Europe, India and USA, and was mainly concerned with the haze over south Asia and the adjacent Indian Ocean. It excluded other equally or even more polluted areas in Asia. The Asian Brown Cloud is a follow-on international research project that includes all of Asia. The brown haze is a worldwide phenomenon and should not be assumed to be just an Indian or an Asian problem. UNEP had commissioned a panel in 2001 to provide an early assessment of the societal implications of INDOEX findings. The panel published its report[1] in August 2002 which was accompanied by a press release[2] prepared by UNEP. This article clarifies the scientific basis of the brown haze in response to a recent article by Srinivasan and Gadgil[3] (hereafter referred to as SG).

The south Asian brown haze covers most of the Arabian Sea, Bay of Bengal and the south Asian region. It occurs every year, and extends from about November to April and possibly longer. The black carbon and other species in the haze reduce the average radiative heating of the ocean by as much as 10% and enhance the atmospheric solar radiative heating by 50 to 100%. These findings are at variance with SG's perceptions that the haze occurs only during January to March, and that the aerosol forcing used by UNEP was unrealistically large because it used 1999 values and ignored IR effects of aerosols. INDOEX and UNEP did not rely just on 1999 values, but used data for 1996 to 1999, and also accounted for the compensating IR effects. The long duration of the haze, its black carbon content, the large perturbation to the radiative energy budget of the region and its simulated impact on the rainfall distribution, if proved correct, have significant implications to the regional water budget, agriculture and health. The link between anthropogenic aerosols and reduction of monsoonal rainfall in south Asia also has been made by over fifteen model studies preceding the UNEP report.

We do not find any reason to modify the findings, the recommendations and the caveats in the UNEP report. The press release, while its direct quotes of the report are accurate, should have given more emphasis to the caveats in the report.

THE equatorial Indian Ocean is a unique natural laboratory for studying the impact of anthropogenic aerosols on climate, because pollutants from the northern hemisphere are directly connected to the pristine air from the southern hemisphere by a cross equatorial monsoonal flow into the inter-tropical convergence zone (ITCZ)[4]. This fact provided the main motivation for the Indian Ocean Experiment (INDOEX; http://www-indoex.ucsd.edu) proposed in 1995 (ref. 4). INDOEX observations started in a relatively small way in 1995, on-board a research vessel[5], which documented the sharp north–south gradients in the pollutants across the ITCZ, giving strong credence to the INDOEX concept. This was followed by a *Sagar Kanya* cruise in 1996 (ref. 6), which identified the large south (of equator) to north increase in the aerosol optical depths from 10°S to 20°N in the ocean and its large impact on reducing surface solar radiation, giving a clue about the absorbing nature of the aerosol. A follow-on satellite study[7] revealed that the absorbing haze covered most of the Arabian Sea and the Bay of Bengal due to long-range transport of the pollutants. Radiation observations during 1998 and 1999 over the Kashidhoo Climate Observatory and from space revealed that the haze absorbed significant amounts of radiation[8] within the atmosphere, accompanied by a large decrease in radiation reaching the surface. The 3-km thickness of the haze, the widespread nature of the brownish haze (Figure 1) and

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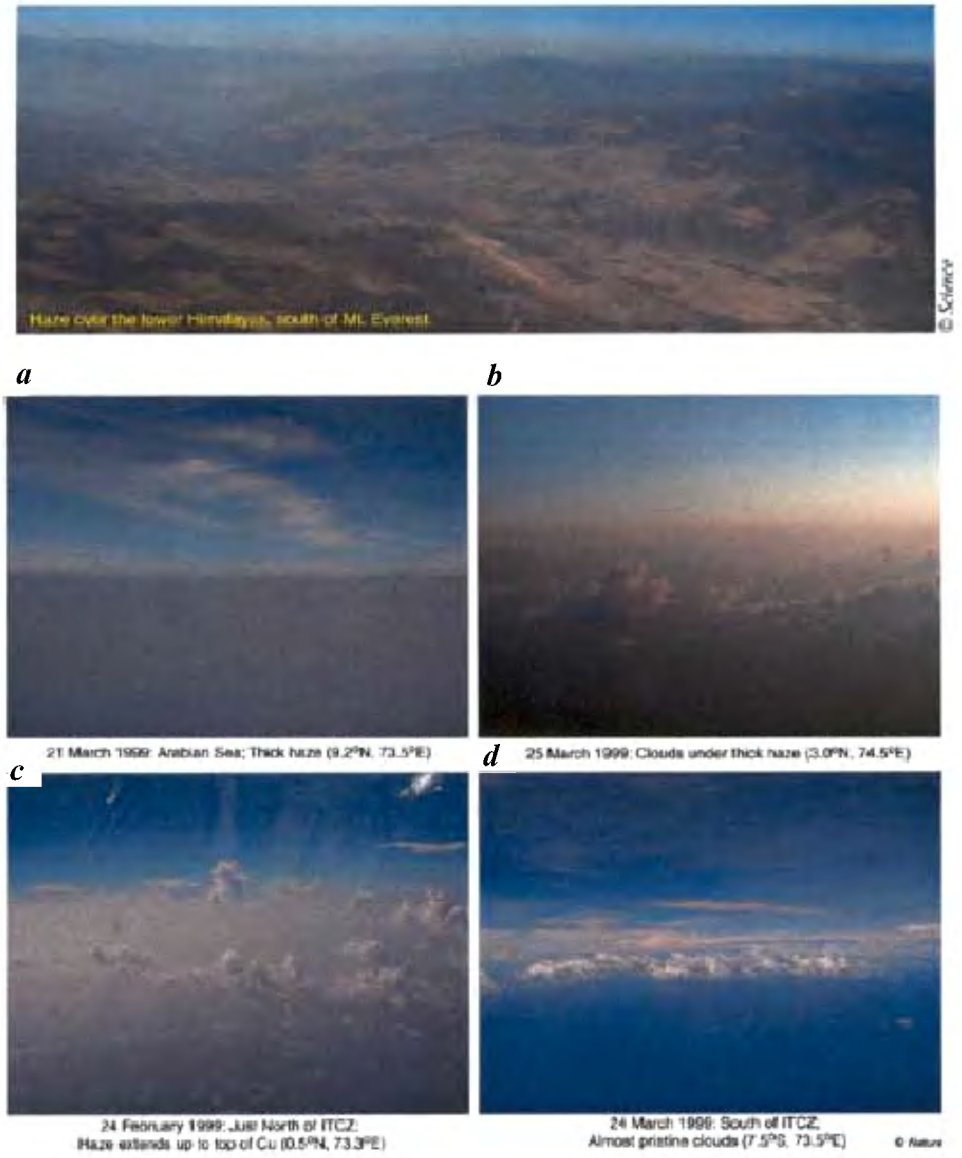

Figure 1. Photograph of the south Asian brown haze over the Nepalese town of Phaplu taken on 25 March 2001, approximately 30 km south of Mt Everest from a flight altitude of about 3-km viewing south (source: Ramanathan *et al.*[18]). The dry, northeast monsoonal winds carry the haze thousands of kilometers south and southeastward, and spread it over most of the tropical Indian Ocean between 25 N and about 5 S, as shown in the photographs *a–d* (source: Satheesh and Ramanathan[8]).

gaseous pollutants, its chemical speciation, including the concentration of black carbon and its large radiative forcing across the north Indian Ocean were identified[9,10] by the intensive field phase during January to March 1999 with five aircraft, two ships, an observatory in the Maldives, surface stations in India and several satellites. INDOEX was conducted by an international science team of over 200 scientists from Europe, India and USA (supported by their respective governments). INDOEX findings have been reported in over 150 journal articles, including two special issues in *Current Science* and two in the *Journal of Geophysical Research*; these publications formed the basis for the UNEP report.

The brownish haze (Figure 1) consists of a mixture of anthropogenic sulphate, nitrate, organics, black carbon, dust and fly ash particles and natural aerosols such as sea salt and mineral dust. The brownish colour is due to the absorption and the scattering of solar radiation by black carbon, soil-derived dust, fly ash and NO_2. *In situ* chemical composition of the haze was determined from the C-130 (refs 9 and 11) and the Citation (refs 10 and 12) aircraft from about 10 N in the Arabian Sea to about 8 S in the southern Indian Ocean (see photographs in Figure 1 taken during research flights from 9 N to 9 S in the Arabian Sea and in the Nepal part of the Himalayas). Chemical composition of aerosols was also determined from *Sagar Kanya*, Pune and Thiruvananthapuram[13–16].

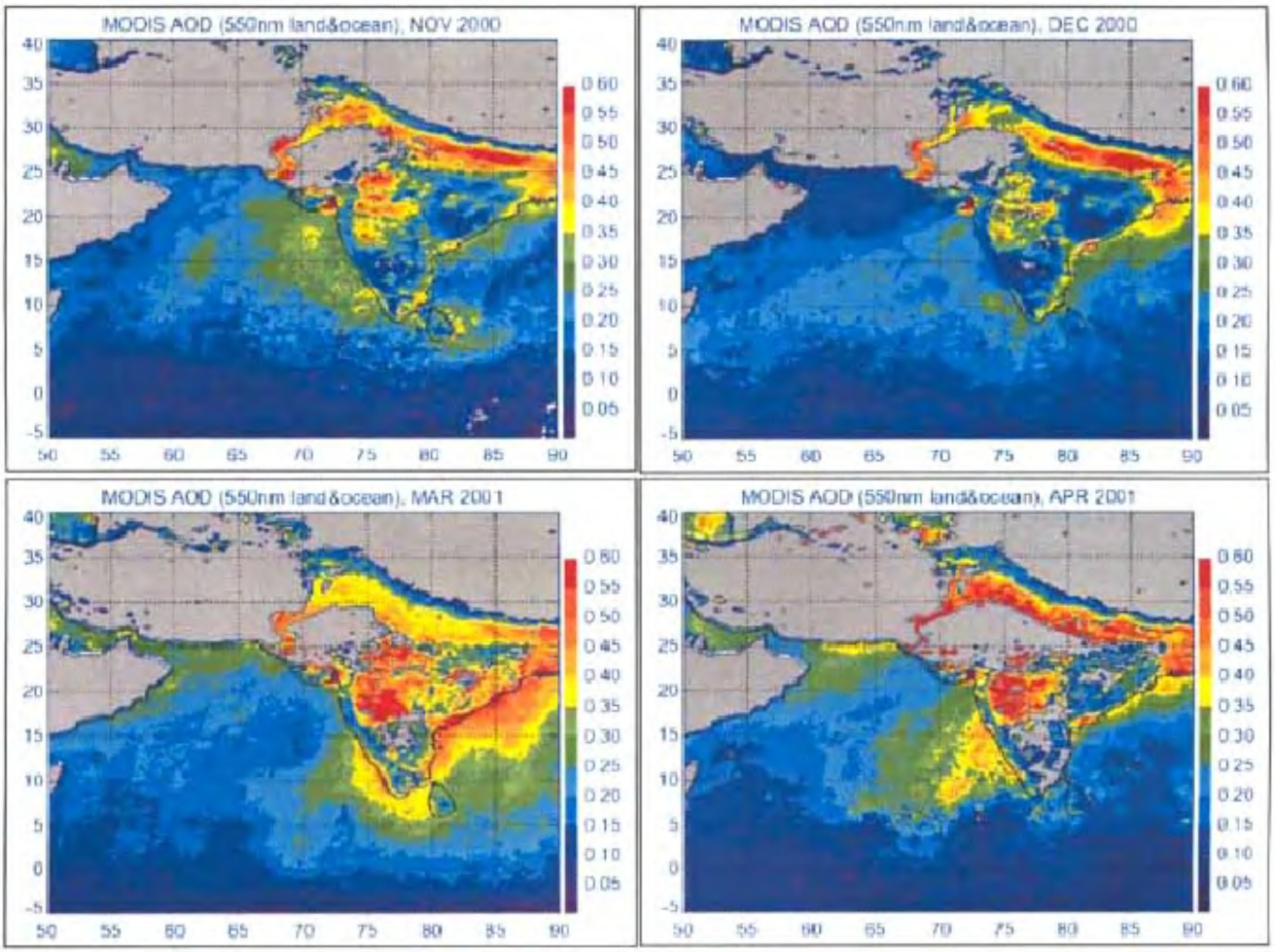

Figure 2. Monthly mean aerosol optical depth at visible wavelength for selected months during 2001. Data were obtained from the MODIS instrument on-board NASA's Terra satellite (source: Kaufman *et al.*[17]).

Spatial and seasonal extent of the haze

Srinivasan and Gadgil[3] (SG) state that the effect of the haze on climate is limited because 'it occurs only during January–March… .' This conclusion is not supported by the data, which on the other hand suggest that the anthropogenic aerosols may linger (see Figure 2) over the region at least for six months, if not longer. We begin with the recent MODIS (on-board TERRA satellite) aerosol optical depth (AOD) data[17] at visible wavelengths for the year 2000, which yielded reliable AOD data over land and ocean on a continuous basis. The data show the aerosol plume for the winter monsoon and the following dry season (November to April) extending from the Himalayas all the way across the southern Arabian Sea. The plume reaches its maximum extent and strength in February and March, hovering over most of Nepal, Pakistan, India, Bay of Bengal, Arabian Sea and extends south of the equator (see also Figure 1). April AODs shown (bottom panel, Figure 2) also reveal large AODs in south Asia and the eastern Arabian Sea, clearly establishing that particulate pollution is not limited to January to March. Figure 3 shows longer term aerosol chemical data collected at the Kashidhoo Climate Observatory, in the Maldives. This site is downwind of India during November to April. The data show that the sub-micron size sulphate aerosols begin increasing from October, reach peak values during December to March, and start their decline during April; they reach low background values (typical of clean marine atmosphere) only for four months during June to September. The low values during the SW monsoon season do not necessarily imply abatement of pollution levels in south Asia, but is rather indicative of the prevailing winds from the cleaner southern ocean.

Source of the haze

In situ measurements[9–16] of CO, organics and aerosol chemical, optical, scattering and absorption coefficients from aircraft, ships and surface stations clearly establish that anthropogenic sources contribute as much as 75%

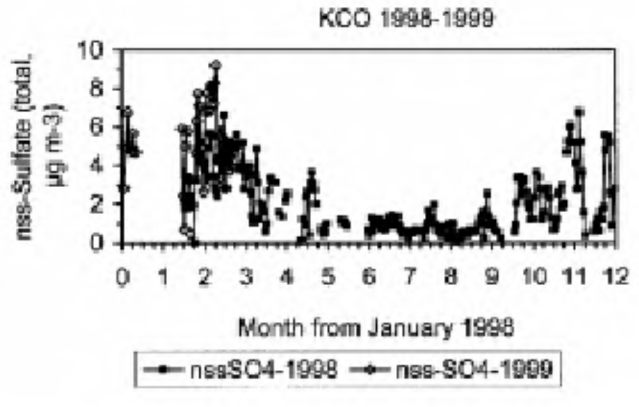

Figure 3. Non-sea salt sulphate data at the Kashidhoo Climate Observatory in the Maldives. Data collected by Prospero, Savoie and Maring (private commun.).

(refs 9 and 10) to the observed aerosol concentration. *In situ* measurements from aircraft[9–12], ships[6,13,16] and surface stations in Thiruvananthapuram and Pune[14,15] also confirm that the pollution and the haze extend from inland up to the equatorial Indian Ocean. Both biomass-burning and fossil-fuel combustion (primarily coal, diesel and two-stroke engines) contribute to the haze[10,18]. The source of the haze over the ocean domain (see Figures 1 and 2) is[19]: (1) NE trades over the western Arabian Sea carrying pollution from SW and central Asia; (2) NW–NE flow along the west coast of India; (3) NE trades over the Bay of Bengal from the eastern part of south Asia, and (4) NE flow from SE Asia.

Why is the haze problem so severe over south Asia?

The large increase in emissions of aerosols and their precursors is an important reason for the haze over south Asia. For example, emissions of SO_2 in south Asia have increased by a factor of 3 to 4 since 1970 (ref. 1). The other important contributors are the unique meteorology of south Asia (as well as the tropics, in general) during the winter monsoon and the dry season, and the six-month long duration of this period. The subsidence associated with the NE monsoon and the long, dry season (November to May for India) precludes the wet removal of haze particles by rain. In addition, the ITCZ inhibits ventilation of the pollutants by long-range transport to the southern hemisphere. In the extra-tropics, the absence of a long dry season, and seasonally distributed rainfall (and snow fall) clean the atmosphere more efficiently.

Interannual variability of the haze

SG suggest that the findings in the UNEP report are based on the INDOEX results for 1999. According to them[3], 'the intensity of the haze happened to be maximum in 1999 when the INDOEX observations were made'. This is a non-issue because the UNEP report was not based just on the year 1999, instead it uses the aerosol forcing for 1996–1999 (ref. 18; see the caption for figure B in the executive summary[1]) and aerosol optical depth data for 1996 to 2000 (figure 4.3)[1].

Furthermore, when satellite data[17,20,21] are integrated over the entire ocean basin north of the equator, the atmospheric aerosol content (as indicated by AOD) for the year 1999 was not unusually large, but was within 10 to 15% of the values observed during 1995 to 2001 (refs 20 and 21) (Figure 4 *a*). The results in Figure 4 *a* are at variance with SG's conclusions because SG based their inferences on sun photometer AOD data from one surface station at the Maldives[22]. Figure 4 *b* compares the satellite AOD data[20] for a 1000 km by 1000 km region centred around the Maldives, with the Maldives data[22]. Clearly in the Maldives, the year 1999 had much higher (by 50 to 70%) pollution levels than 1998 or 2000. Even for this region, when the averages are taken over a 1000 km by 1000 km region, difference decreases by a factor of two. Large interannual variations have also been revealed in ship data and for AODs in limited regions within the Arabian Sea and the Bay of Bengal[23]. The basic inference is that an increase in one region is compensated by a corresponding decrease in another region, such that the average over the whole region is about the same from one year to the next.

Magnitude of the anthropogenic aerosol forcing

Aerosols, by scattering and absorbing solar and long wave (IR) radiation, perturb the radiation fluxes at the surface and the top of the atmosphere, thereby perturbing the atmospheric absorption of solar radiation. The change in radiative fluxes at the surface due to this process is referred to as the *direct forcing* at the surface and the change in the atmospheric radiative heating is referred to as the atmospheric forcing. At the surface, aerosols decrease the direct solar beam and enhance the diffuse solar radiation, and both of these effects have been measured and included in INDOEX forcing values[6,18]. Black carbon (BC) plays a major role in the forcing. This shielding effect of BC amplifies the surface forcing due to all other man-made aerosols (sulphates, nitrates, fly ash) by a factor of two or more in cloudy skies. The solar absorption by BC enhances atmospheric solar heating by a significant factor. BC over the north Indian Ocean (during the INDOEX measurement campaign) contributes as much as 10 to 14% to aerosol content, compared with about 5% for suburban regions in Europe and north America[1]. Lastly, by nucleating more cloud drops, aerosols increase the reflection of solar radiation by clouds, which adds to the surface-cooling effect. This effect is known as the

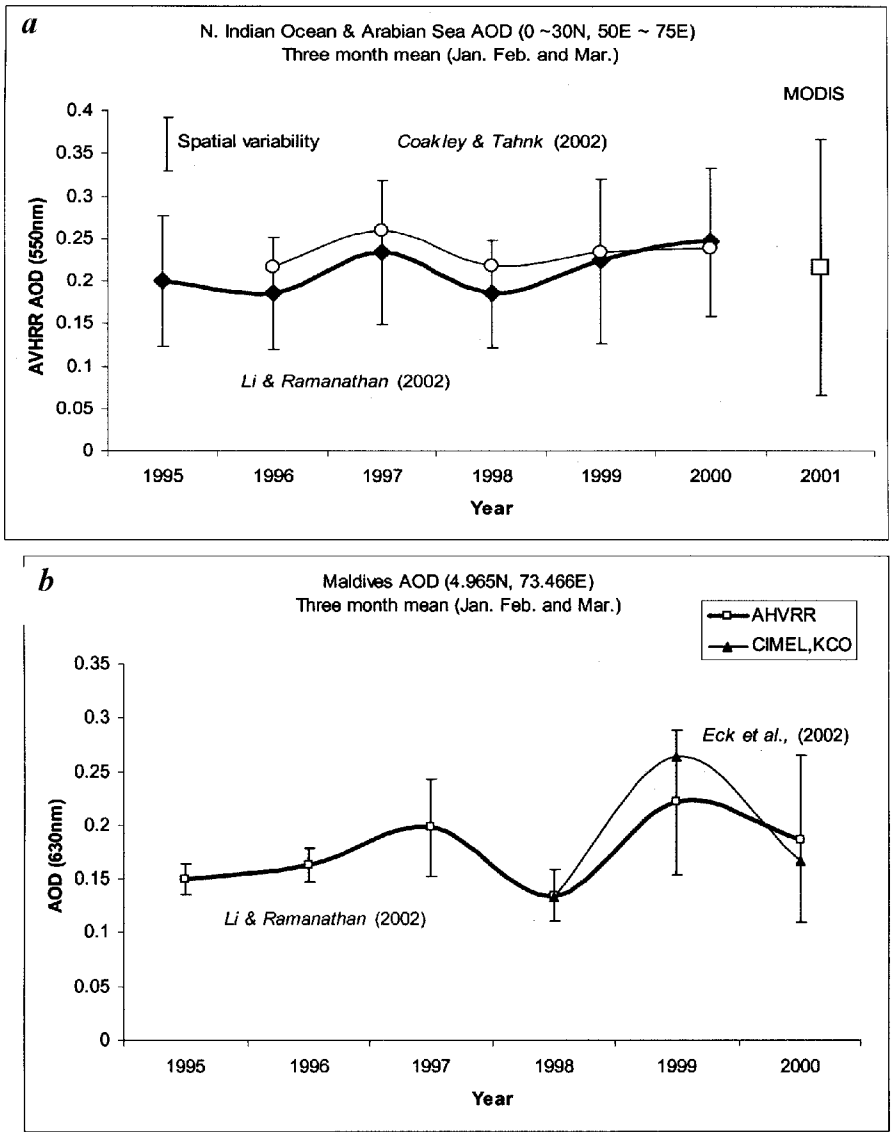

Figure 4. Interannual variability in aerosol optical depth. *a*, Regional averages; *b*, Blue curve is AVHRR AOD for a 1000 km × 1000 km area around the Maldives. Red curve is sun photometer data from a surface station in the Maldives.

indirect forcing. Unless otherwise mentioned, we will focus our attention primarily on the direct surface forcing.

SG suggest that the UNEP report has overestimated the direct surface forcing substantially and recommend that it should be only –10 to –15 Wm^{-2} instead of –29 Wm^{-2}. The most curious point about this suggestion is that the four-year direct aerosol forcing value reported in UNEP (see figure B, ref. 1) is indeed -14 ± 3 Wm^{-2} (and not –29 Wm^{-2}!), and the UNEP range (–11 to –17 Wm^{-2}) is in nearly exact agreement (albeit not for the right reason) with SG's recommended range. This also seems like a non-issue.

SG state that the aerosol forcing (reduction of solar radiation to the ocean surface by the aerosols in the haze) reduced from –29 Wm^{-2} in 1999 to only –11 Wm^{-2} in 2001. The 1999 data used by SG is presumably for the Maldives and the 2001 data are from a five to seven-day ship cruise over the Arabian Sea. As an illustrative example of the problem with such limited data, we point out that the same 2001 cruise data show that the forcing over Bay of Bengal was –39 Wm^{-2}. The basic message is that the relevant forcing for climate impact studies should be an average value, representative of at least an entire ocean basin and for a minimum of a month to a season. The INDOEX forcing estimated by Ramanathan *et al.*[9,18], represents such a large-scale average forcing and was obtained by integrating *in situ* data collected by ships, aircraft and surface stations with satellite data, meteorological data and aerosol-radiation models. The INDOEX average forcing[9] was

indeed for the year 1999, but it was subsequently extended to a four-year period from 1996 to 1999 (ref. 18). Furthermore, as implied by Figure 4, the average forcing for 1999 is not that different from the four-year mean value.

SG also suggest that INDOEX has overestimated the forcing by ignoring the warming influence of the IR effects of the haze. The IR effect for the anthropogenic aerosols is only about 10 to 15% of the solar forcing and has been included in INDOEX[9] and in the UNEP report (see figure 6.2, ref. 1, in which the bar denoted by 'Direct IR' is the IR emission towards the surface by anthropogenic aerosols). SG do not give quantitative values, except to suggest that it will compensate a large portion of the short-wave forcing. The IR effects could indeed be large (as large as 20 to 40%) for natural aerosols such as sea salt and desert dust because of their larger sizes (1 to 20 microns) compared with the 0.1 to 1 micron size of anthropogenic particles.

The UNEP report[1] gives the total (natural and anthropogenic) aerosol forcing (figure 6.1) and also the anthropogenic aerosol forcing (figure 6.2), both for the year 1999. For the direct effect at the surface, the total direct forcing (for cloudy skies) is -20 Wm^{-2}, while the anthropogenic forcing (for the direct effect at the surface) is -16 ± 3 Wm^{-2}. When these forcing values were reestimated for the four-year period from 1996 to 1999 (ref. 18), the direct forcing at the surface is found to be -14 ± 3 Wm^{-2} (see figure B, ref. 1). The indirect forcing (due to nucleation of cloud drops by the haze particles) is[9,18] -6 ± 2 Wm^{-2} (see figure B, ref. 1).

In summary, the fundamental reason for SG's contradicting conclusions is that they rely on data from one island station in the Maldives and from a 5-day cruise in 2001, while the INDOEX estimates synthesize data from aircraft, ships, island stations with multiple satellites and include the entire region covered by the haze.

Link between aerosols, precipitation and the Asian monsoon

The global mean precipitation has been decreasing since the 1950s[24]. This decrease is due to a pronounced decrease in the tropics between 25 S and 30 N, and a smaller increase in the extra-tropics (Figure 5). We must caution that the precipitation data are collected mostly from land stations. Climate models with just the greenhouse gases (GHGs) do not simulate the negative trend, but when sulphate aerosols are added to the model, some of the models are able to simulate a portion of the observed drying trend in the tropics[24,25] (Figure 5). However, sulphates are only part of the aerosol forcing problem, and the addition of BC can enhance the sulphate surface forcing by a factor of two or more[8,9]. In this context, we should point out that the haze is not just a

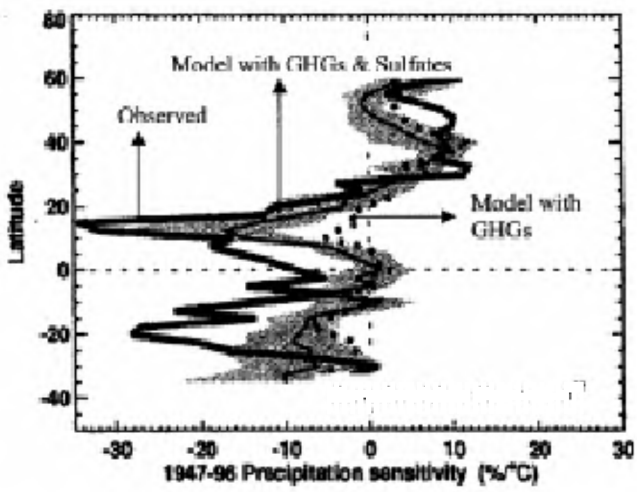

Figure 5. Observed and modelled precipitation trends in the tropics (1947–96). Observations are from surface stations. Model trends are from global climate model simulations with just the observed greenhouse increase since the 1870s (model with GHGs) and with GHGs and sulphate aerosols (source: Hulme *et al.*[25]).

south Asian or an Asian problem, but a global problem, including developed and developing regions, as indeed revealed by recent satellite data[17,18] (Figure 6).

However, the aerosol pollution (particularly BC) is generally larger in the tropics (Figure 6), and thus aerosols may have played a role in the observed tropical drying. There could also be multi-decadal variability of rainfall in the tropics, whose contribution is yet to be properly assessed. Furthermore, trends within individual tropical regions may not coincide with the tropical mean trends. For example, the annual mean rainfall variations in India for 30-year periods are: + 0.4% (from 120 years normal) for 1871–1900, –2.2% for 1901–30, + 3.6% for 1931–60 and –1.8% for 1961–90. These are small variations and it would be difficult to conclude that the annual rainfall has decreased in the last 30 years.

For the Indian subcontinent, models (about 15 of them) with just the GHG increase, predict an increase in the wet season (JJA) precipitation, while all 15 models with GHG and sulphate aerosols show reduced rainfall increases or even strong rainfall decreases[25] (see p. 602, ref. 25). The link between aerosols and reduced rainfall has also been made for other tropical regions, including the well-known Sahelian drought[26]; north–south shift in the east Asian monsoon during the recent decades[27,28]; and rainfall changes in the south and the southwest Asian region[29]. For example, Xu[27] showed that in China the monsoon has moved southwards leading to drying in the northern part and flooding in the south, and this movement started in the late 1970s. He suggests that its main cause may be the negative solar forcing by aerosols. In summary then, several recent studies, including the INDOEX study of Chung *et al.*[29], have suggested that anthropogenic aerosols could have perturbed the tropical as well as the monsoonal rainfall.

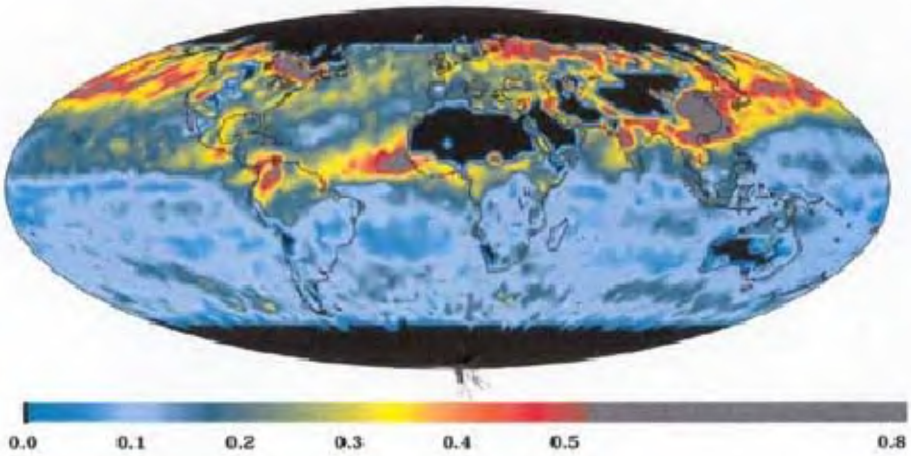

Figure 6. Global distribution of aerosol optical depths for April 2001. Data are from MODIS instrument on-board Terra[19].

We now address SG's skepticism with the UNEP conclusion (based on Chung *et al.*[29]) that the south Asian haze may have led to a decrease in the winter time rainfall in parts of central and southwest Asia. According to SG, 'Model simulation of the rainfall patterns over the region is particularly poor, and hence the reliability of this projection is suspect'. As discussed above, and as acknowledged in the UNEP report, the reliability of the simulation of regional precipitation changes by any model is uncertain (see p. 597, ref. 25) until it is confirmed by a observations. However, there are many reasons for emphasizing (with strong caveats, see p. 2, ref. 1) the model simulation of the reduction in rainfall in SW Asia (defined as the region northwest of India between 50 and 65 E, and 25 and 40 N): the model simulation of the winter-time rainfall (November to March) is within 20% of the observed rainfall (figure 7.7, ref. 1); the calculated reduction was about 10 to 30% during December to June and was statistically significant; there is observational indication that the region has been experiencing drought conditions in the recent decade[1]; the winter-time rainfall contributes as much as 50% of the total rainfall in this region, and thus a 10 to 30% decrease can have major implications to agriculture; lastly the climate model predicted that the haze should have led to a winter-time cooling of India by about 0.3 to 0.5°C, enough to offset the warming over India due to the greenhouse increase (so-called global warming) during winter. Observations from surface stations in India confirmed this prediction[30], thus offering support to the ability of the model to simulate regional climate changes. We recognize that a correct simulation of regional temperature changes does not necessarily guarantee a correct simulation of precipitation changes. Incidentally, a more recent and an independent (from the model of Chung *et al.*[29]) climate model study[28] that uses INDOEX data to simulate aerosol forcing, also shows that BC leads to less rainfall over SW Asia.

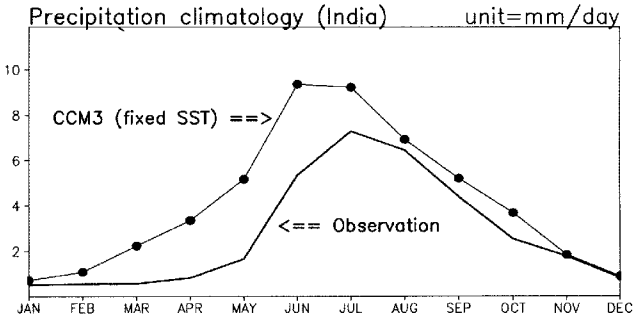

Figure 7. Comparison of observed precipitation with that stimulated by the climate model (CCM3) used in the UNEP report. CCM3 prescribes observed, seasonally varying sea surface temperature (SST). See Chung *et al.*[29] for a detailed description of the study.

SG on the other hand, suggest that the model underestimates winter precipitation by more than 100% (instead of our estimate of 20%). The main reason for the discrepancy is that SG has included most of the northern Arabian Sea in their average, although they claim to be looking at the SW Asian rainfall. As acknowledged and shown (see figure 7.7, ref. 1) in the UNEP report, the model simulation of summer rainfall over SW Asia is very poor, and accordingly, the report does not discuss changes in summer rainfall. Figure 7 compares the monthly mean precipitation for all of India simulated by the model with observations. The average JJA rainfall is within 30% of observations, but the model simulates unrealistically large (100% or more) precipitation during the dry season. It is for this reason, the UNEP report does not emphasize the haze-induced increase in the dry season rainfall for India. Another major change (not shown) resulting from the introduction of the haze is a northward broadening of the ITCZ. Essentially, most, if not all, of the above changes result from the intensification (due to the haze solar heating) of the upward branch of the regional Hadley circulation in the low latitudes (leading to north-

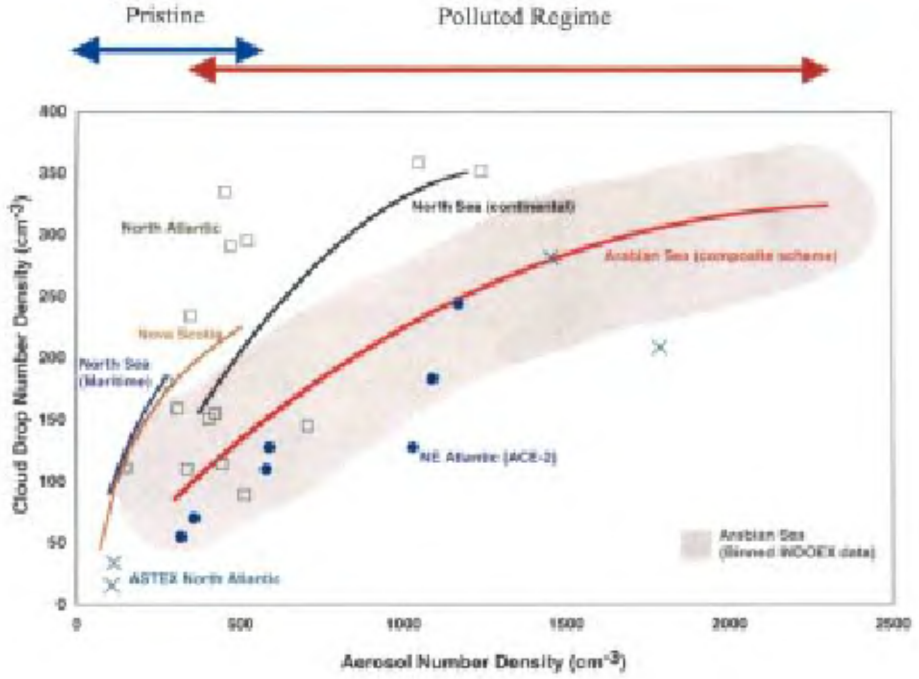

Figure 8. Aircraft data illustrating the dependence of cloud drops on aerosol number density (both natural and anthropogenic). Adapted from Ramanathan *et al.*[18].

ward migration of ITCZ, more rainfall over southern India and the Arabian Sea) and a corresponding intensification of the subsidence in the sub-tropics around 20 to 30 N (cause of less rainfall over SW Asia). As cautioned in the UNEP report, global climate models have shortcomings and results have to be supported by regional models and verified by observations.

In summary, the specific model details of the land regions with more rain and less rain indeed may be uncertain, but the main message to emerge from the model studies is that the haze forcing is large enough to perturb the rainfall patterns over the tropical Indian Ocean and south, southwest and southeast Asia from November to June (see figure 12, ref. 29). It is in this respect that the UNEP report and the press release allude to the haze and its impact on the monsoon. It is clear from SG's concerns that, amongst many Indian meteorologists and the public, the word monsoon means mainly, if not only, the SW monsoon, and the press release should have been more sensitive to this perception. Furthermore, the release while it quoted the report accurately, did so without giving adequate emphasis to the caveats in the report, which might have led to the sensationalism in the media. We wish to clear the air by stating that the UNEP report did not address the haze impacts on the wet season in India. We do wish to emphasize, however, that several studies[24–29] have begun to link anthropogenic haze with the Asian and the tropical monsoon (both wet and dry) systems. As speculated by SG, natural aerosols may play an important role in the SW monsoon, but it is premature to rule out the importance of anthropogenic aerosols.

SG also suggest the agriculture impacts are negligible because it is restricted to rice yield and that too during the winter season. It is debatable if a 5 to 10% reduction is negligible, but the UNEP comments on the importance of agriculture were equally motivated by the simulated haze-induced decrease in winter-time rainfall in SW Asia, a region which is already suffering from severe droughts during the latter half of the 1990s.

The Asian Brown Cloud and the global nature of the brown haze

As revealed in Figure 6, pollution aerosols are found in all inhabited regions of the planet. Figure 6 shows, for the month of April 2001, anthropogenic aerosols extending from the eastern part of North America all the way into the mid-Atlantic Ocean and Europe; it also shows heavy aerosol loading in northern and eastern Europe; dust and anthropogenic haze from Mongolia and China extending all the way across the Pacific; and the biomass burning aerosols from Africa and the Amazon region. The phrase 'Asian Brown Cloud' is a recognition that the brown haze is part of a larger scale problem that involves all of Asia. In addition, as emphasized by SG, the Asian Brown Cloud is only one part of a global problem.

Why the name Brown Cloud?

The precedence is the so-called Denver Brown Cloud, given to a very similar appearance (similar to the photos

in Figure 1) of the polluted sky in Denver, Colorado. The Los Angeles smog is another well-known example. The more scientific reason is that aerosols and clouds are a strongly coupled system. First, aerosols are imbedded in cloudy layers (Figure 1). Aerosols provide the nuclei for cloud drops and without aerosols, cloud-drop formation will require relative humidities in excess of 150% (rarely observed, if ever). INDOEX data[9,18,31] showed that the polluted clouds had factors of three or more number of cloud drops than pristine clouds (Figure 8). Recent studies have also demonstrated that the anthropogenic haze produces copious amounts of smaller drops in convective clouds, thus suppressing precipitation over polluted areas[32]. This phenomenon was observed over the eastern Arabian Sea near the coast and other Asian regions[18] as well. Thus, it is no more valid to think of the aerosols in the haze as a separate phenomenon, by itself, but as really part of the overall cloud system.

Why the major focus on Asia?

The simple and basic reason is that over 50% of the world's population inhabits this region and the region is embarking on impressive growth rates, and thus could be vulnerable to unexpected negative impacts from the haze on health, the hydrological cycle and agriculture. There is another vulnerability to the brown haze, that is germane to the tropics in general and the Asian region, in particular. It is well known that the tropical circulation is driven by spatial asymmetries in *in situ* thermodynamic heating (latent or convective heating and radiative heating are the dominant terms), while extra-tropical circulation is less sensitive to *in situ* radiative heating. Thus the tropical circulation and thereby the hydrological cycle may be more sensitive to the sort of haze-induced radiative heating measured within the south and east Asian haze.

This paper, as well as the INDOEX papers and the UNEP report emphasize the hitherto underestimated impact of aerosols on climate. Globally, the aerosol forcing at present may be comparable to that from GHG emissions. It is important to note that the role of GHGs will increase in the future because of their accumulation in the atmosphere, and by the mid to the late half of this century global warming due to GHGs will likely dominate the aerosol impact. The industrialized world shares the major responsibility for the emission of GHGs and some aerosol precursor gases such as SO_2. Developing nations in Asia, Africa and South America are beginning to contribute in major ways to the aerosol problem, particularly BC from inefficient combustion technology and biomass burning, and the effects are particularly great during the dry season.

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