Black Carbon Research Initiative

National Carbonaceous Aerosols Programme (NCAP)

Science Plan

EXECUTIVE SUMMARY

INCCA: INDIAN NETWORK FOR CLIMATE CHANGE ASSESSMENT

सत्यमेव जयते

Ministry of Environment & Forests, Ministry of Earth Sciences, Ministry of Science & Technology and Indian Space Research Organization

Government of India

March 2011

Cover Picutre:

1. Multi-Wavelength Radiometer (MWR) is an instrument to measures direct solar radiation at 10 different wavelengths. This is a stand-alone micro processor controlled instrument automated to track the Sun from Sun rise to Sun set. Analysis of MWR data can provide spectral opticals depths, which is a measure of aerosol loading in a cloud-free atmosphere

2. Wood Cook Stove

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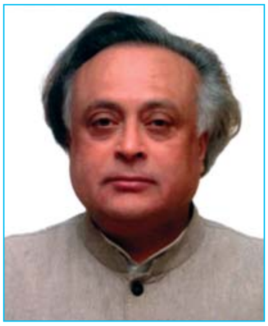
Foreword



I have great pleasure in introducing the document **'Black Carbon Research Initiative - Science Plan'** of the **National Carbonaceous Aerosols Programme** being devised under the aegis of the Indian Network of Climate Change Assessment (INCCA) that we launched last year. The issue of 'black carbon' and its relationship with climate change has gained enormous scientific and popular interest over the last few years. **India is well aware of the importance of the issue, and is committed to addressing it, based on sound scientific assessments.**

The knowledge and understanding on aspects such as vertical distribution and mixing of Black Carbon with other aerosols, effects of cloud cover and monsoon still remains uncertain and incomplete. There is thus a need to have better understanding on the following science questions:

- The contribution of black carbon aerosols to regional warming.
- Role of black carbon on atmospheric stability and the consequent effect on cloud formation and monsoon.
- Role of black carbon in altering the ability of hygroscopic aerosols to act as cloud condensation nuclei.
- Role of BC-Induced low-level temperature inversions and their role in formation of fog especially over northern India.
- Role of black carbon on Himalayan glacier retreat.

With the launch of INCCA in October 2009, I had announced a comprehensive study on Black carbon not only to enhance the knowledge and understanding of the role of Black carbon in the context of global warming but also to address the sources and impacts of the black carbon on melting of glaciers. I had emphasised on 3Ms as the approach – Measure, Model and Monitor.

The Black Carbon research initiative builds on this approach and sets out the science programme and to respond to the scientific questions. The science plan has been developed through an intensive consultative process and with the involvement of experts in the subject and builds upon the work of ISRO, MoES and other experts. The initiative is visualised as an ambitious programme with the involvement of over 101 institutions with 60 observatories nationwide.The study would lead to:

(a) Long-term monitoring of aerosols

(b) Monitoring of impact of BC on snow and

(c) Estimating magnitude of BC sources using inventory (bottom-up) and inverse modelling (top-down) approaches,

(d) Modelling BC atmospheric transport and climate impact.

I look forward to the implementation of the plan. I take this opportunity to thank Dr. J. Srinivasan, Indian Institute of Science for his perspective and my colleagues in the MoEF for their contributions for preparation of the programme.

Jairam Ramesh
Minister of State for Environment & Forests
(Independent Charge), Government of India

Acknowledgements

The Science Plan of the INCCA Black Carbon Research Initiative, National Carbonaceous Aerosols Programme is based on the contributions of J. Srinivasan (IISc), K Krishnamoorthy (SPL), S.K. Satheesh (IISc), A. Kulkarni (IISc), K.J. Ramesh (MoES) and C. Venkataraman (IITB) at the meetings organized by Ministry of Environment and Forests at New Delhi in August, 2010 and at Indian Institute of Science, Bangalore in October, 2010 to workout the details of the scientific programme. The contributions of the following scientists and experts on the draft plan have been noteworthy: M.L. Arrawatia (DST, Sikkim), Shiv Attri (IMD), M. Bhushan (IITB), M.K. Chaudhari (ARAI), Sunil Dhar (Govt PG College, Dharamsala), S.K. Dash (IITD), C.B.S. Dutt (NRSC), Ashwagosha Ganju (SASE), Amit Garg (IIMA), S. P. Gautam (CPCB), S. Ghosh (IITB), T. Gupta (IITK), G. Habib (IITD), Rajesh Joshi (GBPIHED), UC Kulshresta (JNU), R. Kumar (NEERI), M. Kumari (Dayalbagh Institute), J. C. Kuniyal (BPIHED), T. Mandal (NPL), P.R. Nair (SPL), Manish Naja (AIRES), K. Niranjan (AU), G. Philip (WIHG), S. Pushpavanam (IITM), S. Ramachandran (PRL), M.V. Ramana (IIST), K. Achuta Rao (IITD), C.V. Chalapati Rao (NEERI), P.S.P. Rao (IITM), P.D. Safai (IITM), M.M. Sarin (PRL), B. Sengupta (Ex-CPCB), V. Sethi (IITB), Chhemendra Sharma (NPL), Mukesh Sharma (IITK), O.P. Sharma (IITD), R. Sunderraman (IISER), S. Verma (IIT-KGP), Subodh Sharma (MoEF), Rita Chauhan (Natcom Cell, MoEF), Sudatta Ray (Ozone Cell, MoEF). Comments and suggestions by the Ministry of Earth Sciences, Ministry of Science & Technology and Indian Space Research Organization were very valuable.

Executive Summary

I. Background and the Context

Aerosols are suspended particulates in the atmosphere that can modify local climate through different mechanisms. Aerosols alter climate directly by modifying the radiative fluxes and indirectly through their ability to alter clouds. Among the various aerosol types, Black Carbon (BC) aerosols absorb solar radiation directly and hence influence earth's circulation and climate. Black carbon aerosols heat the atmosphere and hence their impact on climate is different from sulphate aerosols, which do not heat the atmosphere. Our understanding of the impact of aerosols on climate is not as good as our understanding of the impact of greenhouse gases (such as carbon dioxide) on climate. This is because radiative properties of aerosols vary widely and also have large temporal and spatial variations. In addition, there is a complex interaction between natural aerosols (such as dust and salt) with anthropogenic aerosols (such as black carbon, organic carbon and sulphate).

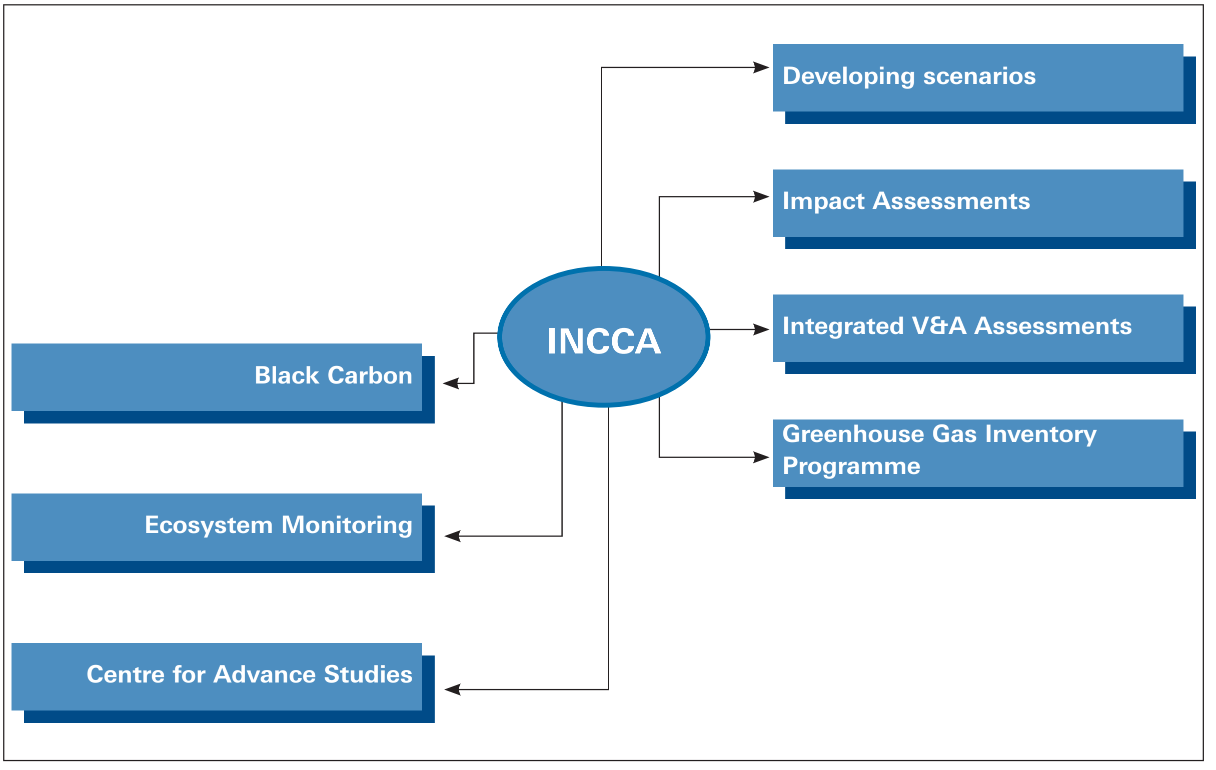
Black carbon is a byproduct of incomplete combustion of fossil fuels, biofuel, and biomass. Black carbon warms the atmosphere due to its absorption and reduces albedo when deposited on snow and ice. The lifetime of black carbon in the atmosphere is small (a few days to weeks) compared to CO_2, which has an atmospheric lifetime of more than 100 years. The sources of BC are fossil fuel, indoor burning of biomass for cooking and heating and outdoor burning of crop residues, savannas and forests. In biomass burning, both black carbon and organic carbon are released. Some of the organic carbons absorb solar radiation and amplify the BC warming while others scatter solar radiation and contribute to cooling. We need to understand how the three sources of black carbon influence our climate.

The largest sources of black carbon are Asia, Latin America and Africa. Some estimates indicate that China and India together account for 25-35% of global black carbon emissions. Over the Indian region, however, a decreasing trend in black carbon concentration has been reported. On a global basis, approximately 20% of black carbon is emitted from burning biofuels, 40% from fossil fuels, and 40% from open biomass burning. Black carbon sources vary by region. There have been several recent investigations, which revealed that deposition of aerosol black carbon on snow can reduce the snow albedo, leading to enhanced absorption of solar radiation and hence faster melting rates of glaciers. Several investigators believe that enhanced warming due to aerosol black carbon at higher levels is responsible for the faster melting of glaciers.

II. Indian Network for Climate Change Assessment (INCCA)

With a view to enhance knowledge about the impacts of climate change, the Minister for Environment and Forests announced the launch of the Indian Network for Climate Change Assessment (INCCA) on October 14, 2009. INCCA has been conceptualized as a Network-based Scientific Programme designed to (a) assess the drivers and implications of climate change through scientific research; (b) prepare climate change assessments once every two years (GHG estimations and impacts of climate change, associated vulnerabilities and adaptation); (c) develop decision support systems and (d) build capacity towards management of climate change related risks and opportunities.

The INCCA is visualized as a mechanism to create new institutions and engage existing knowledge institutions already working with the Ministry of Environment and Forests as well as other agencies.



Programmes envisaged under INCCA

III. Inventory Sources, Measurement and Modeling

An accurate knowledge of emissions from different sectors (e.g. thermal power, diesel transport, residential, agricultural residue burning) is needed for linking sources to atmospheric abundances. Carbonaceous aerosol emissions arise from energy use (vehicles, residential heating and cooking, small industry, power plants, shipping and oil flares) and the burning of forest, grasslands and agricultural residues. In addition, aerosols form as a result of atmospheric reactions of gases including sulphur dioxide, ammonia, nitrogen oxides and hydrocarbons. In the aerosol inventories, the level of detail currently available in India, in activity data and measurements of emission factors under actual field operation, is presently estimated to be medium (Tier II) in industrial sectors and low (Tier I) in rural sectors. This leads to large uncertainties in both magnitude of emissions and their correct attribution to sectors and sources. In addition, there is a need to harmonize the level of detail in inventories estimating long-lived and short-lived climate agents, to enable an accurate understanding of their relative magnitudes and effects.

Deducing the influence of a multitude of emission sources on atmospheric carbonaceous aerosols needs the integration of measurements with multiple modeling approaches. Aerosol measurements from a nationwide network representing regional background aerosols are more appropriate. Modeling of black carbon emission inventory for India and its climate impacts are focused mainly on four aspects: (a) Development of an Indian emission inventory for carbonaceous aerosols; (b) Understanding sources influencing carbonaceous aerosols through inverse Modeling approaches; (c) Understanding the regional atmospheric abundance of carbonaceous aerosols through Chemical

Transport Modeling and (d) Understanding the influence of carbonaceous aerosols on regional climate change and climate futures through General Circulation Modeling.

IV. Impact of Carbonaceous Aerosols

The response of earth's climate to perturbations by atmospheric aerosols and its importance on regional scales is not yet fully understood. The climate impact of aerosols are examined through General Circulation Model (GCM) simulations. The ability of GCM to accurately predict climate effects of short-lived agents like aerosols is influenced by: (i) simplified approximations of various phenomena, (ii) computational/numerical schemes used to solve the resulting complex systems and (iii) the ability to mitigate the effect of unknown/poorly-known inputs or parameters by efficiently integrating available measurement data. Modeling studies over the Indian region point to the large spatial and temporal variations in aerosol radiative forcing. Carbonaceous aerosol radiative forcing has also been derived from measurements.

In India, systematic investigations of the physical and chemical properties of aerosols, their temporal heterogeneities, spectral characteristics and size distribution have been carried out extensively since the 1980s at different distinct geographical regions as part of different national programmes such as the I-MAP (Indian Middle Atmosphere Programme), and later under the ISRO-GBP (Indian Space Research Organization's Geosphere Biosphere Programme).

During the I-MAP, a project was initiated to monitor the aerosol characteristics over the Indian region at few selected locations. This became operational in the late eighties and has been continued after the I-MAP as a part of the ACE (Aerosol Climatology and Effects) project of the ISRO-GBP. A national network called the ARFINET, of Multi-Wavelength Radiometers (MWR), Aethalometers (for measuring BC) and radiation instruments was set up under the ARFI (Aerosol Radiative Forcing over India) project of the ISRO-GBP, to facilitate long-term observations of aerosols over distinct geographical environments and to assess their impacts on regional climate forcing. ISRO is also pursuing a research campaign to understand the climate impacts of atmospheric aerosols over the Indo-Gangetic Plains for the past a few years under the RAWEX (Regional Aerosol Warming Experiment) component of the ARFI project. The ISRO-GBP annual review meeting in 1998 recognized the importance of BC aerosols on the climate system and it was decided to pursue studies of BC in subsequent years. Many international and national field experiments and campaigns have provided vital information on the optical, physical as well as chemical properties of aerosols. These measurements are limited to a certain periods or locations. In this perspective, long-term experiments at different locations have the added advantage of understanding aerosol influences on a longer time scale. A sufficiently long time series can also help us to understand the impact of aerosols on climate change.

V. Need for Enhancing Understanding

Given this background, it is imperative that measurements of aerosols from ground, aircraft and space are performed carefully to answer crucial questions related to climate change with emphasis on black carbon. These measurements are valuable inputs to climate models for impact assessment. A national effort should focus on the following objectives and approaches.

Objectives and Approaches

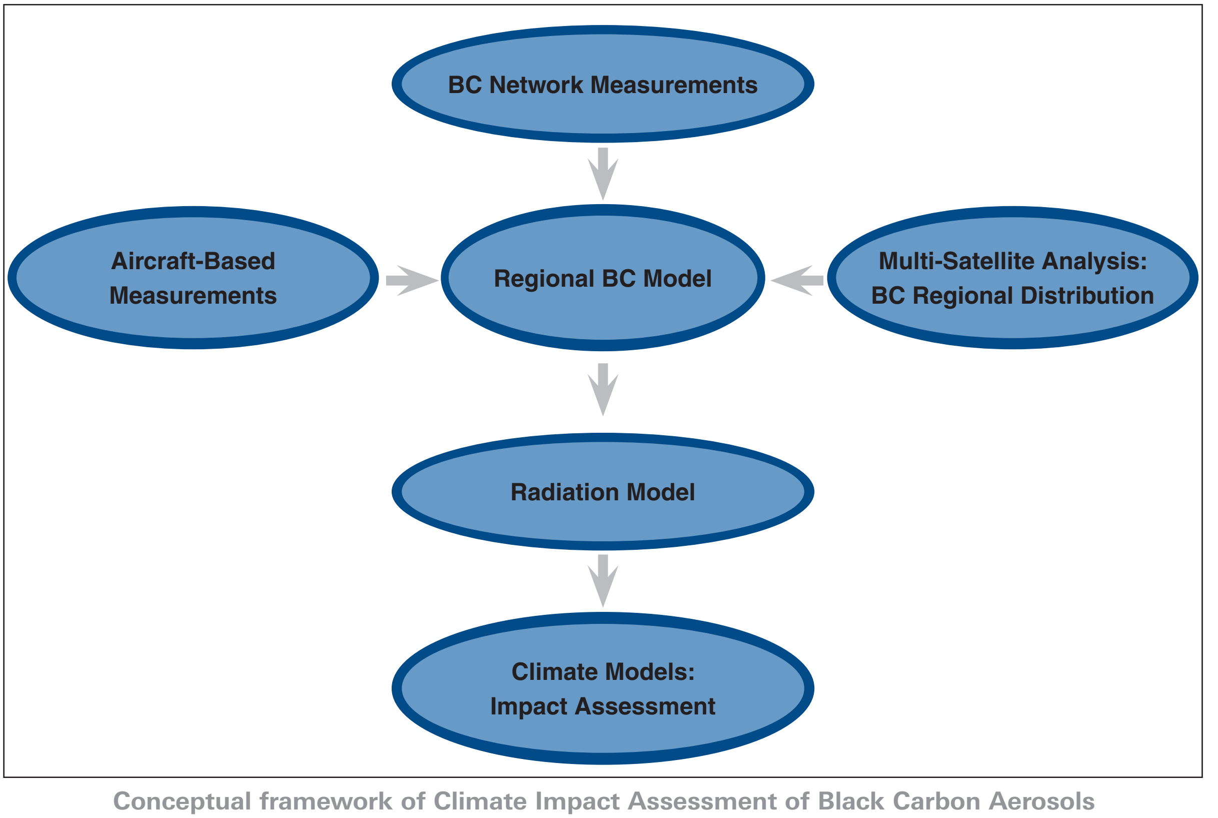
The science plan and the approach of the research initiative include:

- Long-term monitoring of aerosols;
- Assessment of impact of aerosols on Himalayan glaciers;
- Modeling of black carbon emissions inventory over India.
    - Development of an Indian emission inventory for carbonaceous aerosols.

- Identify the sources influencing carbonaceous aerosols through inverse Modeling approaches.
- Quantify the regional atmospheric abundance of carbonaceous aerosols through Chemical Transport Modeling.
- Understanding the influence of carbonaceous aerosols on regional climate change and climate futures through General Circulation Modeling

To understand the impact of dust and black carbon on glaciers there is a need to understand influence of mineral dust and black carbon on Himalayan seasonal snow cover and glacier. Further, there is a need to model effect of mineral and carbon dust on snow/glacier albedo, snow melt, glacier mass balance, glacier retreat and snow/glacier melt runoff. Atmospheric aerosol samples will be collected near glaciated valleys and also around seasonal snowfields to understand the proportion of mineral dust and black carbon. In addition, samples of seasonal snow, accumulation area and ablation area of glacier to understand the proportion of mineral dust and carbon dust also will be collected. Subsequently, the effect of black carbon and mineral dust on snow and ice albedo will be estimated using field and laboratory observations. An algorithm to monitor snow and glacier albedo using satellite data will be developed and snow/glacier algorithm will be validated.

The ISRO-GBP is maintaining 37 surface observatories covering representative locations in India. All these sites have BC measurements. The duration of data available from these sites varies with the location, depending on the start date of measurements at each location. In addition, there have been a few field campaigns (LC) such as ISRO-GBP's LC-I, LC-II and ICARB (Integrated Campaign for Aerosols, gases and Radiation Budget). Thus, we have information



Conceptual framework of Climate Impact Assessment of Black Carbon Aerosols

on the spatial and seasonal variation of BC at the Earth's surface. ICARB's aircraft segment carried out a few measurements of altitude profiles of BC aerosols. It appears that what we don't know about aerosol BC is much more than what we know. Major topics which need immediate attention are: (a) vertical distribution of BC (b) state of mixing of BC with other aerosols (c) effect of BC on cloud cover (d) impact of mitigation of BC aerosols and (e) effect of BC on the monsoon. The major objective of network sites is to monitor key aerosol parameters by establishing long-term monitoring stations. Already existing networks such as the Aerosol Radiative Forcing over India (ARFI) network of ISRO will be utilized for this purpose. A hybrid approach, which involves field experiments including network measurements as well as aircraft-based field measurements simultaneous with multi-satellite analyses is essential for the assessment of the impact of black carbon on Indian climate. Combining measurements with multi-satellite data can create synergy to the benefit of each other.

Establishment of a network of aethalometers (60 Nos) (which measure black carbon) over the entire Indian region is envisaged. Each instrument will be automated and transmit data to a common data centre. Measurements are proposed to continue for 5 years. Maps of BC as well as its optical properties over entire India can be constructed starting from the third year. The programme builds on available BC networks established by other departments such as Department of Space (DOS) and Ministry of Earth Sciences (MoES) to increase the spatial resolution of the network.

Deployment of about 20 Multi-Wavelength LIDAR by dividing the entire Indian region into zones based on aerosol sources is envisaged. Polarized back-scatter signals will be used to

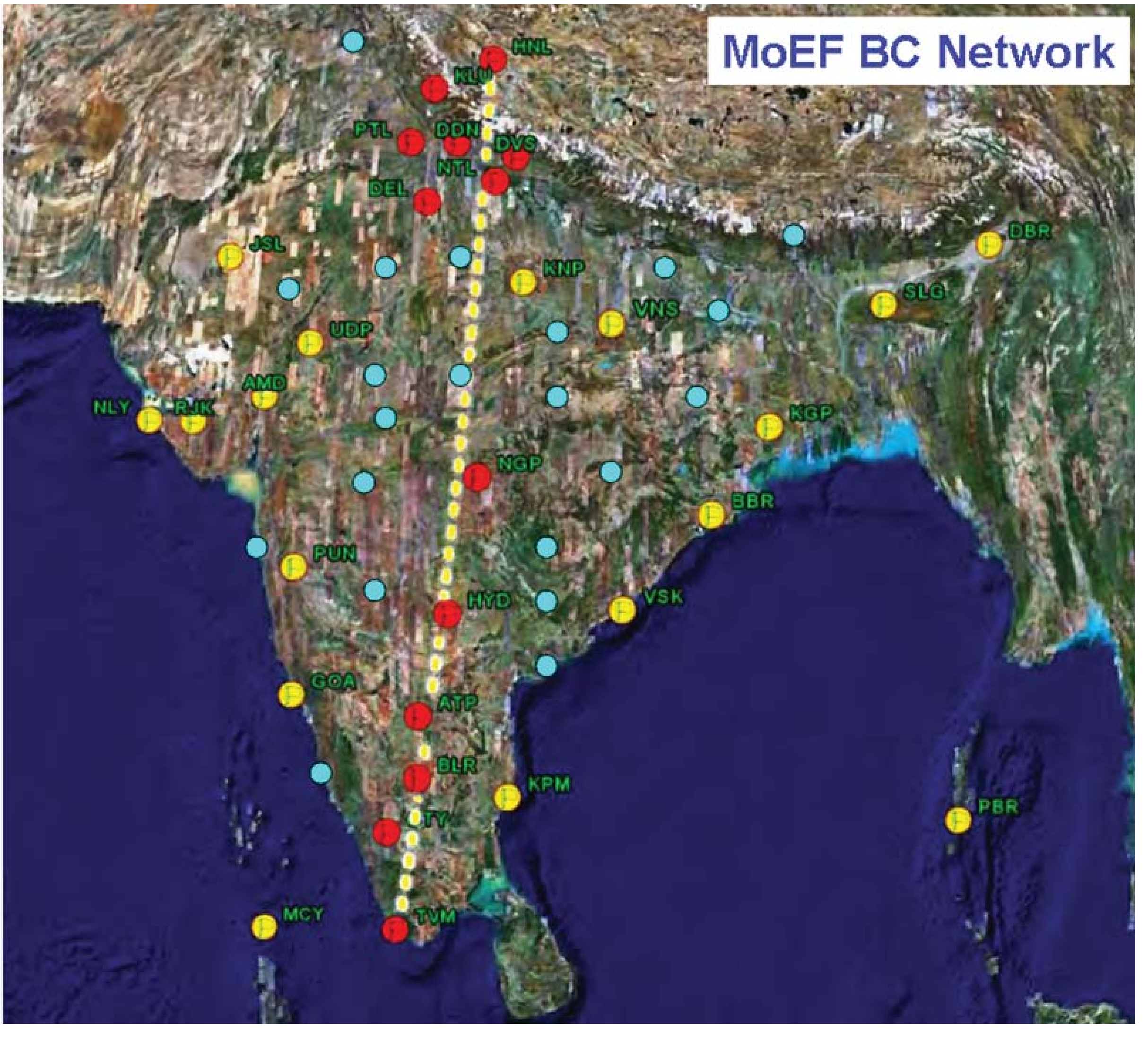
Instruments used for observation and Measurements

obtain BC properties. Mobile facility with a suite of instruments is intended to make concurrent measurements of climate-sensitive aerosol parameters from distinct environments, hot spots and source regions in a campaign mode.

VI. Programme design and Implementation

The programme is visualized as a multi-institutional and multi-agency project. The four major departments associated with the studies include the Ministry of Environment & Forests, Ministry of Earth Sciences, Indian Space Research Organization, Ministry of Science and Technology and the associated agencies. The other institutions identified include the universities, research institutions, premier scientific establishments, colleges and non-governmental agencies to undertake the work on various components of the programme which principally consists of aerosol observations and modeling of the impacts of carbonaceous aerosols (black carbon).

Each of the associated partners will participate in the project activities and perform roles assigned to them and will essentially serve as Lead Institutions, Associated Institutions and Outreach Institutions. While each institution will work in its domain area, some of the institutions will perform



Proposed MoEF network (tentative map) superimposed over the existing ARFI network

functions as assigned to them as lead, associated or as an outreach entity. For example, the lead institution will coordinate the activities of the associated institutions, whereas the associated institutions shall be engaged in observations and analysis.

The project implementation will be overseen by an Apex Steering Committee located at the Ministry of Environment and Forests, with representatives from the Ministry of Environment & Forests, Ministry of Earth Sciences, Ministry of Science and Technology, Indian Space Research Organization and other members drawn from the scientific community.

A Scientific Programme Coordination Committee (SPCC) will monitor the project and suggest any course corrections. The SPCC will supervise the overall science. There will be three Working Groups (WG) for observation, Modeling and glaciers respectively. Major responsibilities such as aerosol monitoring (network observations), glacier studies, and modeling will be assigned to these three working groups. Each working group will have five to seven members.

The MoEF will undertake the administrative coordination of the entire project, whereas the Indian Institute of Science shall be responsible for scientific coordination. The Indian Institute of Science shall establish a coordination cell with appropriate personnel and shall be responsible for the coordination and implementation of the scientific activities among the various participating institutions.

The major expected outcomes are :

(a) Understanding the effect of change in albedo due to black carbon on seasonal snow and glacier melt.

(b) Estimation of albedo and reflectance of seasonal snow and glacier, glacier depth and mass balance, using airborne sensors like laser altimeter, ground penetrating radar and pyranometer.

(c) Modeling effect of enhanced melting on glacier mass balance and retreat.

(d) Development of snow/glacier melt runoff models to understand the influence of changes in snow and glacier melt pattern.

Conceptual Framework for the Implementation and Coordination the Science Programme

Institutions identified for the programme

Ministries/ Departments

1. Ministry of Environment and Forests, Government of India
2. Indian Space Research Organization, Department of Space, Government of India
3. Department of Science and Technology, Government of India
4. Ministry of Earth Sciences, Government of India
5. Council for Scientific and Industrial Research, Government of India

Lead Institutions

6. Andhra University, Visakhapatnam.
7. Aryabhatta Research Institute for Observational Sciences (ARIES), Nainital.
8. Divecha Centre for Climate Change, Indian Institute of Science, Bangalore.
9. Indian Institute of Management, Ahmedabad
10. Indian Institute of Technology, Delhi
11. Indian Institute of Technology, Kanpur
12. Indian Institute of Technology, Mumbai
13. Indian Institute of Tropical Meteorology, Pune.
14. National Physical Laboratory, New Delhi
15. National Remote Sensing Centre, Hyderabad
16. Physical Research Laboratory, Ahmedabad.
17. Snow and Avalanche Study Establishment (SASE), Chandigarh.
18. Space Physics Laboratory, VSSC, ISRO, Thiruvananthapuram.

Associated Institutions

19. Banaras Hindu University,Varanasi
20. Birla Institute of Scientific Research (BISR), Jaipur
21. Birla Institute of Technology, Mesra
22. Birla Institute of Technology, Ranchi
23. Central Arid Zone Research Institute, CAZRI
24. Centre for Development of Advanced Computing, Pune
25. Cochin University of Science And Technology (CUSAT), Kerala

26. Computational Research Laboratory, Pune
27. Dayalbagh University, Agra
28. Dibrugarh University, Dibrugarh
29. GB Pant Institute of Himalayan Environment and Development, Almora
30. Geological Survey of India, Kolkata
31. Goa University, Goa
32. Himachal Pradesh Remote Sensing Cell, Shimla
33. Hindustan University, Kelambakkom, Chennai
34. India Airforce, Nalia
35. Indian Automotive Research institute, Pune
36. Indian institute of astrophysics, Hanle
37. Indian Institute of Remote Sensing, Dehradun
38. Indian Institute of Science Education and Research, Bhopal
39. Indian Institute of Space Science and Technology (IIST), Thiruvananthapuram
40. Indian Institute of Technology, Chennai
41. Indian Institute of Technology, Indore
42. Indian Institute of Technology, Kharagpur
43. Indian Institute of Technology, Roorkee
44. Indian Meteorological Department, Minicoy
45. Indian Meteorological Department, New Delhi
46. Indian Space Research Organisation, Bangalore
47. Indian Statistical Institute, New Delhi
48. Institute of Minerals Materials Technology (IMMT),Bhubeneswar
49. International Management Institute, Kolkata
50. ISTRAC, Port Blair
51. Jawahar Lal Nehru University, New Delhi
52. Maulana Azad National Institute of Technology, Bhopal
53. National Remote Sensing Centre, Hyderabad
54. North Eastern Space Application Centre (NESAC), Shillong
55. Patiala University, Patiala.
56. Regional Remote Sensing Service Centres , Kharagpur
57. Regional Remote Sensing Service Centres, Nagpur
58. School of Planning and Architecture, Bhopal
59. Shri Krishnadevarya University, Anantapur
60. Sikkim State Council of Science & Technology, Department of Science & Technolgy and Climate Change

61. Space Applications Centre (SAC), Ahmedabad.
62. Tata Institute of Fundamental Research, National Balloon Facility, Hyderabad
63. Wadia Institute of Himalayan Geology, Dehradun

Outreach Institutions

64. Ahmednagar College, Maharashtra
65. B.R. Ambedkar University, Agra
66. Deen Dayal Upadhyay Gorakhpur University, Gorakhpur
67. Gogte-Joglekar College, Ratnagiri, Maharashtra
68. Hemwati Nandan Bahuguna Garwal University
69. Jammu University, Jammu
70. Kannur University, Kerala
71. Karnataka University, Dharwad.
72. Kashmir University, Srinagar
73. Kokan Krushi Vidyapith, Raigarh, Maharashtra
74. Krishna University, Machilpatnam
75. Manipal University, Imphal
76. Maulana Azad National Institute of Technology and SPA, Bhopal
77. Mohan Lal Sukhadia University, Jaisalmer
78. Mohan Lal Sukhadia University, Udaipur
79. Motilal Nehru National Institute of Technology, Allahabad
80. National Environmental Engineering Research Institute
81. National Institute of Technology, Raipur
82. National Institute of Technology, Warangal
83. NTR University, Vijayawada
84. Oil and Natural Gas Corporation, Mumbai
85. Patna University, Patna
86. Rani Durgavati Viswavidyalaya, Jabalpur
87. Rubber Research Institute, Kottayam, Kerala
88. Saurashtra University, Rajkot
89. Sharda University, Grater Noida
90. Sikkim University, Sikkim
91. Simla University, Dharamsala
92. Solapur University, Solapur
93. SRM University, Chennai
94. Tamil Nadu Agricultural University, Ooty

95. Tripura University, Agarthala
96. University of Allahabad; National Institute of Technology, Allahabad
97. University of Kashmir, Srinagar
98. University of Mangalore, Mangalore
99. University of North Bengal, Darjeeling/Siliguri.
100. Vikram University, Ujjain
101. Yogi Vemana University, Kadappa

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