Joker of the climate system: aerosols control climate

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Many card games omit the Joker from the game; others, like Euchre, make it an ace. Aerosols are the wild card of the climate system pack. Disregard them in the climate models and predictions become inaccurate. Include them, and it gets murky. The Earth is itself a complex system. Add aerosols and things get even more fascinating, though in troubling ways. Aerosols induce the asymmetric patterns we see in the atmosphere – some places heating up, some cooling down[1], and uneven rainfall patterns[1–3].

The Indian monsoon is driven by the pressure gradient between land and ocean. The wind carries moisture and gathers strength due to the gradient in sea-surface temperatures between the Northern and Southern Indian Ocean[3]. Aerosols induce asymmetry in the energy balance of sea-surface temperature. The surface solar energy over the Northern Indian Ocean reduces in contrast to that of the Southern Indian Ocean. This energy balance impacts many components of the monsoon system[3,4], including solar heating of the surface–atmosphere system, the sea-surface temperature gradient, evaporation, and the Hadley circulation[3]. These factors have impact on monsoon rainfall. Thus, increased emission of aerosols changes the timing, spatial distribution and strength of the monsoon in the Indian subcontinent[5].

It is not only the monsoon that is affected. Aerosols induce cooling. They scatter sunlight, reflecting the energy back. This modifies the gradient of the atmospheric solar heating. This is their 'direct' effect. They also nucleate cloud drops, which increases the albedo of clouds. Thus they also have an 'indirect' effect over the atmosphere.

Aerosols are not exclusively anthropogenic. There are natural aerosols too. But the burning of firewood, coal and biomass for energy is the major source of black carbon, a form of aerosol[2]. These man-made aerosols pollute the atmosphere and, recently, there has been a significant increase in their levels[6]. Recent literature, published by Indian scientists, supports this claim.

Babu, a scientist from the Vikram Sarabhai Space Centre, Thiruvananthapuram, along with his colleagues from the Indian Institute of Science, Bengaluru, examined the distribution of aerosols in the city of Thiruvananthapuram. They find that the mesoscale land-sea breeze circulation and the atmospheric boundary layer regulate aerosol distribution over the coasts[6]. The air masses change rapidly since mesoscale land-sea breeze circulations modify surface aerosols. Thus, the aerosol size distribution is a function of the air mass type. Size distribution and concentrations of particles control the direct and indirect effects. To check this, the team measured 'aerosol optical depth', an index of aerosol levels. It is a measure of blocking of the solar beam by dust and haze. They took measurements from many ground-based instruments. They observed that aerosol optical depth had shown an increasing trend over the city.

The observations of Babu *et al.* become even more significant when combined with other recent work. Tiwari *et al.* studied the concentration of black carbon in Guwahati, Assam[2]. Assam is home to one of the biodiversity hotspots of the country. Yet, this region has gone unnoticed so far in the discourse on climate change. The scientists examined the global impact of aerosols due to these local changes by measuring the aerosol concentration and temperature of the city over a year. And they report a significant cooling trend on the surface due to these soot particles. This cooling trend affects the global climate[2].

An earlier study by Ramanathan had shown that the increase in aerosols due to biomass and fossil fuel burning leads to radiative forcing[3]. Aerosols mix with the clouds to form brown clouds. These clouds then intercept solar radiation, which leads to a reduction in reflectivity (albedo). Studies have shown a direct impact on snow and glacier melting over the Himalayas and the Tibetan Plateau[1–3]. The research so far suggests that aerosols have affected two of the most important climate drivers of the subcontinent.

If aerosols have such high impact on climate, how do we regulate them? Surely the apples-to-oranges method won't work. Carbon dioxide, the household norm in climate talks, always has the same composition. By contrast, aerosols are heterogeneous in different domains and get influenced by source, meteorological conditions, size transformations and several other factors[6]. It is difficult to trace their origins, chemical composition and spatial distribution. So they are poorly understood[4].

We have to start by looking for the sources and monitor the atmosphere from the skies to identify biomass burning sites and activities. That's what Vijayakumar, from the Sri Venkateswara University, Tirupati did. To get more conclusive results, he collaborated with his colleagues at the Indian Institute of Tropical Meteorology, Pune and other institutes. Using satellite measurements and model simulation data, they observed the effects of biomass burning on aerosol composition[4]. They identified that the residue originates from the North Indian states[4].

There are two separate periods for agricultural activities in Northern India: *Kharif* during the monsoon and *Rabi* in winter. To utilize the fields in both seasons, farmers set the fields on fire to clear the remains of the earlier crop. These residues get mixed and are carried to the Gangetic plains and even up to the Brahmaputra Valley.

The scientists identified this pathway by using Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observations, an earth observing system that shows vertical profiles of aerosols. The team also utilized other observational techniques such as satellite imaging, *in situ* aircraft probes and ground-based remote sensors to corroborate their findings.

Once we have the knowledge of the source, we must confirm its path and its spatial presence in the atmosphere. One way is to tag them. Sudheer *et al.* used $\delta^{13}C$, an isotope signature of carbon to evaluate the distribution and presence of carbonaceous aerosols in Jodhpur and Ahmedabad[7]. They found that along with black carbon, aerosols contain organic, mineral and marine aerosols from the Thar Desert region. They confirm that there is heterogeneity in carbonaceous aerosol sources. Small in size and with a longer lifespan, they tend to get mixed with other aerosols along the way[4].

According to Sudheer *et al.*, application of isotopic characteristics along with carbonaceous tracer compounds can be used to identify and quantify various sources with reasonable confidence. Vijayakumar and team, as well as other research teams, support the idea that the aerosols are carried far from their source region[1–4,6–8]; which poses a question: how are they carried to different places?

According to Vijayakumar *et al.*[4], this is due to the combination of wind patterns. The west-to-east pathway of winds carries them towards the Gangetic plains. Supporting his claim, Kumar *et al.* showed that the general wind pattern blew towards the east[7].

The work done by Bharat Kumar and Verma from the Indian Institute of Technology, Kharagpur, is consistent with this line of thinking[8]. They used the Trajectory Model for the projection of the trajectory of aerosols over Kharagpur and Kolkata. The model utilizes residence time of air parcels in a given source region during movement from source to receptor.

They performed a set of combined source–receptor analyses to examine the potential emission flux of aerosol constituents over the Bengal Gangetic plain. Like Babu and co-authors[6], Kumar and Verma, too, did a comparative study of aerosol optical properties and potential emission flux. They found that mean aerosol optical depth was in general high when it was associated with the path of air mass originating from the west of their site[8].

The skies of the North Indian plains have become a witch's brew of dust and particles. Regions which had minimal emission are also affected. Tiwari and co-authors showed that rural areas, like Ballia, have a high concentration of aerosols[1]. Their concentration at any location depends on how efficiently they are dispersed from the source region. That is unfortunate, but not unusual.

So do the disparate pieces of the puzzle fit together? Not yet. We all appreciate the complexities of climate. To draw conclusions, one needs to keep things simple. But in the longer run, we need to take into account all the factors involved. The discipline is waiting for a theoretical formulation that subsumes the given experimental results. Increased effort to understand, rather than reducing uncertainties, would help us.

The steps and decisions taken for climate policies may involve other factors such as politics, economics and development. But at heart, it is a puzzle of climate science. Accuracy of data and improved techniques of prediction may help us prepare for climate changes. Surely we do not know the magnitude – but now we know the signs at least. That's a start.

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