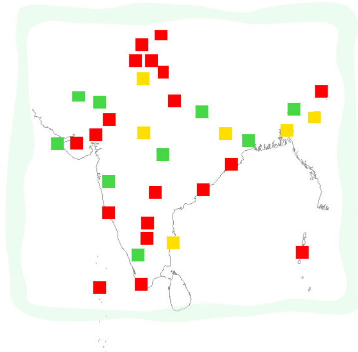
ARFI

Project under ISRO-GBP

Aerosol Radiative Forcing over India

From the Lab to the Field



Regional aerosol radiative forcing and climate impact assessment

Space Physics Laboratory
Vikram Sarabhai Space Centre
Indian Space Research Organization
Thiruvananthapuram, India

2010

MWR-Multi Wavelength Radiometer
The workhorse of ARFI network

MWR, designed and developed in-house at SPL to measure spectral aerosol optical depths at ten wavelengths in the UV through near infrared region.

Instrumentations

MWR - Columnar AOD at 10 wavelengths (UV through Near IR), retrieved columnar size distributions
QCM impactor - Mass size distribution & Total mass concentration of composite aerosols (0.05 to 25 μm)
Aethalometer - Mass concentration of BC aerosols, spectral absorption coefficients
Optical Particle Counter - Number concentration of composite aerosols in 16 channels (0.3 to 25 μm)
Electrical Low Pressure Impactor - Number size distribution (0.03 to 10 μm in 12 channels)
Sequential Mobility Particle Sizer + Counter - Number size distribution (10nm-1000nm) in 44 channels
Integrating Nephelometer - Total and back scattering coefficients at 3 wavelengths (450, 550, 700 nm)
Multi-Filter Rotating Shadow band Radiometer - Global, direct and diffuse component of solar radiation
High Volume Samplers - Mass concentration of bulk aerosols chemical composition
Net radiometer - Downwelling, upwelling and net shortwave and longwave solar and terrestrial radiation
Automatic Weather Stations - Apparent wind speed and direction, T, RH, rainfall and sunshine.

Project Team

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Project Director, ARFI

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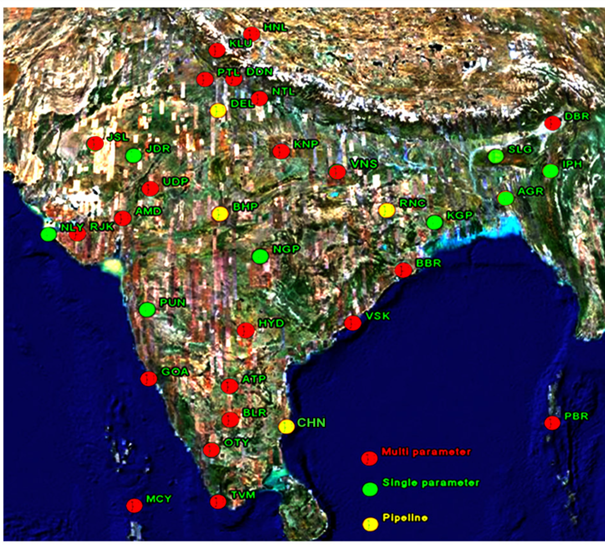
Tushar Prabhu, Indian Institute of Astrophysics, Bangalore (Hanle)

Network Observatories

	Stn	Lat (°N)	Lon (°E)	Alt (m)
Trivandrum	TVM	08.50	77.00	0002
Minicoy	MCY	08.20	73.00	0002
Ooty	OTY	11.40	76.70	2520
Port Blair	PBR	11.64	92.71	0060
Bangalore	BLR	12.97	77.59	0960
CHN	CHN	12.70	79.92	0050
Anantapur	ATP	14.46	77.67	0025
Goa	Goa	15.46	73.83	0070
Hyderabad	HYD	17.48	78.40	0557
Visakhapatnam	VSK	17.70	83.10	0020
Pune	PUN	18.54	73.85	0457
Bhubaneswar	BBR	20.20	85.80	0078
Nagpur	NGP	21.15	79.15	0300
Naliya	NAL	22.23	68.89	0050
Rajkot	RJK	22.30	70.73	0142
Kharagpur	KGP	22.50	87.50	0028
Ahmedabad	AMD	23.10	72.60	0055
Ranchi	RNC	23.23	85.23	0654
Bhopal	BHP	23.30	77.30	0078
Agartala	AGR	23.50	91.25	0043
Jodhpur	JDR	26.26	72.99	0236
Udaipur	UDP	24.60	73.90	0577
Imphal	IPH	24.75	93.92	0765
Varanasi	VNS	25.30	82.96	0078
Shillong	SHN	25.60	91.91	1033
Kanpur	KNP	26.40	80.30	0050
Jaisalmer	JSR	26.92	70.95	0225
Dibrugarh	DBR	27.30	94.60	0111
Delhi	DEL	28.60	77.20	0239
Nainital	NTL	29.20	79.30	1960
Patiala	PTL	30.33	76.46	0249
Dehradun	DDN	30.34	78.04	0700
Kullu	KLU	31.90	77.10	1154
Hanle	HNL	32.78	78.95	4350
...	...	...	...	...

ARFI Network - 2009
Evolution of a modest Research ...



ARFI showcases the evolution of a modest research theme into a national endeavour with a unique national and international identity

Objectives

- Generate regular fortnightly maps of the aerosol environment (aerosol spectral optical depth, mass concentration, concentration and mass mixing ratio of aerosol Black-Carbon and size distribution) over India and adjoining oceans, by establishing a network of aerosol observatories, so as to delineate the natural and anthropogenic hot-spots, sinks and vertical distribution
- Delineate and quantify the impact of long-range transport of aerosols from different source regions within and external to India (east and west Asia, Africa and south China) by carrying out integrated campaigns
- Estimate the aerosol radiative forcing at top of the atmosphere, Earth's surface and in the atmosphere and generate regional radiative forcing maps
- Estimate the climate implications of elevated aerosol warming over the Indo-Gangetic Plains and Himalayan foothills
- Assess the long-term implications to regional and global climate
- Developement of small satellites for atmospheric aerosol studies

Rationale and Approach

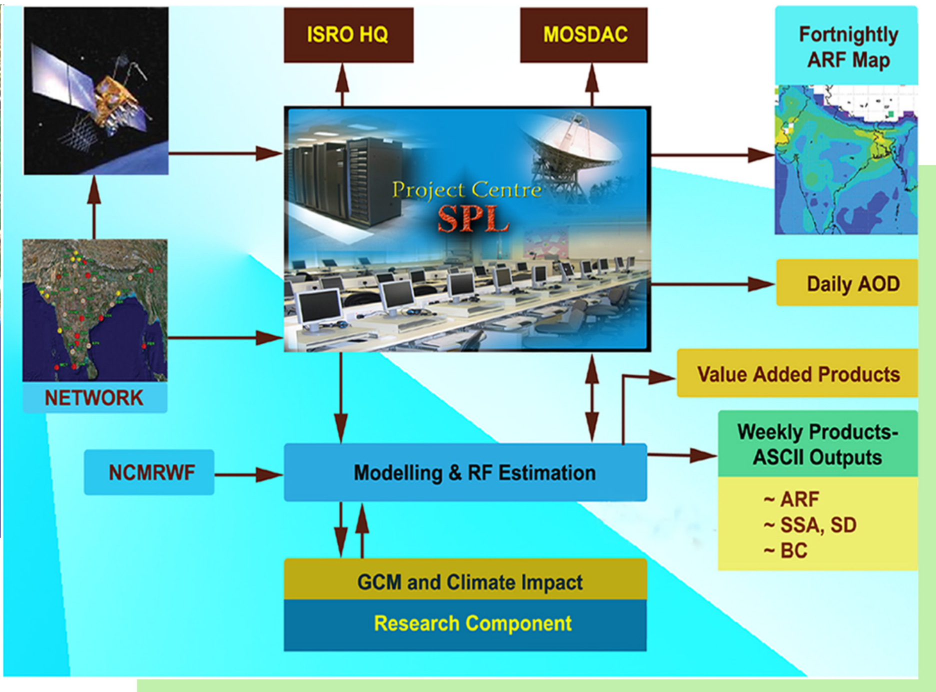
Climate impact of aerosols remains uncertain despite concentrated efforts of global scientific community. This is mainly because (a) aerosols are not represented in climate models with adequate spatio-temporal heterogeneity and (b) the climate models are not matured enough to faithfully represent aerosol impacts on regional/global scale. This calls for more accurate and resolved (space, time and spectral) assessments of physico-chemical properties of aerosols and better representation in models.

Being a multi-paramter problem and owing to the large heterogeneity in space and time, isolated measurements are not adequate for accurate aerosol characterization; rather, the need is a sustained, region-specific, and synergistic approach. This is more so for India, with its large natural diversity, tropical nature, wide range of human activities, long coastline, vast semi-arid and arid regions and the contrasting monsoons. The ARFI network is designed to make comprehensive measurements of all the aerosol parameters needed for climate impact assessment.

In addition to the network stations, concerted (multi-disciplinary) campaign mode efforts involving concurrent measurements from diversed platforms onboard ships, high altitude balloons and aircrafts also form integral part of ARFI. This is supplemented with the measurements at background sites such as Antarctic, Arctic and Himalayas and satellite data complementing the network and campaign measurements, providing a synergy.

Keeping the data from the network stations and campaigns as ground truths and anchoring points, the satellite retrieved parameters are compared, validated and used to fill the spatio-temporal gaps in the data sets.

The database thus built up will be used to generate assimilation models for the computations of aerosol radiative properties in different seasons over India and its adjoining oceanic regions. These modeled optical parameters, anchored with measurements will be used for estimating the radiative forcing due to aerosols.

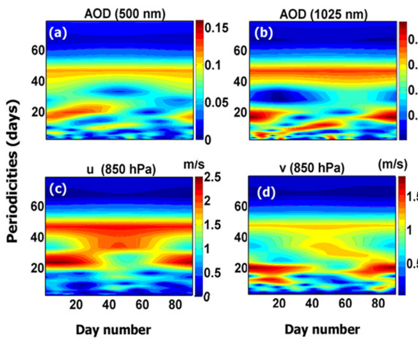


Configuration

In order to achieve the desired objectives, it is essential to have continuous measurements of vital aerosol parameters with adequate temporal and spatial resolution to account for the spatio-temporal heterogeneity. A national network of aerosol observatories is being established for continuous, spatially resolved data. In addition to this fixed network, which provides time series data, a central mobile ARFI laboratory is planned capable of making all the required aerosol measurements including altitude profiling using a micro-pulse lidar. This mobile laboratory will be moved to distinct aerosol environment by simultaneous integrated campaigns (like the recent ICARB) using ships and aircrafts. The data, thus generated, will blend with satellite data to evolve regional aerosol maps.

Major Scientific Outcomes from ARFI

Natural varibilities *unique to tropics often overlooked in models*

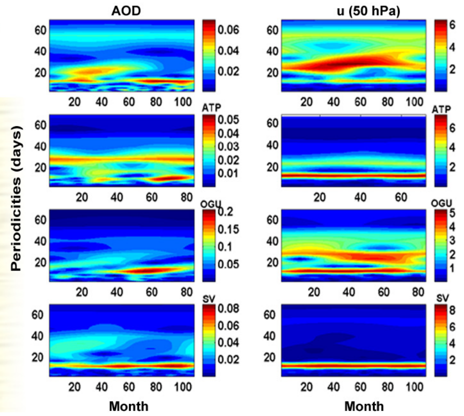


MJO and Quasi 16 day oscillations in wind modulate the seasonal mean AOD by ~ 25% each and collectively upto ~ 45% depending on their phase

[GRL-2009]

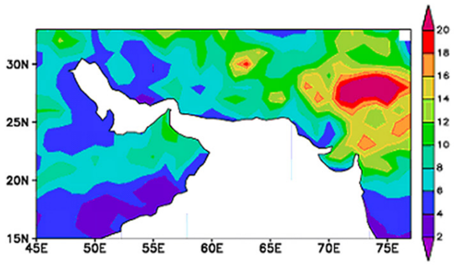
The stratospheric QBO produces modulations of 10 to 20% to the long-term, annual mean AOD

[ASL-2009]



Anomalous absorption of Asian dust

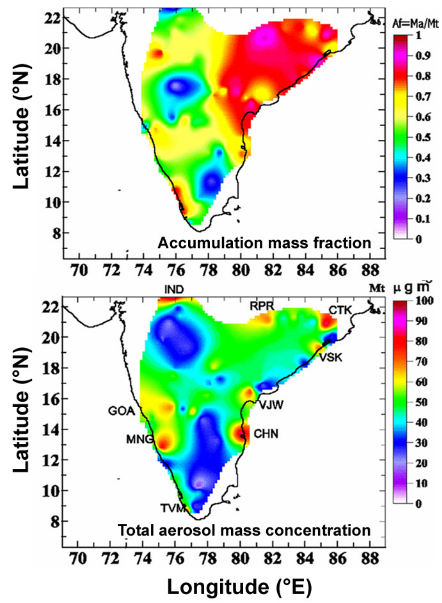
ARFI investigations revealed that the mineral dust over Asian region is more absorbing in nature compared to that over African region. It also revealed that over the IGP, aged dust is more absorbing than nascent dust. The mixing of dust with other absorbing species such as BC and the iron enrichment in Indian soil are the probable causes. [JGR-2007]



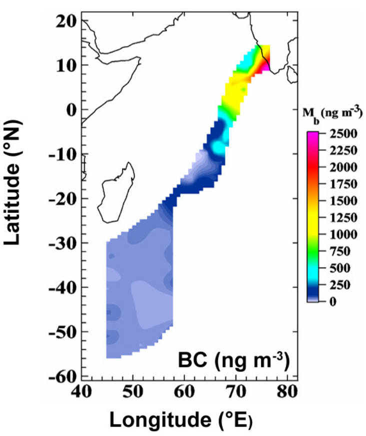
Spatial variation of near surface aerosols during LC

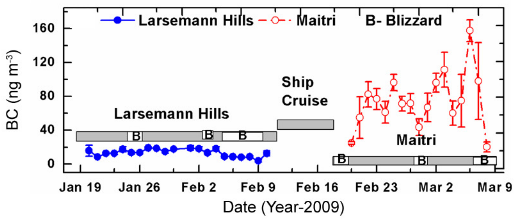
Over the peninsular India, hot spots of high aerosol concentrations are centered around urban centres. The eastern region of the peninsula has significantly higher accumulation mode fraction than the western part

[JGR-2005]



BC over Southern Ocean and Antarctica

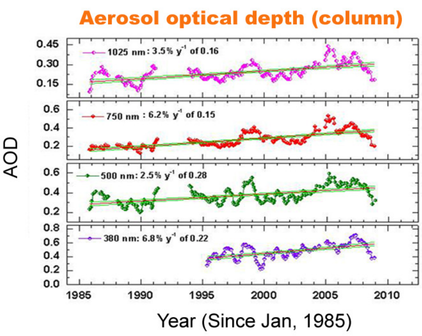


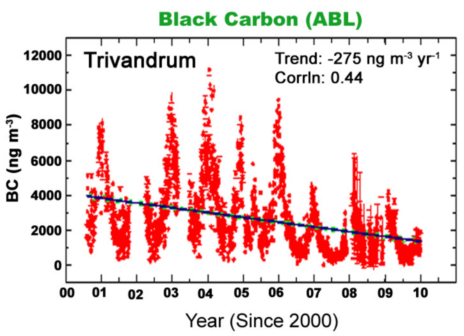


Reveals the large spatial gradients across the oceans [GRL-2005] and even over Antarctic continent [JGR-2010].

It also brings out the scavenging of BC by blizzards which will have significant climate impact.

Long-term trends: Raising new questions

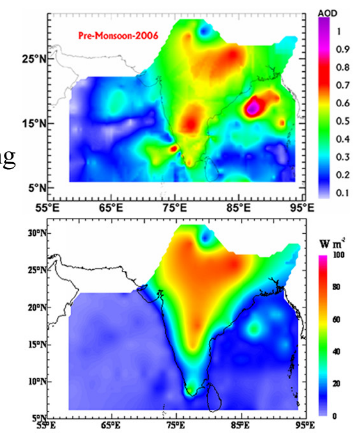




While the decreasing trend in BC would be indicative of the emission control measures and improvement in technology, the increasing trend in AOD raises new questions. (a) whether the abundance of scattering aerosols is increasing? or (b) is there an increase in the aerosol abundance above the ABL?? [WMO Report 'Climate Science', 2009]

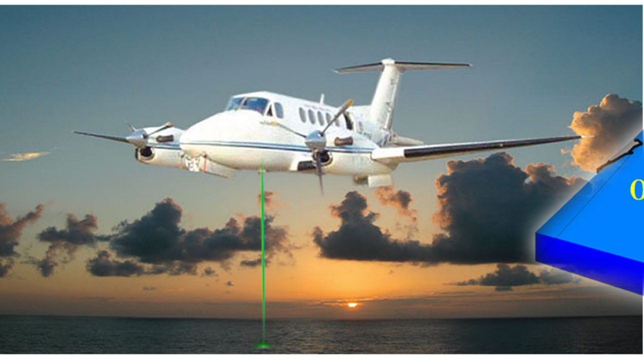
Regional Composites of AOD and Forcing

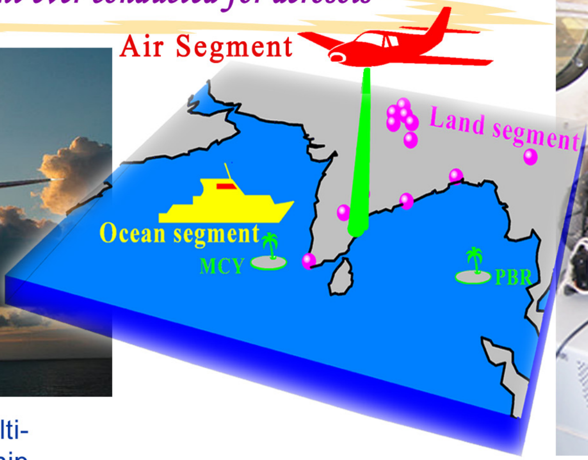
First time spatial synthesis of AOD and aerosol radiative forcing over Indian landmass and the adjoining oceanic regions



ICARB Integrated Campaign for Aerosols, gases and Radiation Budget

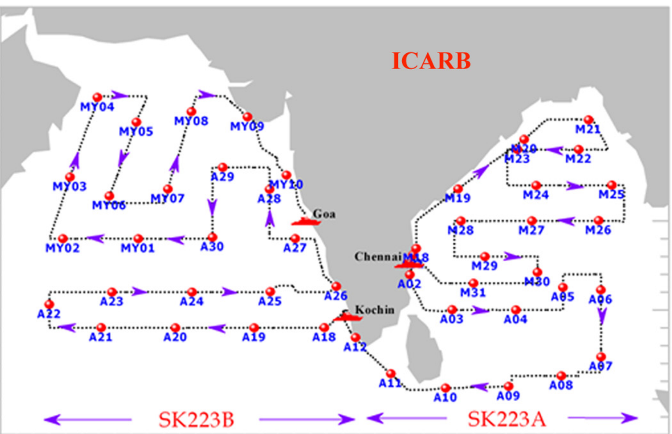
The biggest multi-institutional, multi-instrumented, multi-platform field experiment ever conducted for aerosols

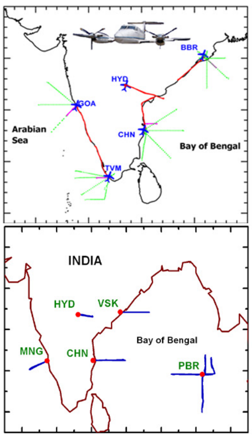


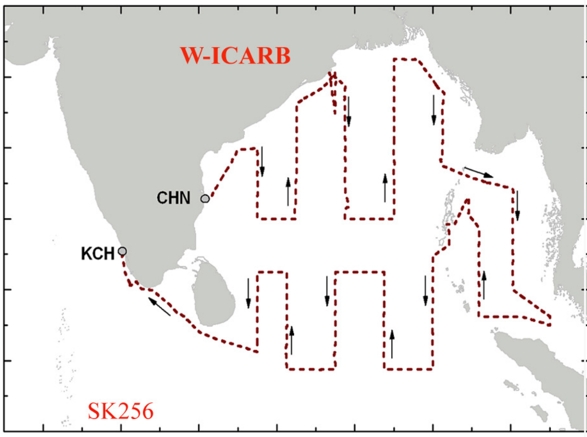


ICARB follows an integrated, multi-platform approach involving aircraft, ship and satellites, besides the ARFI network to quantify the heterogeneity of aerosols. Conceived as a series of 'mega' campaigns, the first of it was conducted during March-May 2006, covering about 4 million km² oceanic area of Bay of Bengal, North Indian Ocean and Arabian Sea, followed by the second one (W_ICARB) during December 2008 to January 2009 focusing on BoB, with extensive concurrent airborne measurements for the first time from Port Blair.

The campaign was structured following an integrated-segmented approach, consisting of three observation-intense segments; viz., the land, ocean and the air segment. The land segment comprised of fixed aerosol observatories, making continuous time series measurements of several aerosol parameters following a common protocol. The ocean segment comprised of the measurements of more than 20 aerosols and trace gas parameters, using about 40 different instruments by a team of 100 scientists from 26 national laboratories, academic institutions and universities. The air segment was executed using NRSA (now NRSC) aircraft, which comprised of 26 sorties from five base stations, including first-ever aerial sorties from Port-Blair profiling the aerosol parameters vertically and spatially during the first phase (ICARB) and 17 sorties during second phase (W-ICARB).







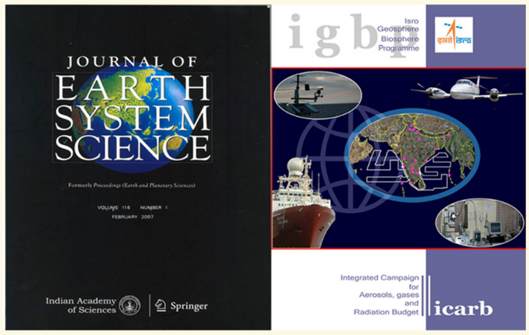
ALLURING EVENTS OF ICARB

The brain storming session and planning meeting of ICARB at Ponmudi, Trivandrum. Jan-2006

Dr. G. Madhavan Nair, the then Chairman, ISRO, onboard ORV Sagar Kanya during ICARB 2006 for visiting the experiments and interacting with the team; [16 Mar 2006].

Dr. B. V. Krishna Murthy, Former Director, SPL and Prof. R Sridharan, the then Director, SPL discussing the mission details with the Project Director and the Chief Scientist [15 Mar 2006].

Dr. P S Goel, the then Secretary, MoES, visiting the ship prior to flag off [17 Mar 2006].



The gratifying moment of ICARB

The special issue of JESS, a compendium of ICARB results, being released by Dr. G. Madhavan Nair, the then Chirman, ISRO during the annual project review meeting at Andhra University, Visakhapatnam

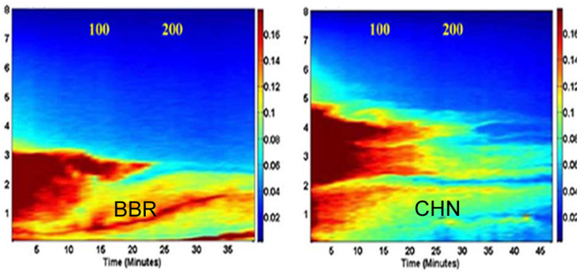
Aug-2008

Evolution of ARFI and ICARB

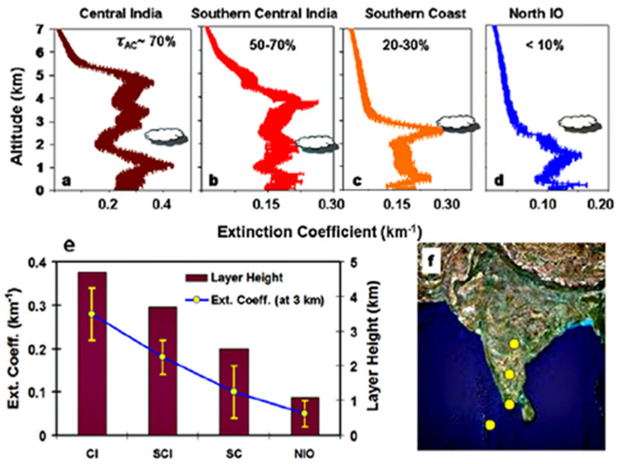
The evolution of ARFI and ICARB projects present the saga of 25 years' of collective national teamwork, which stood the test of time to become benchmarks in atmospheric science endeavors. Entwining the concepts of in-house design and development of scientific instruments; algorithms for operation, data deduction, and scientific analysis; realizing and maintaining a national network through collective team-effort involving national laboratories, academic institutions, and universities spread across the country, and above all contributing to the noble cause of capacity building, these projects showcase the evolution of a modest research theme into a national endeavour with a unique national and international identity. The early 1980s witnessed a rejuvenation of atmospheric science research in India, with the advent of the Indian Middle Atmosphere Program (IMAP). During this, a 10-channel multi-wavelength solar radiometer (MWR) was designed and developed in-house in SPL and a mini-national network of MWRs was realized in 1987, instigating the concept of a national network with common protocols for instrumentation and data deduction.

Taking cue from the success of IMAP, ISRO gave shape to its Geosphere Biosphere Programme (the I-GBP) in 1991, to address to specific scientific themes of national and regional significance, besides fundamental research on Geosphere and Biosphere interactions. This evolved into a professional, multi-pronged, approach in the scientific endeavors related to aerosols, clouds and radiation taking the science on par with the frontline work in the international scene. Leading from the front, SPL gave shape to two major national projects, unparalleled in recent history on aerosols, namely the Aerosol Radiative Forcing over India (ARFI) project and Integrated Campaign on Aerosols and Radiation Budget (ICARB). From the modest, concept-proving network of 1983, ARFI has travelled a long way to a national operational network of ~34 observatories spanning the length and breadth of India; from Trivandrum to Hanle, and Nalia to Dibrugarh, and aims at generating regional aerosol database, radiative forcing maps and climate impact assessment. The ICARB, on the other hand envisages mega-field experiments, focusing on specific themes that feed to ARFI.

Results from ICARB



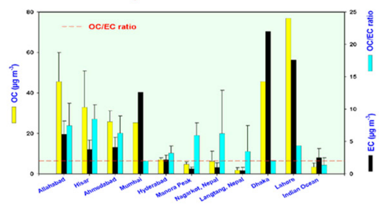
First Experimental evidence of elevated atmospheric warming by absorption in the elevated aerosol layers over the Indian landmass and its northward gradient, whcih has large implications to regional weather and climate including monsoon [GRL-2008; JGR-2009]



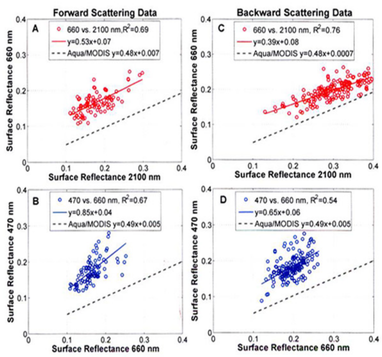
OC/BC ratio from measurements reveal much higher values over lot of Indian sites compared to the ratios for urban sites in the US and Europe

[Current Science-2009]

The large OC/BC over Indian region is usually overlooked in models

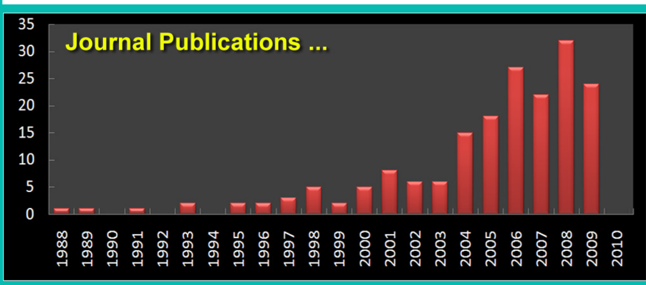


How Accurate is MODIS Aerosol Retrieval Over Land?

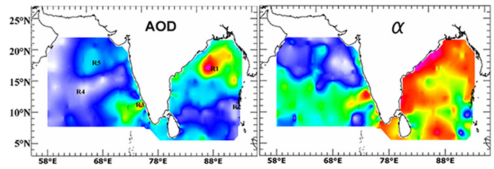


A comparison of the aircraft measured surface reflectance with that used in MODIS algorithm for the bands 470, 660 and 2100 nm over Bangalore revealing large offset that leads to higher uncertainty in the MODIS derived AODs

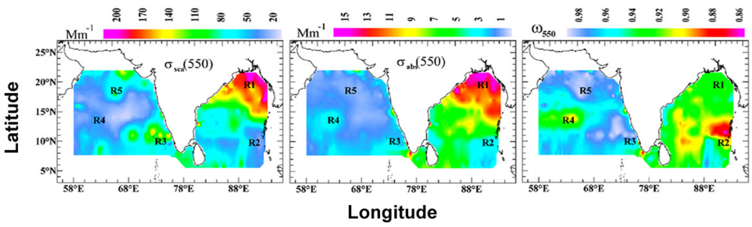
[IEEE TGRS, 2009]



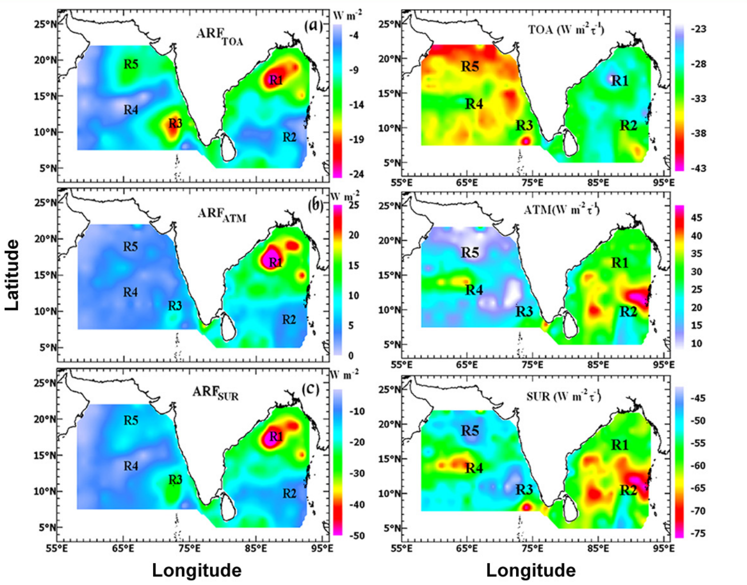
Spatial distribution of AOD (500 nm) and Angstrom exponent (α) reveals large spatial heterogeneity in columnar aerosol abundance and size distribution even over small oceanic regions with pockets of high AODs over northern BoB and southern AS



[QJRMS-2009]

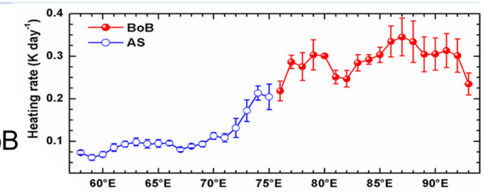


Large latitudinal and longitudinal gradients in scattering and absorption coefficients over BoB, while longitudinal gradients are only noticeable over AS. Unexpected regions of low SSA (high absorption) over central parts of BoB and AS located far away from the continental source regions [GRL-2008]



Large spatial variation of the ARF at the top of the atmosphere (TOA), atmosphere (ATM) and surface (SUR). Interesting observations are: High atmospheric warming over the ocean down the peninsula and around Sri Lanka and unusual high values of forcing efficiencies over the central parts of the AS and BoB [QJRMS-2009]

Longitudinal variation of aerosol induced heating rate over BoB and AS depicting 3 to 4 times higher rates over the BoB compared to AS

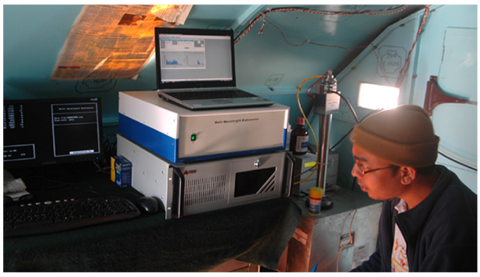


Fellow of Indian National Science Academy
Fellow of Indian Academy of Sciences
Fellow of National Academy of Sciences, India
S S Bhatnagar Award
PRL Award
SCOPUS Young Scientist Award
Asian Young Aerosol Scientist Award
WMO Young Scientist Award
Associate of Academy
Young Scientist Award from INSA and NASI ...

Awards and Honours received by ARFI Scientists

Aerosol observatory at Hanle
4530 m above msl
On the top of the World

With the successful installation and commissioning of aerosol observations from Mt Saraswati (32.78° N, 78.95° E, 4530 m amsl), Hanle in the trans-Himalayas, on 09 August 2009, in collaboration with the scientists/engineers from the Indian Institute of Astrophysics, ARFI attained another distinction of being the first and only atmospheric observatory in India, having regular aerosol measurements from the highest location. This observatory is expected to throw insight into the background aerosol conditions, far removed from human habitats; and insight into the processes of formation of new particles, as well as aerosol cloud interactions.



Clockwise-Top: Setting up the instruments, operation of MWR, Aethalometer with pump and SMPS+Counter inside the IGLO-hut
Left: A view of IGLO-Hut at Mt. Saraswati in Hanle

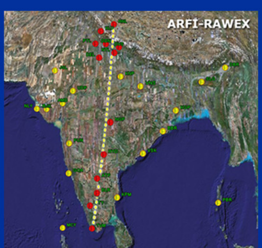
The Last Frontier
On the land of Penguins

The last frontier is no more a clean and pristine environment. Extensive scientific observations on aerosol parameters were made over the Antarctic Ocean and continents during the 27th and 28th Indian Scientific Expedition to Antarctica (ISEA) during 2007-08 and 2008-09. The observations were made from Maitri (70°S, 12°E, 123 m amsl) and also from Larsemann Hills (69°S, 77°E, 48 m amsl), where India's third station is coming up. Expedition to the Arctic is in the pipeline.

Upcoming Missions

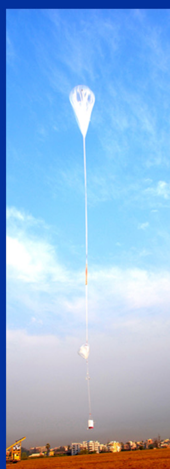
Regional Aerosol Warming Experiment: A multi-year, multi-disciplinary, field experiment focusing on the synergies of aerosol warming and monsoon is being implemented with the following objectives.

1. To characterize the elevated aerosol over the indian region, their amplitude, frequency of occurrence, seasonal trends and gradients of Indian monsoon.



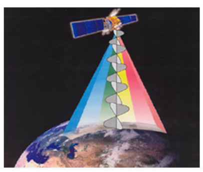
2. To quantify the contribution of absorbing aerosols (dust and BC) in the regional warming and to delineate the share of long-range transport and local contributions to the warming.

3. Estimation of the radiative impact of these elevated aerosol layers using multi-layer radiative transfer calculations and then assess the climate implications, including its impact on the commencement, advance and distribution of Indian monsoon through model simulations.



Balloon Experiment: In order to quantify the absorbing aerosols in the free troposphere and its vertical profile, balloon borne experiments are planned from the high altitude balloon facility at TIFR, Hyderabad. In this connection, a commercially available Aethalometer is converted to a high altitude balloon payload, with necessary telemetry module and air sampling facility at lower pressures. The first flight was successfully conducted during March 2010.

Small satellites for atmospheric aerosols: Dedicated small satellites for measurement of aerosols over land and ocean, such as MAPI for multi-spectral and multi-angle measurements of polarized components of reflected radiation from the Earth having capability of aerosol retrieval. The sensor measures radiance at various spectral channels and at various angles and for the measurements of aerosol absorptions are being conceived.



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