

ENS in 49 overs =  $60.7 + (100 - 60.7) \times 0.978 = 99.1$ .

### *For the second interruption*

PAR-2 =  $60.7 + (N2 - N1) / (100 - N1) \times (99.1 - 60.7)$ .

N2 = Normal score percentage corresponding to 66.7% (32.67/49 × 100) overs and 5 wickets = 68.3.

N1 = Normal score percentage corresponding to 55.8% (27.32/49 × 100) overs and 5 wickets = 61.5.

PAR-2 =  $60.7 + (68.3 - 61.5) / (100 - 61.5) \times (99.1 - 60.7) = 67.5$ .

Since New Zealand did not bat after the second interruption, their ENS at the end of the innings =  $67.5\% + 0\% = 67.5\%$ .

The target score in 32.4 overs (32.67/50 × 100% overs) = 76.7%.

MF =  $76.7 / 67.5 = 1.1362$ .

Target for team-2 in 32.4 overs =  $114 \times 1.1362 = 129.53$ .

Target in 32 overs, i.e. 98% (32/32.66 × 100 = 98) overs = 99.3%.

Target score for South Africa in 32 overs =  $0.993 \times 129.53 = 128.62 = 129$  runs.

1. See, for example, [http://www.cricket.org/link\\_to\\_database/ABOUT\\_CRICKET/RAIN\\_RULES/](http://www.cricket.org/link_to_database/ABOUT_CRICKET/RAIN_RULES/)
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ACKNOWLEDGEMENTS. I thank Dr Srinivas Bhogle, NAL, Bangalore for his valuable suggestions, which helped in making some significant improvements in the method. I also thank the referee who took a lot of pains to configure the manuscript to bring it into a format suitable for *Current Science*.

Received 30 May 2002; revised accepted 12 August 2002

## Asian Brown Cloud – fact and fantasy

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*The wide publicity given to the release of a United Nations Environment Programme (UNEP) report on the so-called Asian Brown Cloud and its multifarious impacts on health, agriculture and climate on both regional and global scales, has led to considerable concern. We find that the UNEP news release (and hence the media reports based on it) is a blend of observations and scientifically sound deductions on the one hand and sensational statements with little scientific basis on the other. The UNEP report is based on the findings of an international programme called the Indian Ocean Experiment (INDOEX). The term Asian Brown Cloud was coined by leaders of INDOEX to describe the brown haze occurring during the period January to March, over the South Asian region and the tropical Indian Ocean, Arabian Sea and Bay of Bengal. It is important to note that, the haze is not a permanent feature of the atmosphere over the Asian region and the surrounding seas. It occurs only during January–March, in the season following the southwest monsoon and northeast monsoon seasons.*

*It is suggested in the UNEP report that the impact of the haze assessed with the help of an atmospheric general circulation model is a decrease in rainfall in northwest Asia (including Saudi Arabia, Pakistan, Afghanistan). However, we find that the model simulation of the rainfall patterns over this region is particularly poor and hence the reliability of this projection is suspect. Also, the expected magnitude of the impact on crop yields is small and there is no basis for the statement in the UNEP news release that the 'vast blanket of pollution across South Asia is damaging agriculture'.*

THE wide publicity given by the electronic and print media to the release of a United Nations Environment Programme (UNEP) report on the so-called Asian Brown Cloud<sup>1</sup> and its multifarious impacts on health, agriculture

and climate on both regional and global scales, has led to considerable curiosity as well as concern. This has brought up a number of questions about the nature of the Asian Brown Cloud such as: (i) Is what has been described as a blanket of pollution, really a cloud? (ii) Is it brown, and if so, why? (iii) Is it a special feature of the Asian region? There are also questions about the likely impact on regional and global scales such as: (i) Will it

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have a large impact on our climate by modifying the 'mighty monsoon', as reported? (ii) Will it have a disastrous impact on our agricultural production, particularly food grains? (iii) Will this pollution over Asia also have an impact on the rest of the globe?

Here, we address these questions in the light of the results of scientific studies reported in the UNEP report and elsewhere. We believe that it is important to share our perspective on the so-called Asian Brown Cloud and its impacts, because much of what was said in the UNEP news release<sup>2</sup>, on which most of the media reports are based, is inconsistent with these results. The UNEP report is based on the findings of an international programme called the Indian Ocean Experiment (INDOEX), the national component of which has been discussed in special issues of *Current Science* dated 10 April 1999 and 2001.

The term Asian Brown Cloud was coined by leaders of INDOEX to describe the brown haze occurring during the period January to March, over the South Asian region and the tropical Indian Ocean, Arabian Sea and Bay of Bengal. This wintertime haze appears brown, when seen from an aircraft, because of the substantial contribution by man-made particles such as soot. The haze has been described as a 'blanket of pollution' in the news release, because 'the discovery during INDOEX of the so-called South Asian haze is a clear evidence of the magnitude of the aerosol pollution problem' (UNEP report, p. 2). It is not clear why, after describing what was observed during INDOEX as haze, it was decided to call it a cloud. The word 'cloud' may have been used to suggest that it is much denser than a haze. Perhaps the name 'Asian Brown Cloud' was chosen to give an impression of the Asian region choking under a thick and permanent blanket of dirty atmosphere.

However, the haze is not a permanent feature of the atmosphere over the Asian region and the surrounding seas. It occurs only during January–March, the season in which INDOEX observations were made. Thus, the haze occurs in the season following the southwest monsoon and northeast monsoon seasons. Even during January–March, there is considerable variation from year to year in the intensity of the haze. The intensity of the haze happened to be maximum in 1999 when the INDOEX observations were made<sup>3</sup>.

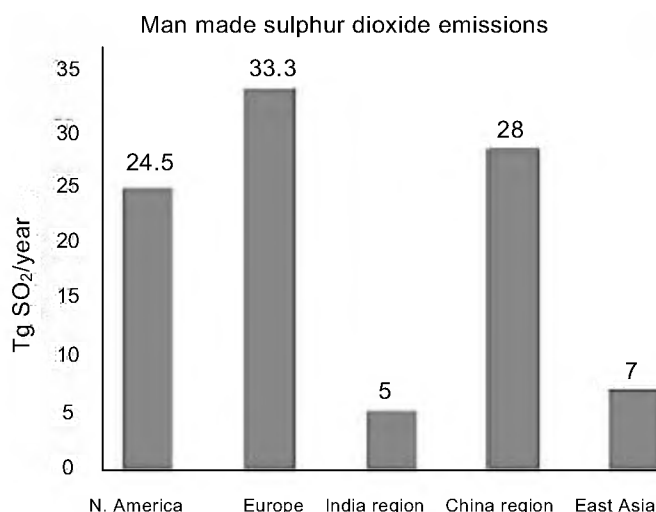
The scourge of pollution is by no means restricted to the Asian region. This is clearly seen in the estimates of the emissions of man-made sulphur dioxide from different regions of the world (Figure 1). Brown haze is a characteristic of most of the big cities in North America, Europe and the rest of the world (e.g. pictures of haze over Los Angeles available from [www.wolkenatlas.de](http://www.wolkenatlas.de)). The appearance of the haze over the adjacent ocean is also not a characteristic restricted to Asia. For example, a thick plume of haze emanating from the east coast of the US and extending over more than 1000 km over the

Atlantic was observed on 4 May 2002 (see picture of Atlantic haze from <http://earthobservatory.nasa.gov>).

In the past decade, considerable attention has been given to the presence of man-made particles in the atmosphere. However, the flux of natural aerosols (such as salt and dust), averaged over the globe, is three to five times larger than that of anthropogenic aerosols. Recent studies<sup>4–6</sup> have shown that over the Arabian Sea, the natural aerosols become dominant during May–September. During the southwest monsoon, the natural aerosol loading is about twice as large as the loading due to anthropogenic aerosols in the winter season. Hence we expect natural aerosols to have a larger impact on the monsoon than the anthropogenic aerosols.

In the studies presented in the UNEP report, the impacts of pollution/haze on the climate have been assessed with the help of an atmospheric General Circulation Model. Particular emphasis has been given in the news release and media reports, to the decrease in rainfall in northwest Asia (i.e. Pakistan, Afghanistan). However, the results of such assessments are meaningful only if the model used can simulate the observed climate over the region. As we show below, the model simulation of the rainfall patterns over the region, where the haze is supposed to lead to a decrease in rainfall, is particularly poor and hence the reliability of this projection is suspect.

We first consider briefly the terms haze and cloud and the observations of aerosols over the Indian region and surrounding seas. We then discuss the nature of the impact on radiation, climate and agriculture.



**Figure 1.** Estimated man-made SO<sub>2</sub> emissions for different regions (India region includes Bangladesh, Maldives, Sri Lanka, Myanmar, Nepal, Pakistan; Chinese region includes Cambodia, Vietnam, Laos, Mongolia, North Korea; East Asia includes Japan, South Korea, Indonesia, Malaysia, The Philippines, Thailand).

## Asian Brown Cloud, haze, pollution and aerosols

Haze consists of a combination of water droplets and minute particles. The water droplets in a haze are less than 0.001 mm in radius. There are two possible sources for the particles in a haze<sup>7</sup>. They are either generated naturally (e.g. sea salt, dust) or man-made (e.g. sulphate or soot). From an aircraft, the haze appears brown, when the fraction of soot or dust is large. One of the major findings of INDOEX is that during January–March, a majority of the minute particles (around 75%) in the haze was of anthropogenic origin.

A cloud contains liquid water condensed from the water vapour in the atmosphere. Clouds form in the tropics when the air cools and becomes saturated. The typical radius of droplets in the clouds is larger than that in the haze, being about 0.01 mm to 1 mm (or even larger in rain clouds). Use of the word cloud (which most people associate with an entity that can give rain) for the haze, has led to considerable confusion amongst laymen as well as scientists. The haze occurs only in winter, i.e. January–March, the season in which INDOEX observations were made. Also neither the brown haze nor its extension over the adjoining ocean are features restricted to Asia.

*Thus, it appears that the term 'brown cloud' for describing the wintertime haze over the Asian region is not appropriate, and the implicit suggestion that it is a feature that characterizes only the Asian region is incorrect.*

An important characteristic of the haze is a marked decrease in visibility<sup>7</sup>. This occurs because of the presence of aerosols, i.e. the particles and water droplets dispersed in the atmosphere. India is one of the few countries in the world where systematic measurements of aerosols have been made over the past two decades, by scientists of the Indian Space Research Organization<sup>8–16</sup>. In addition, observations of visibility have been made by the India Meteorological Department, at several stations for more than four decades.

Since 1981, altitude profiles of aerosol extinction have been obtained using balloon-borne and rocket-borne payloads<sup>8–10</sup>. The aerosol characteristics over the Indian region have been studied by setting up multi-wavelength radiometer stations at a few sites<sup>16</sup>. Measurements from lidars revealed aerosol characteristics in the atmospheric boundary layer and aerosol extinction in the troposphere and stratosphere<sup>11–15</sup>. The first measurements of aerosols over oceanic regions adjacent to the Indian subcontinent were made in 1995 at Minicoy island in the Arabian Sea<sup>16</sup>. Subsequently, several observational experiments were conducted over the ocean<sup>17,18</sup>. The observations over the Indian region showed clearly the increasing trend of the aerosol load<sup>19</sup>.

A major contribution of INDOEX was the elucidation of the chemical composition of the aerosols (which showed a significant concentration of soot) and derivation of the radiative forcing associated with the aerosols<sup>20,21</sup>. The presence of soot in the haze causes heating of the atmosphere, which is diametrically opposite to the effect of sulphate aerosols which cause cooling of the atmosphere. With simultaneous measurements from aircraft, ships and satellites, the spatial extent of the haze over the Arabian Sea and the tropical Indian Ocean could be studied.

## Impact of aerosols on radiation budget

Aerosols can modulate the radiative energy balance of the atmosphere by changing the amount of solar and terrestrial radiation absorbed and scattered by the atmosphere. The size distribution of aerosols and their chemical composition control the manner in which aerosols alter the radiation budget of the atmosphere. The presence of aerosols decreases the solar radiation reaching the surface of the earth and usually increases the solar radiation reflected to space. In the infrared region, the presence of aerosols increases the atmospheric radiation reaching the surface and decreases the atmospheric radiation emitted to space<sup>22,23</sup>. Aerosols can also act as cloud-condensation nuclei. An increase in the concentration of aerosols increases the number of cloud droplets and hence also the reflectivity of clouds. The presence of soot in clouds increases the absorption of solar radiation and hence can lead to a cloud-cover change. Thus aerosols can also have an indirect impact on the radiation budget.

Measurements made during INDOEX during January–March 1999 showed that the solar radiation reaching the surface of the ocean decreases by about 29 W/m<sup>2</sup> due to the aerosols. This is comparable to depletion of solar flux observed elsewhere in the world. For example, measurements over the Atlantic Ocean show that the solar radiation reaching the surface decreased by 26 W/m<sup>2</sup> on account of aerosols that are transported from the east coast of USA<sup>24</sup>. All the important characteristics of aerosols over the Atlantic, viz. mass loading, optical depth and forcing, are found to be similar to those over the Arabian Sea and Indian Ocean. Kaufman *et al.*<sup>25</sup> have shown that solar radiation decreased by 34 W/m<sup>2</sup> in the Amazon on account of aerosols generated by forest fires.

It is important to note that there is considerable variation from year to year in the concentration of aerosols and hence also the resultant depletion of solar radiation. The large reduction in solar radiation that occurred during INDOEX in 1999 was on account of the unusual atmospheric circulation pattern that prevailed during that year<sup>26</sup>. Observations over the oceanic regions in 2001 showed that the reduction in solar radiation was smaller, being only 11 W/m<sup>2</sup> over the Indian Ocean<sup>23</sup>.

The impact of aerosols on the radiation incident at the surface of the ocean can lead to an impact on evaporation. In fact, a claim has been made in the UNEP news release that a 10% reduction in the levels of solar energy hitting the region's oceans in turn reduces the evaporation of the moisture which controls summer rainfall. It should be noted that aerosols are also good absorbers in the infrared, and hence the infrared radiation emitted by the ocean surface will be absorbed by aerosols and re-emitted to the ocean surface. This will partly off-set the reduction in solar radiation at the surface<sup>22</sup>. Hence, the net effect of the anthropogenic aerosols will be to reduce the net radiation flux at the surface only by about 10–15 W/m<sup>2</sup>. This value is smaller than the error in the estimate of evaporation flux from the ocean surface. Thus we expect the impact of the reduction of net radiative flux at the ocean surface due to aerosols on evaporation, to be small and not easily discernible. Even if there is some change in evaporation, the suggestion that this change in one season will lead to a change in rainfall in the following season has no scientific basis.

### Natural versus anthropogenic aerosols

In the atmosphere, besides the anthropogenic aerosols, there are natural aerosols (such as sea salt and dust). The total flux of natural aerosols averaged over the globe is about three to four times larger than the flux of aerosols generated by human activities. However, on a regional scale, the flux of anthropogenic aerosols can be three to five times larger than the natural aerosol flux in certain seasons. Hence, in any assessment of the impact of aerosols on climate and agriculture, both natural and anthropogenic aerosols must be considered together.

Natural aerosols can have an impact on the radiation budget. For example, dust aerosols can heat the atmosphere (from the surface to about 5 km altitude) by absorbing solar radiation. Dust aerosols are good emitters and hence can cool the atmosphere by increasing the emission of infrared radiation to space.

The flux of natural aerosols depends upon the wind speed. Hence, over the Indian region and the surrounding ocean, there is a high flux of natural aerosols during the monsoon and a relatively low flux during winter<sup>4–6</sup>.

*Thus, we expect natural aerosols to have a greater impact on the monsoon than the anthropogenic aerosols.*

### Impact of aerosols/haze on climate and the monsoon

It is important to note that the results of the studies of the impact of aerosols on surface temperature and rainfall presented in the UNEP report are for the January to

March season. Hence no inference can be drawn about the impact on the southwest or northeast monsoon from these studies. The South Asian region and the surrounding ocean receive very little rainfall during January–March, with the average rainfall over most of the Indian region being less than 10 cm (Figure 2). The contribution of the rainfall in this season to the annual rainfall is also small over the Indian region (Figure 2).

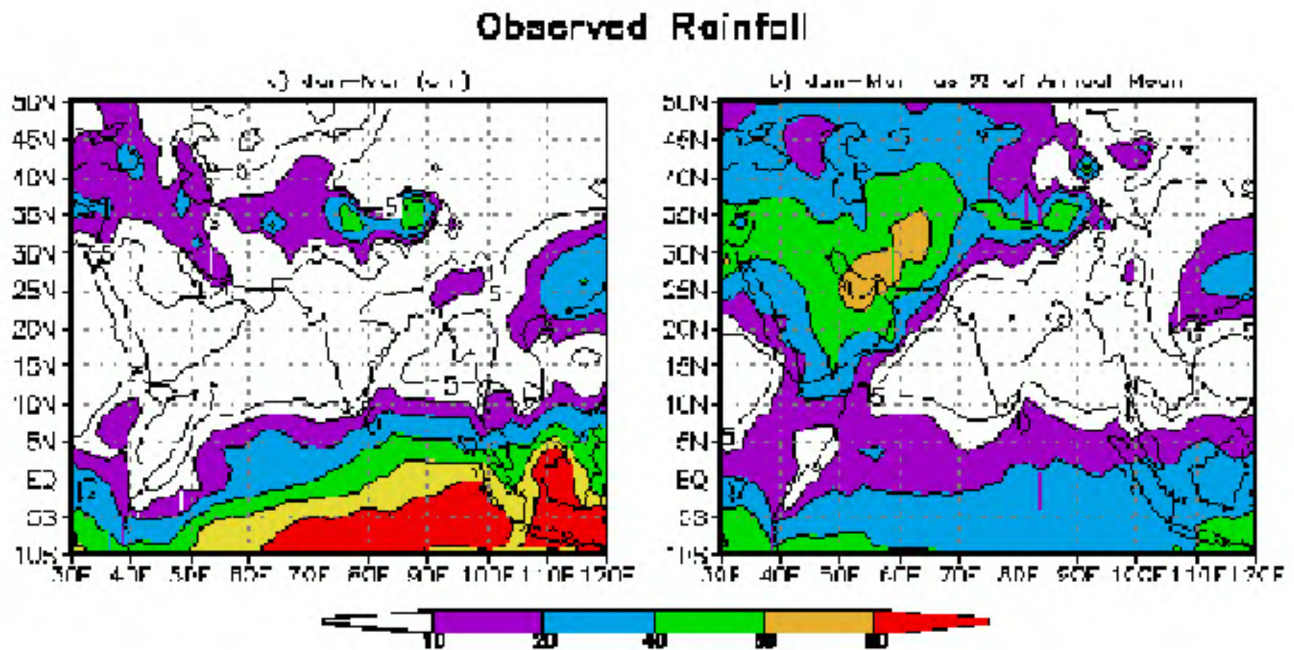
The methodology for assessment of the impact of haze in the UNEP report is similar to, but not as rigorous as, that adopted for the impact of increase in greenhouse gases. It involves a comparison of model simulations with and without the factor (in this case, aerosols/haze). This methodology is adopted in the studies presented in the UNEP report, with the use of an atmospheric model (version 3 of the Community Climate Model of the National Centre for Atmospheric Research, USA, commonly known as CCM3) and of the atmospheric model coupled with a simple ocean model<sup>27,28</sup>. The change induced by the haze is shown in figures 7.5 and 7.6 in the UNEP report (Figure 3).

Features which are common to simulations by both the models seem to be (i) an increase in rainfall over the southern parts of India and the equatorial Indian Ocean, and (ii) a decrease over Saudi Arabia and to some extent over Pakistan and Afghanistan. Among these, the second feature, viz. the decrease in rainfall in the regions to the northwest of India, has been emphasized as being a very important impact<sup>2</sup>. The rainfall over northwestern parts of India increases in one model and decreases in the other. Over the regions near the northern parts of the Bay of Bengal (including parts of Bangladesh), the rainfall increases in one model and decreases in the other. Since the haze has a direct impact on the solar radiation received at the land surface, it may have been expected that the nature of the impact on the surface temperature would be robust. However, even in the case of surface temperature patterns, there are large differences between the two models over East Asia.

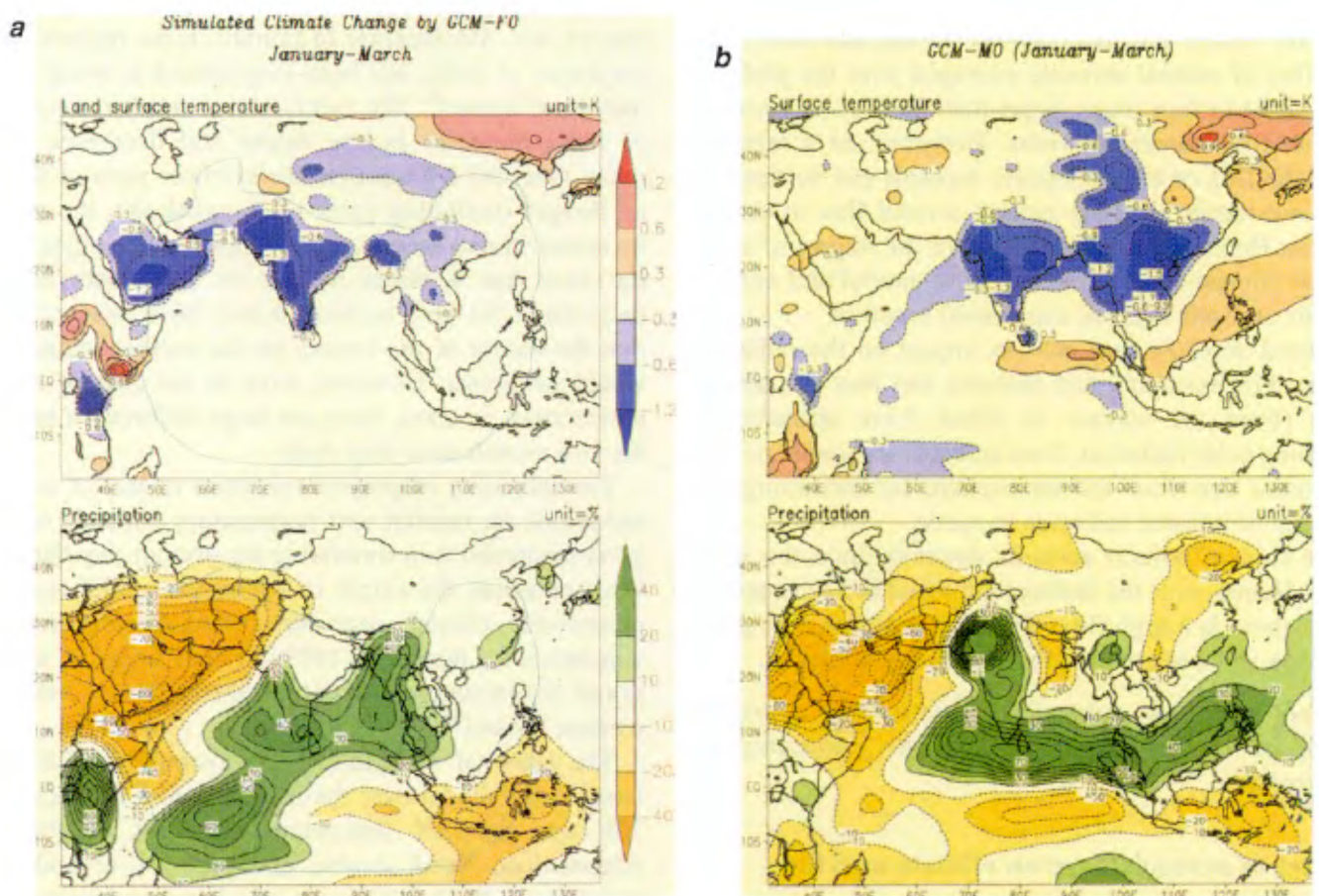
The reliability of projections about impact of any perturbations on rainfall and temperature depends on how good the model is in simulating the present-day climate<sup>29</sup>. We can assess the extent to which the model simulates present-day climate over the critical region from the simulation for the period 1979–95 done under an international programme called Atmospheric Model Intercomparison Project<sup>30</sup>.

The seasonal variation of the average rainfall simulated by the model over the land region in the sector 40–70E and 15–35N (encompassing most of Pakistan, Afghanistan, Saudi Arabia and parts of several other countries in West Asia) over which a decrease has been predicted, is shown along with the observed seasonal variation<sup>31</sup> in Figure 4. It can be seen that the seasonal variation of rainfall simulated by the CCM3 model over this region is markedly different from the observed





**Figure 2.** *a*, Observed rainfall (in cm) over part of the Asian region and the surrounding seas during January–March; *b*, Observed rainfall during January–March as percentage of the annual mean rainfall.



**Figure 3.** *a*, Simulated climate change (January–March) with NCAR/CCM3 + observed SST. (Upper panel) Land surface temperature change in units of K. (Lower panel) Precipitation change displayed in units of percentage (Chung *et al.*<sup>27</sup>) *b*, Surface temperature change (January–March) simulated with the CCM3 + Slab Ocean Model (Kiehl *et al.*<sup>28</sup>).

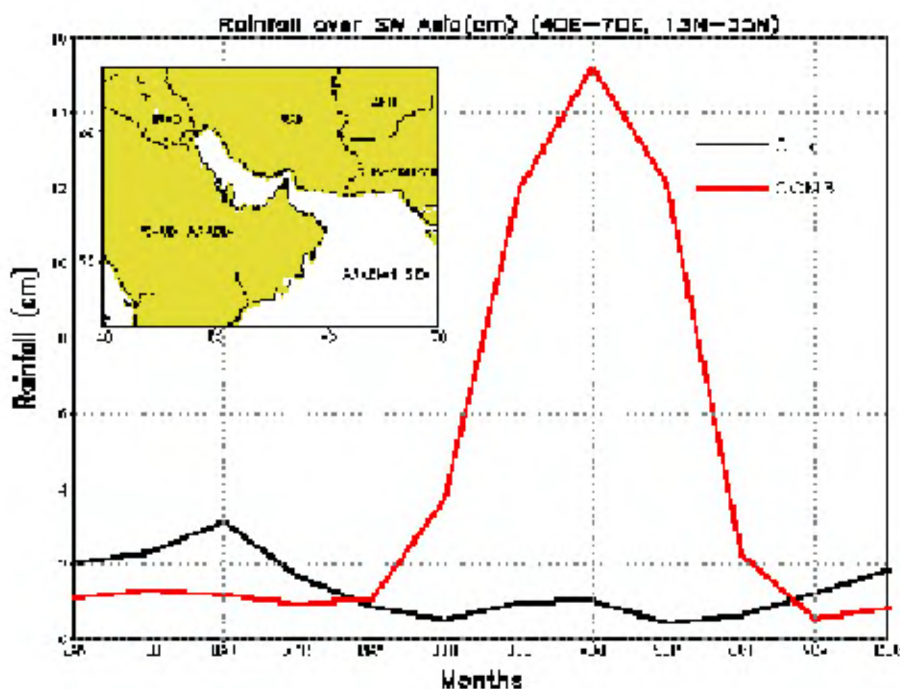


Figure 4. Variation of the average monthly rainfall (cm) from Xie-Arkin observations (black line, Obs) and CCM3 (red line). (Inset) Map showing the region over which rainfall has been averaged.

seasonal variation. The simulated rainfall during January to March is less than the observed variation (being less than half the observed), whereas in August it is almost 15 times higher than the observed variation. The simulation of the rainfall during the summer monsoon by the CCM3 model is known to have large errors over the desert regions, with as much rainfall over Saudi Arabia as over the Indian monsoon zone<sup>32</sup>. When this model was coupled with an ocean model, the monsoon weakened considerably<sup>33</sup>.

*It is clear that the reliability of the projection of a decrease in rainfall over this region due to the haze, on the basis of simulation by this model, is suspect. Despite this hazy understanding of the impact of the haze on rainfall, statements suggesting pollution over India leading to a decrease in rainfall over neighbouring countries have been made in the UNEP news release.*

### Fact and fantasy

We find that the UNEP news release on the Asian Brown Cloud (and hence the media reports based on it) is a blend of observations and scientifically sound deductions on the one hand, and sensational statements with little scientific basis on the other. The observations on the spatial extent of the Asian haze during January–March 1999, the chemical composition of the aerosols suggesting significant contribution of soot, and their impact on the

radiation budget belong to the first category. These facts need to be taken into account in our effort to reduce such emissions over the Indian region.

Based on the observational studies of this haze, assessment of its impact on climate was done using a climate model (with and without coupling to a simple ocean model). The results of these simulations with and without the haze, have led to the following statements:

‘A vast blanket of pollution stretching across South Asia is damaging agriculture, modifying rainfall patterns, including those of the mighty Monsoon and putting hundreds of thousands of people at risk’.

‘The global models used in the report suggest that the haze may reduce precipitation over Northwest India, Pakistan, Afghanistan, Western China and the neighbouring Western Central Asian region by between 20 per cent and 40 per cent’.

‘Preliminary results indicate that the... haze... is disrupting weather systems, including rainfall and wind patterns and triggering droughts in western parts of the Asian continent’.

We have shown that the simulation of rainfall by the model for the region over which rainfall is supposed to decrease due to the aerosols is poor. Thus, the projection of a decrease in rainfall over this region is not reliable. Furthermore, since the anthropogenic aerosols occur during the winter and the reported simulations are only for this season (outside the southwest and northeast monsoon

seasons), nothing can be deduced from these simulations about the impact of aerosols on the monsoon.

Based on the observational studies of the haze and the associated change in weather (derived from an atmospheric model), the impact on the yield of some crops, including wheat and rice has been assessed with the help of crop models. Results regarding the impact on the biomass and yield of wheat and rice indicate a change of less than 2% in wheat (section 8 of the UNEP report). Less than 10% of the rice is grown in this season in India. When the impact of the haze on radiation as well as the weather is considered, the change in rice yield is again 2% or less. It appears that there is no basis for the statement in the UNEP news release that 'the vast blanket of pollution across South Asia is damaging agriculture'.

Thus it appears that several statements in the UNEP news release, reported verbatim in the media, are based more on fantasy than facts.

### Concluding remarks

It is clear that the news release has created awareness about pollution. This should give an impetus to the ongoing programme of reduction of harmful emissions in our cities. People living in Asia must be concerned about this haze, because it has immediate and long-term impacts on their health. However, as we have indicated, Asia is by no means the only source of such pollution. It is surprising that rather than recognizing pollution as a problem which has an impact over many regions of the world, and acknowledging the Indian efforts at curbing it, the attitude of the INDOEX scientists, as reflected in the news release, involves blaming the developing countries in Asia for the pollution of the planet. Rather than advocating international agreements to control pollution, the attitude seems to be one of imposing an asymmetric control regime, as is evident in the statement by Lelieveld *et al.*<sup>34</sup>, 'Unless international control measures are taken, air pollution in the Northern Hemisphere will continue to grow into a global plume across the developed and developing countries'.

There are major inconsistencies between the alleged adverse effects on the monsoon and agriculture mentioned in the news release, and the results of scientific studies discussed in the UNEP report. It is difficult to attribute the large discrepancies to oversight. It is important for the people in the Asian region to understand that the implications in the UNEP news release, of immediate

and catastrophic consequences of the haze on the monsoon and agriculture, have no scientific basis.

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ACKNOWLEDGEMENTS. We thank Dr K. Kasturirangan, Chairman, Indian Space Research Organization and Dr R. Narasimha, Director, National Institute of Advanced Studies, Bangalore for several useful suggestions.