Wading through black carbon aerosols, climate and sustainability

Prof. S. K. Satheesh, is the recipient of the prestigious Infosys Prize 2018 in Physical Sciences. A man of very few words, Satheesh is basically a scientist, more precisely a climate scientist, with his own intuitions, visions, ideas and very strong views on science, research, and policy related to climate change in global as well as national perspectives.

Born on 1 May 1970 at Perumkadavila, a quiet and remote village in the southern part of Thiruvananthapuram, the capital city of Kerala state, Satheesh had his schooling in and around the village, in the local medium (Malayalam). After schooling, and graduation in Physics in 1990, he moved to the Kerala University Centre at Kariavattom in Thriuvananthapuram for his Masters in Physics with specialization in applied electronics during 1990–1992. It was during this period that Satheesh was attracted to atmospheric and space science through his involvement in a research project running in the department. This involved studying the ionospheric characteristics using a high frequency (HF) radar, which transmits high power radio waves from the ground towards the sky and collects the amplitude and phase of the signals returned from the ionosphere, scattered from electron density fluctuations. The return signals are recorded as a function of time, and analysing this data, inferences are drawn on the characteristics of the ionosphere – a thick layer of the upper atmosphere where charged particles (ions and electrons) formed by the interaction of solar radiation with atmospheric constituents make the medium conducive for interaction with radio waves. These, along with several other informations, are used to understand the deterioration of communication links from satellite to ground.

The interest in this subject drove Satheesh towards the field of radio communication, when he got an opportunity to work as a research scholar in the Space Physics Laboratory (SPL) of the Vikram Sarabhai Space Centre (VSSC), the biggest constituent of the Indian Space Research Organisation (ISRO). SPL has been pursuing multi-disciplinary research on atmospheric and space sciences, spanning across the entire neutral atmosphere, ionosphere and magnetosphere, including radiative interactions of various constituents with solar radiation and its implications, dynamical and electrodynamical coupling between the different atmospheric regions, and processes involving Sun–Earth relations. Satheesh joined SPL as a Junior Research Fellow in 1993 and it is at this point that I came across this young research student, who was to work with me – in fact, my first 'Ph D Student' – in a research problem relating to atmospheric aerosols (tiny suspended particles in the Earth's atmosphere) and their interactions with solar radiation and consequence to weather and climate. The basic process involved in this theme is quite similar to what attracted Satheesh during his masters programme – interaction of electromagnetic waves with refractive index fluctuations. My project was observation intensive at that time, to generate primary data on aerosols (which has been almost non-existent over India) over different distinctive geographical locations on the Indian mainland and adjoining oceans, by establishing ground observatory network with an in-house developed solar radiometer forming its backbone. With a small network in place, the immediate job Satheesh took up was to strengthen the database, analyse the available data and develop science-specific algorithms.

It was around this time that the ISRO had formulated its Geosphere–Biosphere Programme (GBP) and under this programme, the immediate requirement was to initiate investigations on natural aerosols, especially aerosols over oceanic regions and to understand how these change with over-ocean winds and due to long-range advection. To enable this, an observatory was installed at the tiny island Minicoy, the southern-most island of the Lakshadweep archipelago, with the support of the India Meteorological Department. It was a challenging task, as the access to the island is only by ship, which anchors a few kilometres away and we had to literally jump from the ship to small boats (that are maintained in a state of 'near-dynamical equilibrium' by some crude means) with the instruments and personal luggage and then travel through the choppy waters for about an hour to reach the island. However, it was worth, because being so tiny an island (about 10 km in length and having a maximum width of 800 m), it could well be considered as a huge ship in the ocean, far less influenced by local human activities. The radiometer was installed and the study was initiated in 1994 and this in fact started marine aerosols research in the country. Satheesh was wedded to this observatory, travelling into and out of the island regularly in all seasons (it used to be a real challenge during the monsoons, when he had to literally jump into the ocean and wade through to the beach). With this experience he also participated in marine expeditions aboard ships (*Sagar Kanya* and *Sagar Sampada*) to understand the spatial variation of the aerosol properties across the Indian Ocean, as well as provide primary data to validate some products from satellites which were being generated in ISRO at that time. These hard-earned data provided the first insight into the role of winds in generating sea-spray aerosols and in transporting dust from the middle east to the Arabian Sea. Satheesh developed his Ph D dissertation on this and received his degree from the University of Kerala in 1997.

The merit of his work and observational skills earned him a postdoctoral position in the famous Scripps Institution of Oceanography (SIO) at the University of California, San Diego, under the

Satheesh (extreme left) on the Minicoy beach during installation of the radiometer in 1994 (on the left) and making measurements aboard *Sagar Sampada* in 1997. (Photo by K. Krishnamoorthy)

INDOEX project of V. Ramanathan. As a part of his research activity, Satheesh worked for about two years in the Climate Observatory, setup again at a remote, small island Kaashidhoo in the Republic of Maldives, and also made ship-borne experiments, besides working at the SIO. These works led him to develop a comprehensive chemical model of Indian Ocean aerosols, and use it for assessing the climate forcing potential at regional scales. The pinnacle of his post-doctoral fellowship work was quantification of the role of absorbing anthropogenic carbonaceous aerosols (which include the black carbon and organic carbon) in significantly contributing to atmospheric warming, with possible far-reaching implications to water cycle and monsoon over this region. This finding, published in *Nature*, has been well received and widely referred to by the global scientific community. It also made it into *Nature* news: 'Sooty air sweeps away clouds', (*Nature*, doi:10.1038/news000504-12, 2000) and in perspectives in the *Science* magazine: 'Absorbing Phenomena', *Science*, 2000, **288**, 989–990, doi:10.1126/science.288.5468.989.

Shortly, Satheesh joined the Centre for Atmospheric and Oceanic Sciences (CAOS) of the Indian Institute of Science as an Assistant Professor (in December 2000). Being primarily an observational scientist, he started establishing an aerosol laboratory at the CAOS, with several state-of-the-art instruments supported by funding from several national institutions, including the ISRO and DST. The laboratory has grown over time, and now accommodates several scholars working for their Ph D under his supervision, and also post-doctoral fellows. With a futuristic vision and long-term objectives, he has set up a climate observatory at the Indian Institute of Science's second campus at Challakere, a remote rural location, about 200 km northwest of Bengaluru, where he has installed several monitoring instruments.

Satheesh's research is primarily on atmospheric aerosols, their optical and microphysical properties, how they interact with the solar radiation, how they modify the properties and lifetime of clouds and how the heterogeneous chemical reactions modify atmospheric ozone concentrations and the implications of all these on the climate. He focused specifically on light absorbing (*black*) *carbon aerosols*, a byproduct of all low temperature combustion, and how they affect not only just human health, but also the climate, especially over the Indian subcontinent. With this goal in mind, he participated actively in several major field experiments, the most important among them being the ICARB (Integrated Campaign for Aerosols, gases and Radiation Budget) organized by ISRO in March–May 2006 for which I was the project director. As principal scientist of the air segment of this multi-instrument, multi-platform field experiment, Satheesh contributed extensively to the success of the campaign with the aircraft measurements carried out in excellent co-ordination with the observations aboard the research vessel (with me as the Chief Scientist) over the oceanic regions around India. It has been a pleasure to work with him throughout the two-month long campaign. The synthesis of ICARB data led to the 'discovery' of elevated absorbing aerosol layers over the Indian region, the strength and height of which increased northwards from the Indian Ocean to Central India. The climate implications of this elevated layer drew global attention, and is being followed up by ISRO under its project Regional Aerosol Warming Experiment (RAWEX).

Besides participating in field experiments, Satheesh also organized major international field experiments over India to unravel the climate implications of absorbing aerosols. The major ones are: (i) the RAWEX-GVAX (Ganges Valley Aerosol Experiment) jointly with the Department of Energy, USA; the ISRO and the Department of Science and Technology of India in 2011–12 and (ii) the SWAAMI (South West Asian Aerosol Monsoon Interactions) jointly with National Environment Research Council, UK and the Ministry of Earth Sciences, India in 2017; both of which have taken the aerosol science to higher levels. His current research interests include the climate implications of black carbon (soot) emissions from high-altitude aircrafts and the implications of absorbing aerosols in the domain of optical communications.

In addition to contributing to science, he also took care of human resource development by guiding the research work of a large number of students in their masters and doctoral works; several of whom are working in the field of aerosols in different parts of the world. As a more matured researcher, Satheesh started diversifying his activities; focusing more on climate change adaptation and sustainability. Since 2016, he is the Director of the South Asia Regional Office of the international science-cum-policy programme, 'Future Earth', supported by various organizations and the United Nations agencies/organizations. Since 2016, he is the Chairman of the Divecha Centre for Climate Change (DCCC) in the Indian Institute of Science. He co-ordinates and guides its entire activity; which include *inter alia* putting forth policy suggestions to the Government of India's Ministry of Environment, Forest, and Climate Change; Department of Science and Technology and Ministry of Earth Sciences, in matters dealing with climate and environment; the societal implications of climate change and the way forward for sustainability.

With the kind of impacts he has been making in the field, it is natural that he received many recognitions at regular intervals. He was the Young Associate of the Indian Academy of Sciences (2001–2005); recipient of the START Young Scientist Award 2001; INSA Young Scientist Medal (2002); the WMO Young Scientist Award in 2002; DST's Swarna Jayanthi Fellowship in 2006; Asian Aerosol Young Scientist Award in 2007; the PRL Award in 2007; Rajib Goyal Prize in 2008; the Shanti Swarup Bhatnagar Prize (CSIR) in 2009 (awarded for the first time for an 'aerosol scientist'), the TWAS Prize 2011 by The World Academy of Sciences (TWAS);the ASI–ISRO award in 2017 and the first recipient of the prestigious Devendra Lal Memorial Award of AGU (American Geophysical Union) in 2017. Satheesh is an elected fellow of all the three National Academies of Science of India (since 2009–10); TWAS since 2013; and JC Bose Fellow since 2015. Thus, it seems quite natural that he has been selected now to receive the prestigious INFOSYS prize.

Personally, I am proud of having been his Ph D supervisor and I have always enjoyed being associated with him in various scientific endeavours. Satheesh is always calm and composed, even during challenging times. I wish to see him scaling still higher peaks.

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