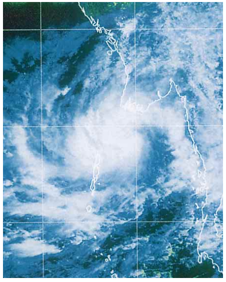


CHAPTER XIII

# India and the Global Climate Change

At the outset, it is important to point out that global change is more than climate change and concerns the functioning of the entire earth system which consists of solid earth, oceans, cryosphere and atmosphere. The emphasis now is on the changing earth in all its components. This write-up deals with only atmospheric science, the other areas are covered elsewhere.

## The "Upper Atmosphere" by S.K. Mitra

Global change science began in India with the publication of the book *The Upper Atmosphere* by S.K. Mitra in 1947. He considered, for the first time, the atmospheric environment as a whole-neutral and ionized - its thermal structure and distribution of constituents, its motions, the interaction of the solar radiation and the particle streams from the sun with these constituents. He also considered the atmosphere from the surface to the fringe of the upper atmosphere.

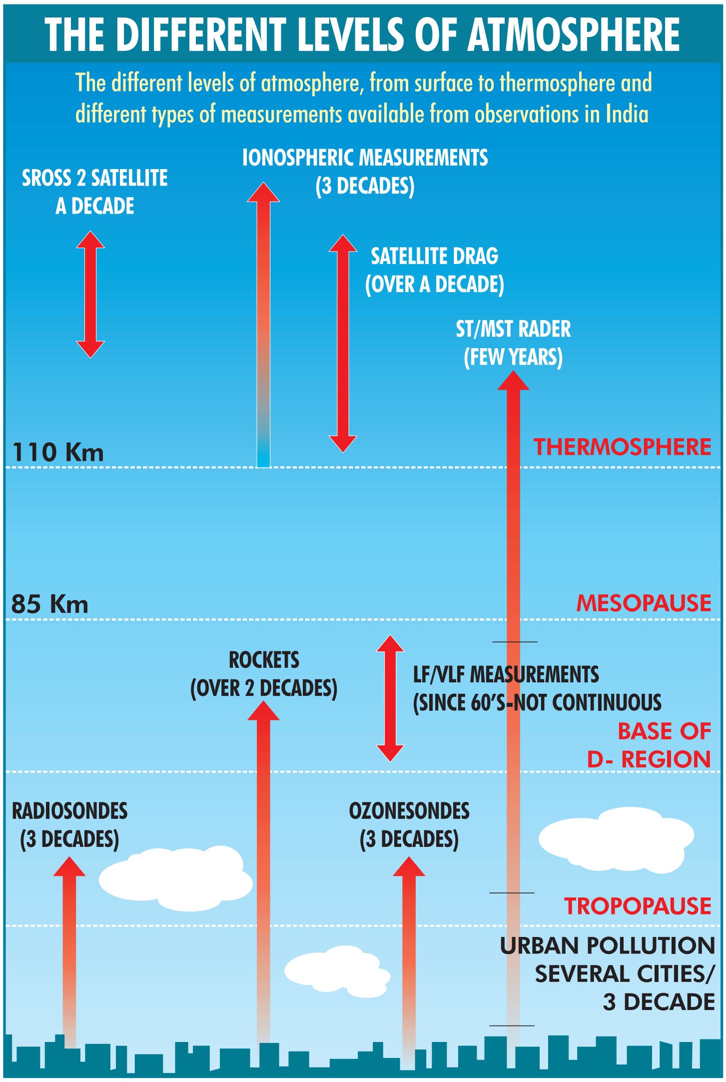
## The International Geophysical Year

The next major milestone was the International Geophysical Year (IGY) which was started on July 1, 1957, and continued in an extended capacity through IGC (International Geophysical Cooperation) till December 31, 1959. It marked a watershed in the Indian scientific research on the study of our planet and the sun. Coordinated national efforts under the framework of controlled intercomparison under specified conditions were perhaps introduced for the first time. It brought a revolution in Indian science in several areas: in ionosphere, in cosmic rays, in geomagnetism, in solar physics, in meteorology and in several related areas of earth sciences. This was also the occasion for first organized entry of Indian science in the inter-national arena. New information emerged on the role of solar radiation -- both electromagnetic and particles on the earth's atmosphere.

Of direct interest or relevance to the present scenario of global change was the preparation of the Standard Atmosphere for Tropics developed as early as 1979. This included a *reverse lapse rate* (i.e. increase in temperature) above the tropopause rather than an isothermal atmospheric stratosphere. The considerably higher tropopause level observed was also included.

The important roles played by minor species for climatic changes had not yet been recognized. However, three particular minor species were even then considered to be of significance: water vapour, ozone and carbon dioxide.

For ozone the question of large scale global changes through human activities had not yet been brought up. Dobson spectrophotometers provided values of total ozone and this could be directly used: profiles could be and were indeed derived from Umkehr method. Some results even at that time caused surprise. One was the existence of low ozone content at equatorial latitudes -- some of us called it the *Natural Ozone Hole* at latitudes where production is the largest. Large day-to-day fluctuations in ozone content were noticed; the




largest fluctuations were in January to March believed to be associated with westerly disturbances. Another interesting result was the low ozone values for the Indian stations as compared to Japanese stations with nearly the same latitudes.

The third minor constituent on which some attention was given during the IGY was carbon dioxide ($CO_2$). It was already known that the atmospheric $CO_2$ content had been continually rising due to increasing use of fossil fuels (a problem that is now taken to be one of the most serious threats to climate stability). The IGY-time atmosphere contained approximately 315 ppm of $CO_2$ with an annual increase of about 0.7 ppm although fossil fuel combustion added annually 1.6 ppm of $CO_2$.

## Human Activities and Space Environment

In the 1970's, there was already increasing global concern about the nature and extent of human effects on our environment. The controversy centred around: (a) the $CO_2$ problem and (b) the ozone problem. While these two were the main centres of public interest, it was pointed out that there are other possible sources of environmental hazard. Examples are the inadvertent heating of the ionospehre by high power HF radio transmitters; ionospheric holes produced by spacecrafts effluents, and ionospheric modification by the then proposed Solar Power Satellite Launch Vehicles (SSLVs).

In a monograph brought out in 1982 (by the National Physical Laboratory, New Delhi) the question of human activities was reflected in a more comprehensive way, covering the entire atmospheric environment, the canvas extending from the surface to about 1000 km. Three broad levels were considered:

a The Tropospheric Level where the principal anthropogenic sources are carbon dioxide and aerosols (the role of $CH_4$ and $N_2O$ were to be added later),

b The Stratospheric Level where the principal problem was the question of ozone depletion (the ozone hole was yet to be discovered), and

c The Ionospheric Level where high power transmitters and spacecraft effluents inadvertently modify the ionosphere.

Important points noted are the following:

i In the tropical areas the tropopause level is higher (at Thiruvananthapuram around 16 km) in contrast with level of about 8 km at mid-latitudes.

ii In the troposphere there is complete mixing. Consequently, chemically inactive constituents will be completely mixed in the atmosphere and are eventually washed out by rain. Photodissociation is effective in most cases only when the injected material is lifted up in the stratosphere, as with CFMs -- the most important man-made ozone depleting source.

iii Ozone lifetime is a few days near the ground, a few weeks in the stratosphere, but a few hours or fraction of hours at heights above 60 km. Thus short term changes in ozone at lower heights essentially local and a result of dynamics.

Several important points, relevant to India emerged. For the hypsithermal period (4000-8000 years ago), when the world as a whole was warmer by about 3°C, much of India, especially southern part in an estimate by Kellogg (1979) was wetter. Analysis for the last 50 years, for which the Northern Hemispheric warming averaged about 50°C Kellogg's prediction was of cooling over Japan and much of India.

Reference ozone atmosphere over India as well as reference profiles of minor constituents were formulated. It was noted that Indians (whether in India or domiciled in other parts of Asia and in Africa) have a very low melanomic rate (only about 1/10th of the Caucasians).

A totally new perspective was the recognition of the role that ions could play not only in the region of the middle and the upper Ionosphere, but even in the troposphere and stratosphere. This early work of extending investigations of effects of human activities to the middle atmosphere has been continued, in particular by Indian Institute of Tropical Meteorology (Pune) and the National Physical Laboratory, leading on to joint international efforts (as a part of IUGG) on changes in middle and upper atmosphere.

On the thermal structure model calculations showed cooling in the upper stratosphere, mesosphere and thermosphere. Daily radiosonde data for the troposphere and stratosphere and temperature profiles determined from weekly rocket flights from Thumba to heights of 70 km revealed that warming in the lower atmosphere has taken place over India from 1963 to 1997, whereas the stratosphere and lower mesosphere have undergone cooling. Modeling suggests that other changes may also have occurred. An increase in water vapour and decrease in NO in the mesosphere and thermosphere is most probable. Ion composition is also likely to change in the middle atmosphere with implications for a number of atmospheric processes. The models also suggest the mesosphere may become wetter and cooler.

Serious studies to examine global change signals in the middle and upper atmosphere require availability of consistent and continuous series of data on temperature, density and composition (neutral atmosphere) and of ion density and ion composition (for Ionosphere). Fortunately, over the five decades covered under this article, an exhaustive series of data have become available.

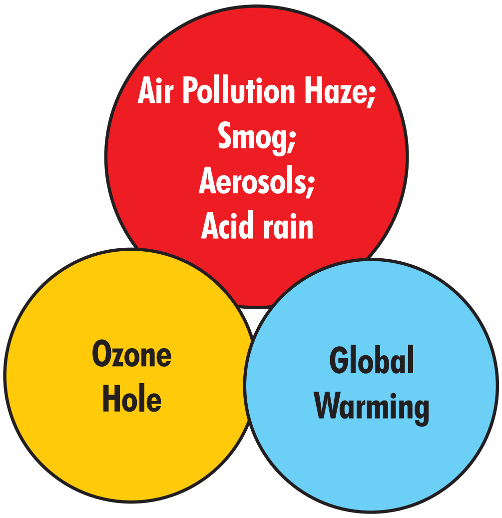
## The Indian Middle Atmosphere Programme

The next major event was the undertaking in India of an extensive programme covering the atmospheric region from surface to 120 km as a part of the International Middle Atmosphere Programme.

It was the largest programme undertaken in India under an International umbrella after the first major effort in IGY. Indian interest in this programme arose from several excellent facilities that existed and the interest regarding the role of the middle atmosphere in monsoon circulation and atmospheric chemistry. Some special aspects are outlined below :

- Accessibility to 3 rocket ranges: Thumba (90°N), SHAR (140°N) and Balasore (21°N).
- Availability of a national balloon launching facility at Hyderabad.
- A dense network of radiosonde stations operated by the India Meteorology Department (IMD) and its continuing operation of key experiments: (a) Ozone measurements with Dobson spectrophotometer and balloon-borne sensors, and (b) atmospheric turbidity measurements in 10 stations.

**A NEW SCENARIO IN WHICH OZONE CHANGES, URBAN POLLUTION & GLOBAL WARMING ARE INTERLINKED**




- Development of new facilities.
  Meteor Radar at Thumba
  Lidar at Thumba
  Laser heterodyning facilities at Delhi.

The Indian Programme that was organized involved the participation of some 200 scientists operating in stations spread over India with direct involvement of seven science agencies, several National Research Institutions and 11 Universities. A major fallout was the undertaking of an MST Radar as a national facility.

A major aim was to evolve a first order reference middle atmosphere over India. This was achieved.

Regarding the neutral middle atmosphere, a revised International Tropical Reference Atmosphere up to 80 km was proposed and later extended to 1000 km. For minor species, constituents examined included: ozone (fairly extensive), water vapour, methane, $N_2O$, CFCS (limited). On minor constituents, measurements of ozone were the most comprehensive and involved essentially all known techniques excepting satellite-borne measurements.

Some interesting findings emerged:

i the larger-than-predicted night/day ratios in ozone at all heights above 27km; night values being higher up to 60 km,

ii height-dependence of changes in ozone during a solar eclipse (16 February, 1980): decrease below 25 km, no perceptible changes between 25 and 35 km, and increase above 35 km,

iii the higher altitude of ozone peak concentration at Thiruvananthapuram (27 km) than in Hyderabad (24 km),

iv Anomalies associated with cloud cover or passing weather disturbances: bulges of increased values in the range of 800 to 500 mb and fluctuation patterns in ozone profiles with depleted values in 500-100 mb range,

v Large depletion in ozone between 10-22 km in the Indian Antarctic station *Dakshin Gangotri* (70°S, 11°E), located in the fringe of the 'Containment Vessel'.

In one of the rocket flights there was evidence of increase in ozone around 5 km during a storm with lightning discharges.

For other species ($CFCl_3$, $CF_2Cl_2$, $CCl_2FCClF_2$, $CBrC1F_2$) there was only one set of balloon-borne measurements conducted over Hyderabad in 1985 with a cryogenic gas sampling arrangement as a joint effort of Max Planck Institute for Aeronomie at Lindau and the Physical Research Laboratory at Ahmedabad. It was noted that the decrease in concentration started at an altitude higher than in mid-latitudes and also the rate of decrease was slower.

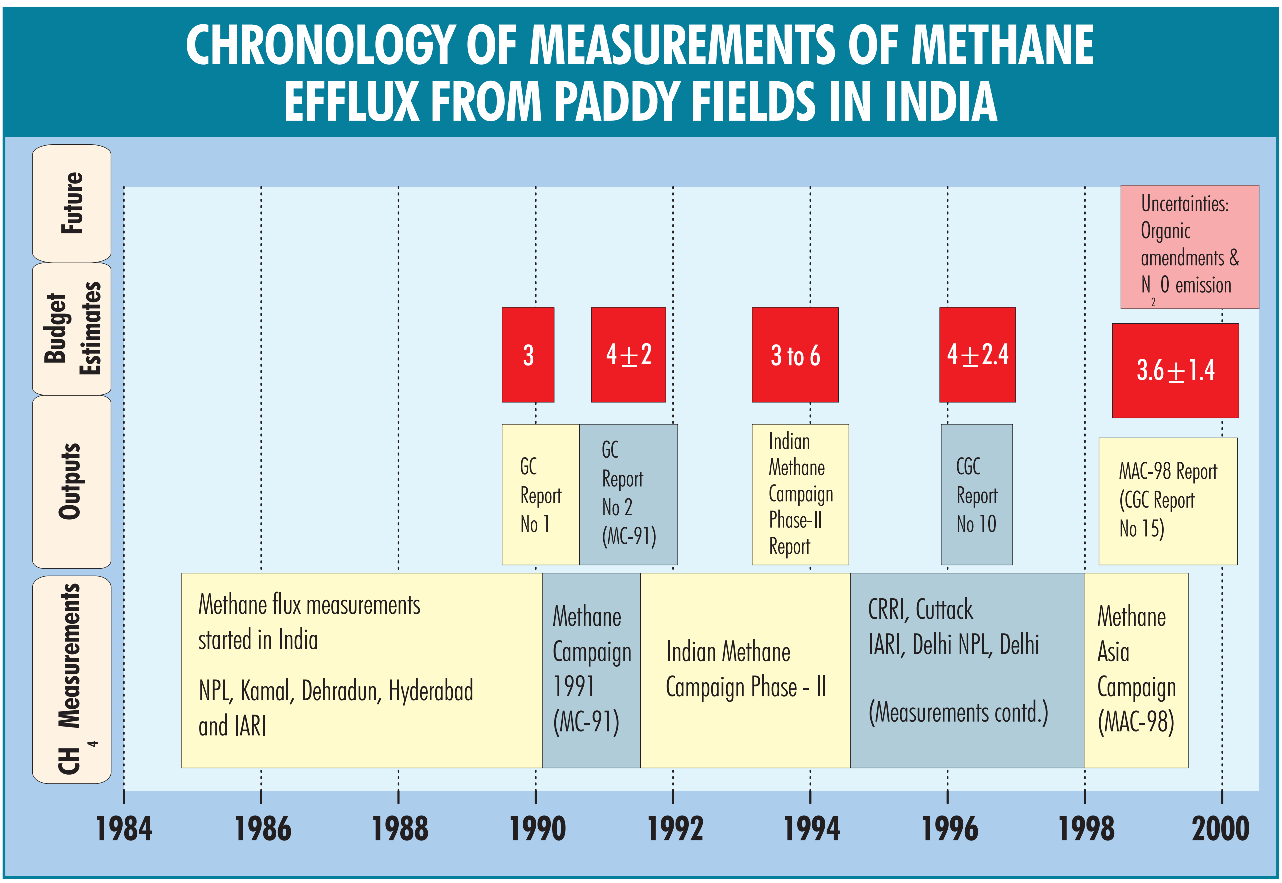
## Methane Emission from Paddy Fields: An Exciting Study

In the early 90s just before the First Assessment Report of the Intergovernmental Panel for Climate Change was to be released, a new effort was mounted that changed radically the view of methane emission from paddy fields, from India in particular but also globally.

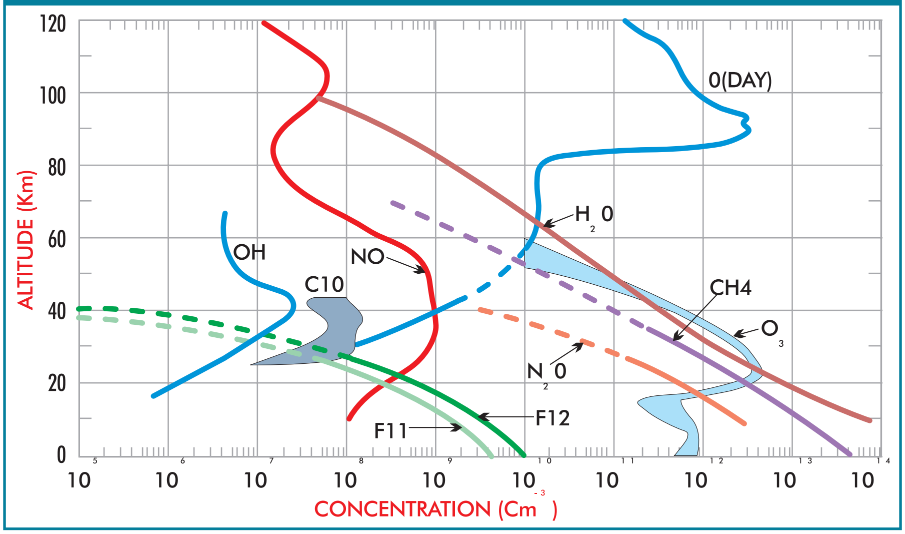
Earlier, in the absence of adequate $CH_4$ emission data from India, the US-EPA estimate for India was 37.8 tg $CH_4$ per year. This was based on data collected from experimental paddy fields in

Europe and America and extrapolated for the Indian region. However, measurements undertaken by National Physical Laboratory on $CH_4$ afflux, conducted later, yielded a value of 3 tg $CH_4$ per year which was based on a few actual field measurements made during the period 1985 to 1990 at selected rice growing regions in the country. This budget was not based on measurements carried out over a full cropping season and did not reflect fully the $CH_4$ flux from major rice growing regions in the country. Therefore, to have a more reliable budget estimate a $CH_4$ measurement campaign was launched in 1991 to cover the gap. During this campaign care was taken to generate internationally compatible data which were better calibrated nationally as well as internationally. Also stress was given on measurements over the whole cropping period from all water logged paddy areas in the country (as these were expected to emit maximum $CH_4$). It was seen that the rain fed waterlogged and deep/semi deep category of paddy fields which together constitute 41% of the total harvested area are a source of 94% of the total $CH_4$ emitted from all harvested water regimes whereas in comparison the upland and irrigated areas (53% of total harvested area) have negligible contribution. Maximum $CH_4$ budget estimated was around 6 tg/yr and the minimum around 2.5 tg/yr from the Indian paddy fields. The mean was around 4.0 tg/yr -about 1/10th of the value suggested by US-EPA.

The lower value for India indicated that the global value may also be considerably lower than the estimated around 100 tg $CH_4\,yr^{-1}$. Meanwhile measurements in other countries in Asia (Philippines, China, Thailand, Vietnam etc.) also indicated lower values. NPL and ICAR continued the measurements to reduce uncertainties, identify key factors controlling the emissions and the role of



**PROFILES OF IMPORTANT MINOR SPECIES OBTAINED DURING IMAP**




organic amendments and nature of cultivars. It was primarily the Indian efforts that led to the revision of IPCC methodology in 1996.

## New International Efforts: ALGAS and INDOEX

A new look on the changing atmosphere became possible from several international efforts organized recently. These include: Indian Ocean Experiment (INDOEX) and ALGAS.

ALGAS was a 2-year programme covering 12 countries in the Asian region -- Bangladesh, China, India, Indonesia, Republic of Korea, Mongolia, Myanmar, Pakistan, Philippines, Thailand and Vietnam. These represent 51% of the global population. The objective was to generate an inventory of long-lived greenhouse gases for these 11 countries for the year 1990 , following internationally laid guidelines, provide baseline projections for 2020, identify mitigation strategies and define least cost options. Although the total emission from this region is only 3% of the global emission, its growth rate is high -- 6% for India, 8% for Bangladesh and 10 % for Pakistan. Unlike other regions emissions from agricultural sources can dominate. Emissions from agricultural sources in terms of $CO_2$ equivalent is 50 % of emissions from energy and industry for India, 126% for Bangladesh, 62% for Pakistan and 325% for Sri Lanka. For the subcontinent as a whole the ratio is 55 %. For energy production 65% of $CO_2$ emission from fossil fuels come from coal in the case of India and 70% in case of China. The quantities consumed have increased by a factor of 4.5 for India from 1970 to 1997 and by a factor of 2.6 in case of China from 1973 to 1996.

ALGAS concentrated mainly on greenhouse gases $CO_2$, $CH_4$, $N_2O$ because of the requirements of UNFCCC but nevertheless also provided data on CO and NOx from some sectors. No estimates were made of aerosols.

INDOEX, on the other hand, concentrated primarily on aerosols and the resultant radiative forcing covering the western part of the ALGAS region. In addition there were measurements also of CO, NOx and ozone. Thus information provided by the two are in some senses complementary.

INDOEX was an extensive international programme, involving several hundred scientists from the USA, Europe, India and the island countries -- Maldives, Mauritius and Reunion. Aerosol cooling or heating (from aerosols such as sulphates, soot, organic carbon, mineral dust) has a large element of uncertainty (especially in the indirect component) and complicates our understanding of the combined impact of increasing GHGs and aerosols. In addition, in the developing South, East and South East Asia, aerosol emissions from a variety of sources (fossil fuel, biomass burning, etc.) are increasing at a rate faster than those of greenhouse gases.

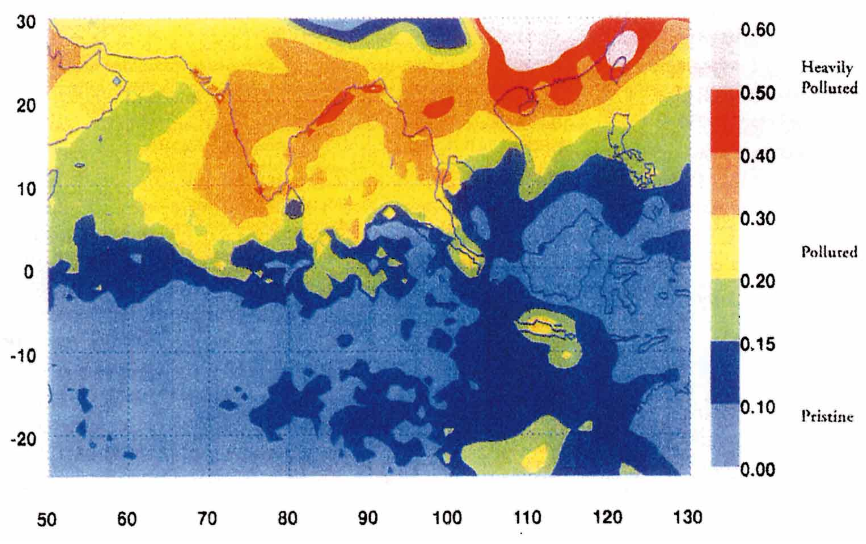
INDOEX addressed this question by focussing on a region in the Arabian Sea and the Indian Ocean during January to March -- at a time when the 'polluted' air from the Indian subcontinent and the pristine air masses from southern Indian Ocean meet over the tropical Indian Ocean at latitudes between 0° and 15°S.

Indian contributions were critical -- through own experimental arrangements in groundbased stations (Delhi, Mount Abu, Pune, Ahmedabad, Thiruvananthapuram, Vishakapatnam, Mysore, Minicoy, and Mauritius), on board *R.V. Sagar Kanya* and the use of INSAT and IRS P3 satellites. In addition, the Universities of Goa and Dharwar collaborated with French efforts in launching constant pressure balloons from Goa (totalling 19 flights during IFB 1999), and groundbased observations on aerosols and ozone in Dharwar and Goa. MST Radar operating in Gadanki alongwith a Lidar and LAWP was also operated in a campaign mode. Three lidars were available at Mount Abu, Pune and Thiruvananthapuram. There was also a special campaign on biomass burning of shifting cultivation in one of the hilly northern parts of Andhra Pradesh -- Eastern Ghat. A specially set-up group on weather forecasting provided daily weather forecasts and trajectory information that proved valuable for the entire operation. Experiments on board *Sagar Kanya* were made in four consecutive years 1996 –1999, with cruise paths, covering the region of interest and providing an insight into the variability in ocean and atmospheric parameters .

When observed data were integrated with data from satellites and climate models, an extensive haze layer was discovered -- called the 'Great Asian Haze'. A part of the aerosol consisted of black carbon (soot), arising from incomplete combustion of biomass and fossil fuels. These are absorbing aerosols and reduce significantly the solar energy reaching the earth's surface and the oceans.

INDOEX coverage was limited to the Indian subcontinent and the surrounding oceans and was also focussed on the period January to March when the wind is predominantly southwards. Transport to long distances of pollutant plume originating from the Indian landmass brings in a new parameter : the question of transboundary pollutant transport. INDOEX data suggest that soot particles, sometimes lodged in submicron sulphate and organic aerosols, travel long distances. This is, however, not unique to the Indian or the Asian region. African dust storms have been seen to spread over the Atlantic to the Eastern coast of the United States. Asian pollutants have been observed to reach northwestern USA across the Pacific Ocean. Plumes generated in the USA and Europe are also known to travel far. Haze cloud originating from

**The Great Asian Haze**
*INDOEX Data for Jan-Mar 1999*




***The regional map of aerosol column amount. The valves over ocean are retrieved from satellite data and over land are estimated using a 3-diamensional model.***

Indonesian forest fires have caused health concerns in the neighboring countries, and have caused the creation of a special study group in East Asia.

What is special, however, is (a) the absorbing nature of the haze cloud, arising from a large presence of black carbon, (b) relatively low values of tropospheric ozone even in the polluted region indicating that NOx concentrations in this region are still low, and (c) model calculations showing possible impact of such aerosol cloud in modifying ozone concentrations in distant regions (e.g. Europe) if the aerosol emissions continue to increase at the present rate. There is also possibility of reduction of NO limitation in future producing large-scale photochemical smog.

## Impacts of Aerosol Loading

Changes in climate forcing are still not clear for a situation in which both scattering and absorption by aerosols are involved. INDOEX calculations indicate the possibility of a number of changes: reduction in daytime low cloud cover by 20% to 18% (decrease by 2%), suppression of precipitation from low clouds and reduction in evaporation from the oceans by about 6%. The aerosol heating induces a large dynamical response causing ITCC to move northwards, enhancing convective rainfall over the haze area and reducing precipitation over the Indonesian region. These are all very serious consequences, even though quantitatively approximate at this stage. It is clear that climate change scenarios developed only on the basis of changes in long -lived greenhouse gases can be misleading. It is thus strange that this critical factor continues to be outside the only international framework convention in position.

For countries like India, where food security is at the core of the development process, the effects arising from haze-induced reduction of sunlight is a new parameter that should now be added to previously examined efforts from changes in temperature and precipitation and $CO_2$ enrichment. The effect of such reduction is a decrease in agricultural yield of nearly the same magnitude. Although India is now comfortably placed in terms of food production, the projected requirement of substantial increase in yield (from around 2 t/ha to about 4 t/ha in the case of rice in about 20 years) will need a new strategy, given the growth rate currently below this requirement and the complex nature of different elements of global change. The strategy is to optimize the combined effects of these perturbations through selective mitigation efforts. A reduction in aerosol loading appears to be one such effort.

As mentioned earlier, aerosol-associated health hazard has already assumed critical state. World Bank estimates suggest over 80,000 deaths annually in India due to outdoor air pollution and a staggering number of 5,00,000 deaths for children below 5 years due to indoor pollution ( 3,00,000 deaths for children below 1 year). These deaths are the third in order after malnutrition and water-borne diseases. The most serious hazard is acute-respiratory infection (ARI) for children below 5 years. Risks include acute respiratory infection, chronic obstructive pulmonary diseases and cardiovascular diseases.

New Policy questions have emerged (some of relevance to the Kyoto Protocol). The presence of a huge sunlight-absorbing haze layer extending over some 10 million square kilometers over the Asian and the northern Indian Ocean region confirmed that urban air pollution (till now considered local)

**Climate Forcing Pollutants**

| Protocol GHGs | | | Short lived Gases | Particulates |
|---|---|---|---|---|
| 1.56 $Wm^2$ | $CO_2$ | 1 | $O_2$ | • Cooling Aerosols |
| 0.47 $Wm^2$ | $CH_4$ | 21 | CO | |
| 0.14 $Wm^2$ | $N_2O$<br>HFC | 310<br>140 | $NO_2$<br>$SO_2$ | • Heating Aerosols |
| Little now | $SF_6$<br>PFC | 23,900<br>Large | | (transport over long distances) |
| GLOBAL | | | LOCAL TO REGIONAL | |
| Decades and Centuries | | | Weeks and days | Days |

Past 100 years T 0.3-0.6 — Sea Level: 10.25 cm

Asia 1990: $CO_2$ Equivalent 12% of World. — Population over 50% of world has continental and ocean basin scales. It has provided an interface between air quality and global warming and emphasized the incompleteness of the Kyoto Protocol where aerosols and ozone precursor gases are not included.

Two special aspects are only beginning to be recognized: one is that the pollutants are of three distinct categories : the long lived gases ( $CO_2$ ,$CH_4$ , $N_2O$), the short lived gases (CO, NOx, $SO_2$) and the particulate materials of different sizes and composition including climatically important soot carbon (see Table). All these have been increasing very rapidly with growth rates of 4-6% in most cases, 3-5 times higher than in most industrialized countries. The emphasis, however, has been largely on the long-lived gases.

What is now emerging is a new scenario in which ozone changes, urban pollution and global warming are interlinked. New efforts in this direction are now being taken up.