INDOEX (India): Introductory note

INDOEX (Indian Ocean Experiment) is an extensive international programme, involving several hundred scientists from the USA, Europe, India and the island countries Maldives, Mauritius and Reunion with the primary goal to study 'natural and climatic forcing by aerosols and feedbacks on regional and global climate'. Aerosol cooling (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 East and South East Asia, aerosol emissions from a variety of sources (fossil fuel, biomass burning, etc.) are increasing at a faster rate than those of greenhouse gases. This dominant, but as yet inadequately quantified, role was summarized in the Second Assessment Report of the Intergovernmental Panel for Climate Change (IPCC, 1996).

INDOEX addresses this question by focusing on a region in the Arabian Sea and the Indian Ocean during January to March – at a time when the 'polluted' air from

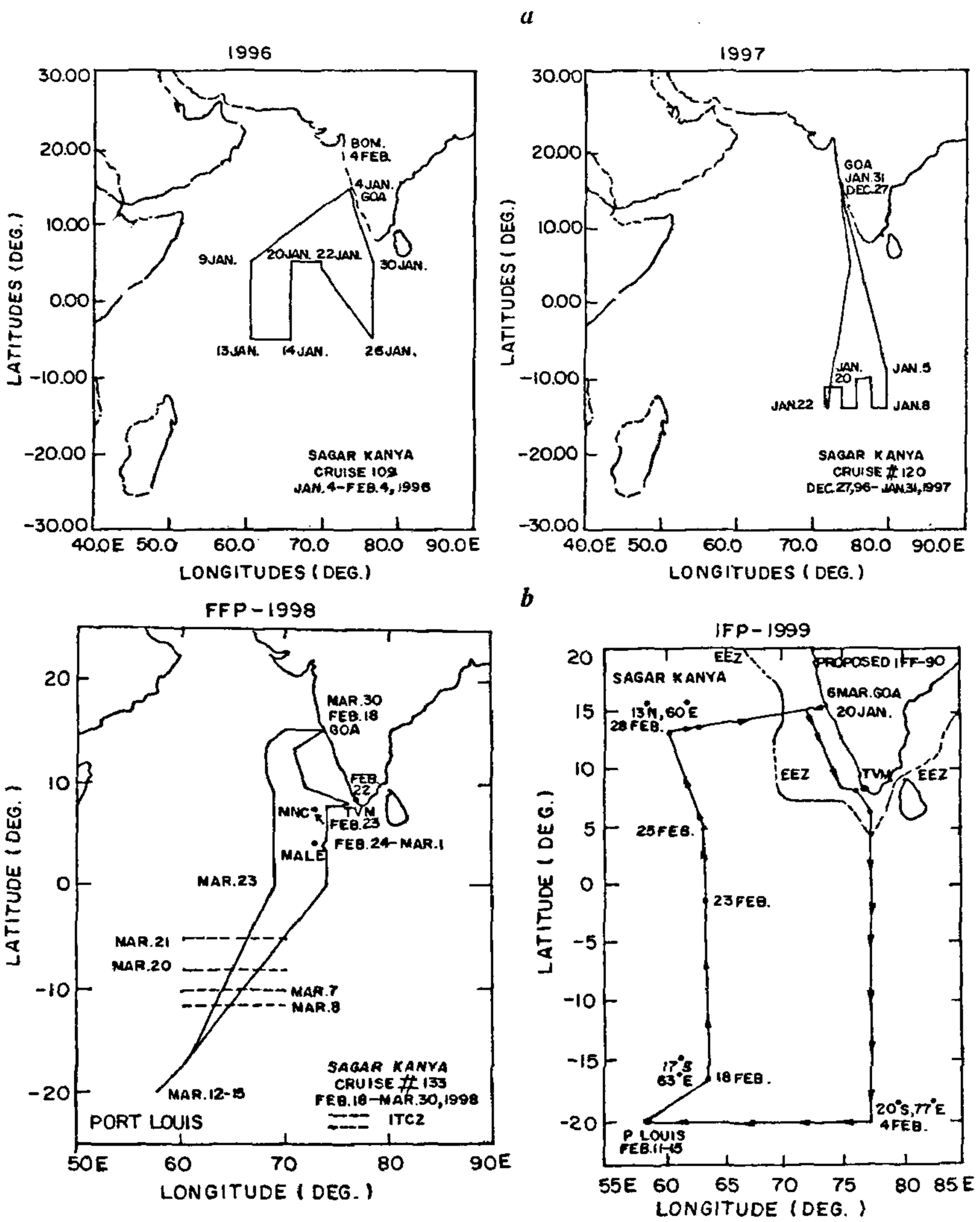


Figure 1. Pre-INDOEX cruise path *Sagar Kanya* for 1996, 1997 and FFP 1998.

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. For this, data collections are organized with a variety of platforms (land-based, ships, aircrafts, satellites) on aerosols, on ozone and reactive gases such as NO_x, CO, on solar radiation fluxes and on cloud properties. The land-based stations include the Indian stations at Delhi (NPL), Ahmedabad and Mt. Abu (PRL), Pune (IITM), Goa (French Group), Thiruvananthapuram (SPL), Kaashidhoo Climate Observatory in the Maldives (a joint operation of Maldives and the USA), Port Louis (joint operation by Mauritius University and Indian institutions like VSSC and IITM) and the network of IMD on ozonesondes and radiosondes. Three lidars are in operation in India: at Mt. Abu, Pune and Thiruvananthapuram. The ship cruises until recently were mainly those of *Sagar Kanya* with the exception of the cruise of NOAA *RV Malcon Baldridge* in 1995. The three pre-INDOEX cruises of *Sagar Kanya* were conducted with a variety of equipment from India, USA and Europe in 1996, 1997 and 1998. For 1999, when the intensive field campaign will be undertaken, the USA will operate research vessel *Ronald H. Brown. C-130, Citation* and *Mystere* aircrafts will fly from the Male Airport in February and March 1999. Geostationery satellites –(METEOSAT 5, INSAT and FY-2) and polar orbiting satellites (NOAA-12, 14, K and ScaRaB) will study the entire region.

Cruise paths for the three cruises already undertaken by *Sagar Kanya* are shown in Figure 1 *a* and *b* along with cruise path for the fourth campaign planned for 1999. So far, experiments conducted aboard ORV *Sagar Kanya* in 1998 have been the most comprehensive.

Since a variety of measurements have already been made, especially during the Field Phase Programme of 1998 (FFP 1998), results of considerable interest are

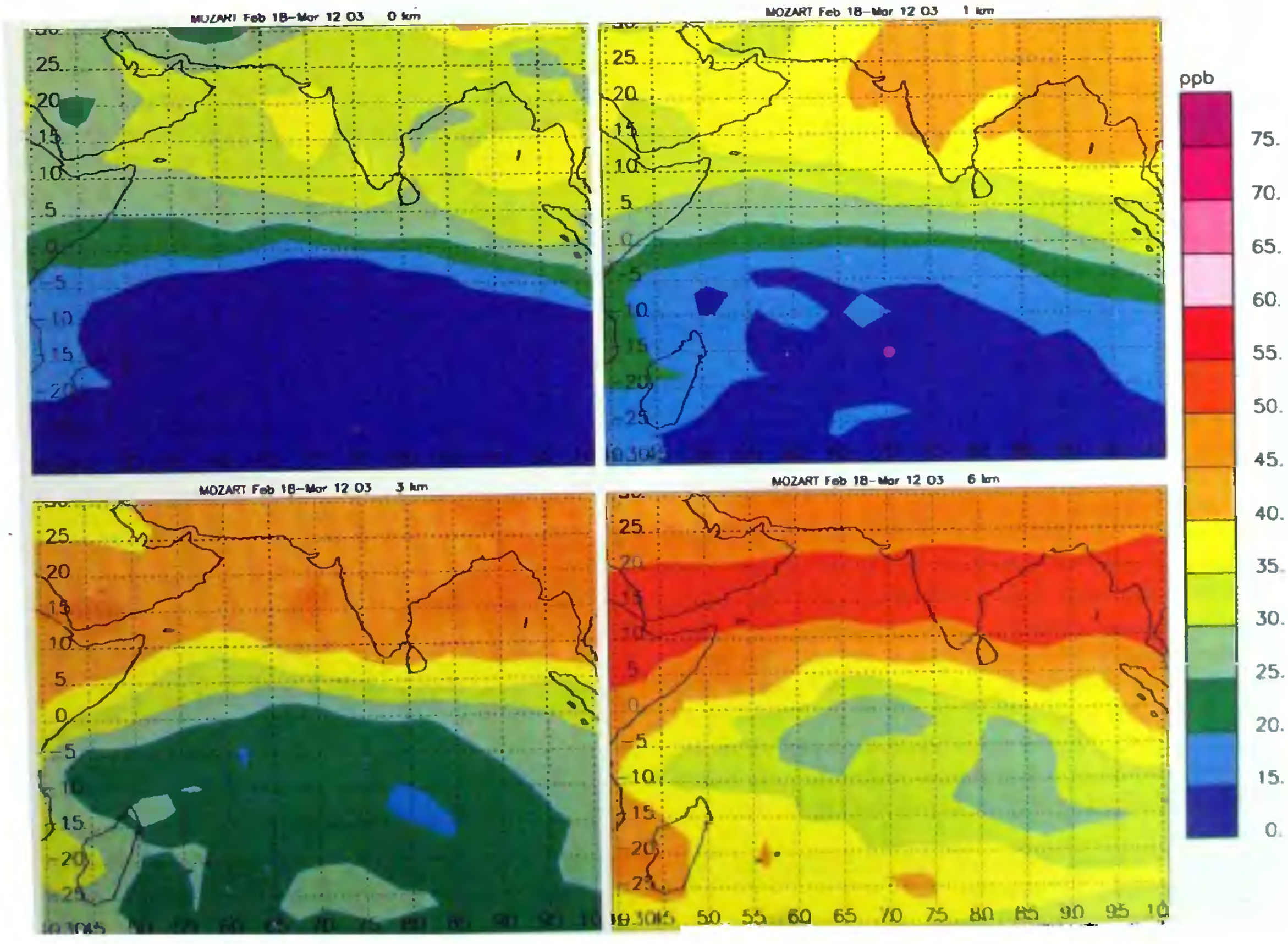


Figure 2. 3-D model calculation by G. Beig using MOZART model of Brasseur *et al.* for the INDOEX region for the period 18 February to 2 March corresponding to conditions of 1998 cruise (from G. Beig, private communication).

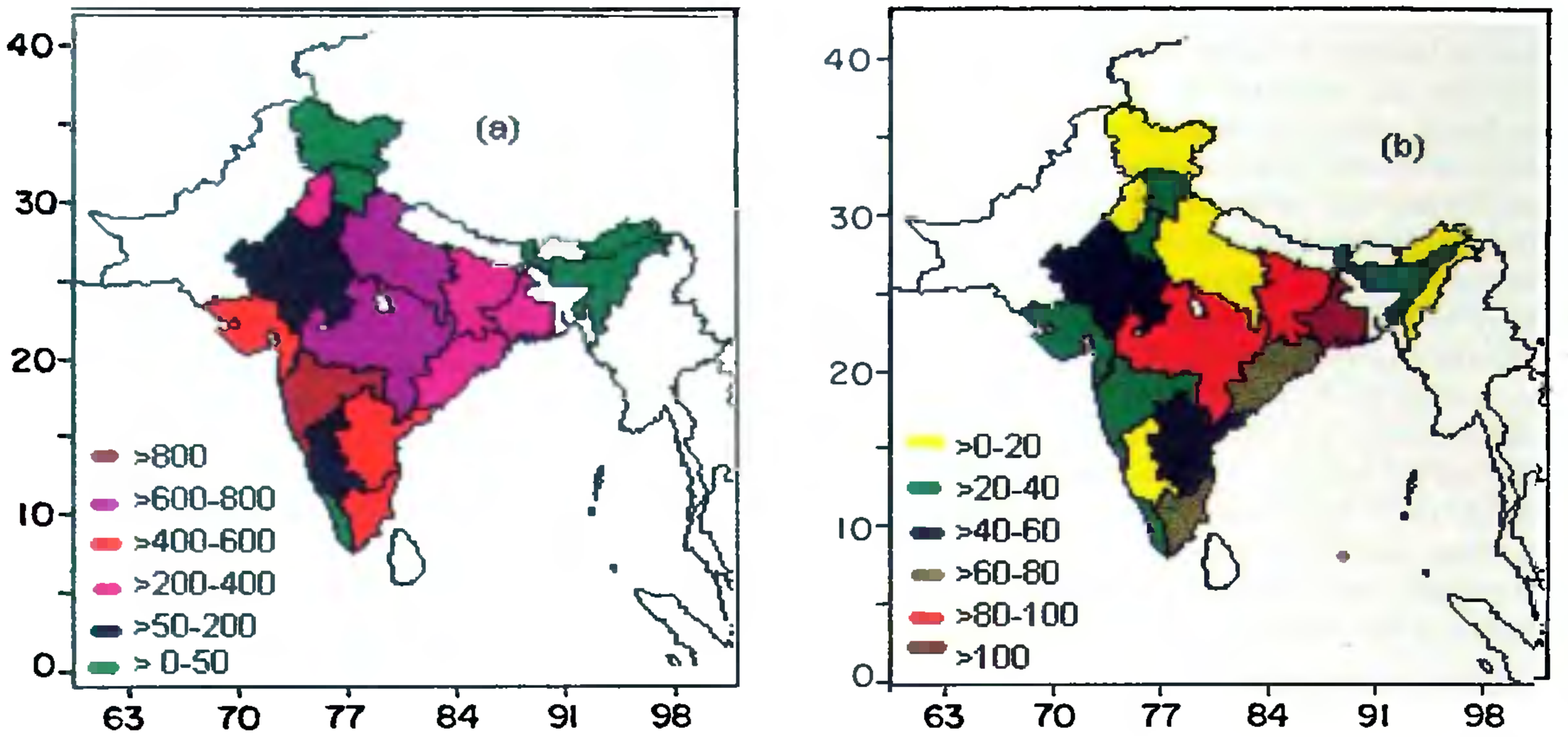


Figure 3. Inventory of SO_2 emissions from the Indian subcontinent from (*a*) fossil fuels and (*b*) biomass burning (prepared by S. Bhattacharya and Amit Garg) in 1000 tons for January, February and March 1998.

already emerging. Some of these have already been published or are in the course of publication by scientists from the participating countries in standard journals. V. Ramanathan and his colleagues, for example, are having six papers published in the *Journal of Geophysical Research* based on INDOEX–FFP 1998 observations.

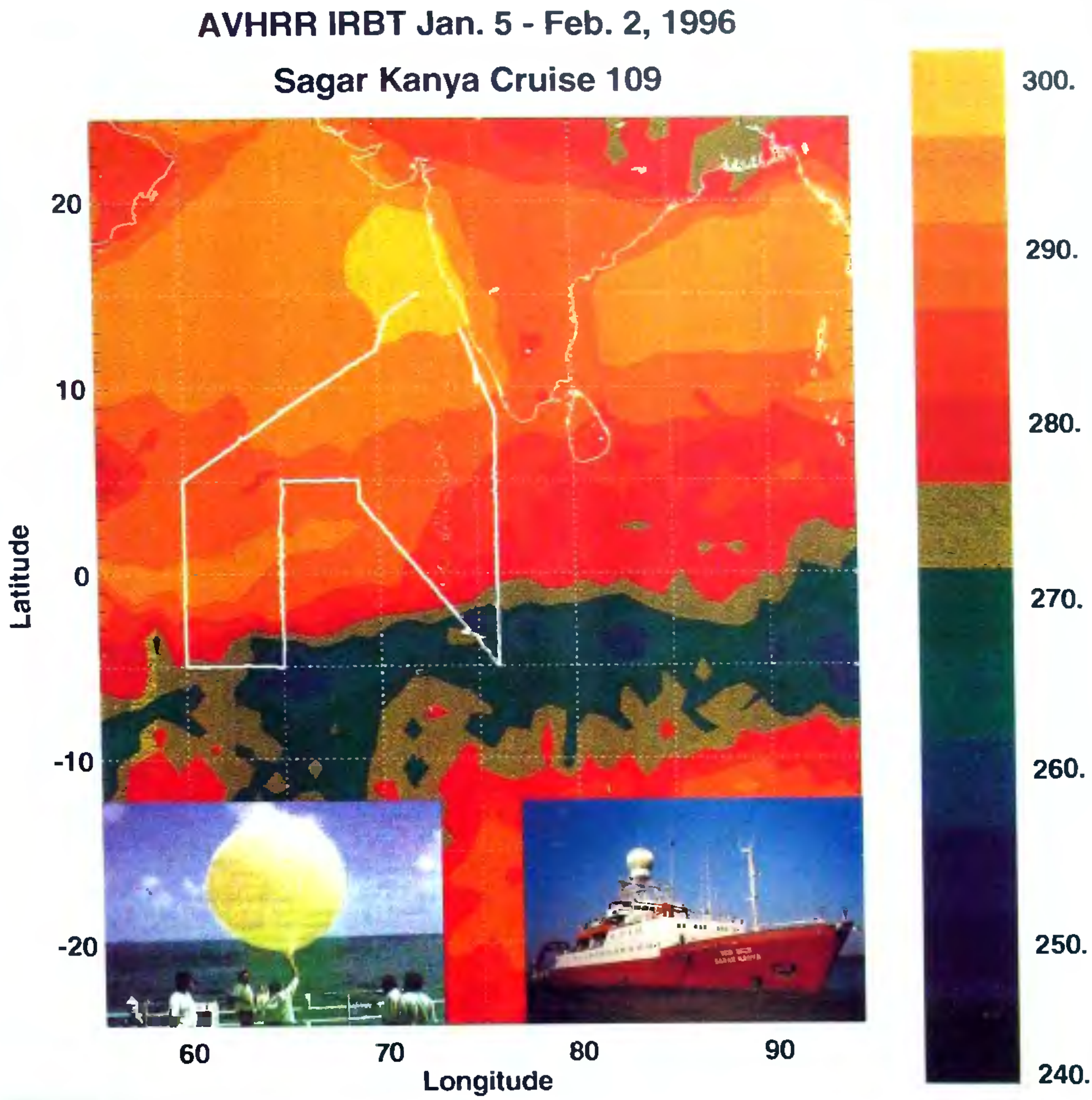
The Indian participation has been, and continues to be, extensive. To assess the scientific results obtained so far by Indian scientists, the National Steering Committee organized a special workshop in Delhi at the National Physical Laboratory during 16–18 November 1998. The special section in this issue covers some of the important findings of the Indian measurements principally through the three cruises but also with land-based measurements including those undertaken in Port Louis.

Just before the 1998 cruise, an intercomparison campaign was carried out in Thiruvananthapuram during 5 to 9 January 1998. This campaign covered use of the following: (i) aerosol samplers, (ii) radiometers, (iii) lidar, (iv) measurements of O_3 and NO_x and (v) boundary layer measurements using sodar, tethersonde and tower-based instruments. The compared results will be published separately as a special report under INDOEX-India series. In addition, ship-surface instrument calibration and intercomparison efforts were made as outlined below:

- on 22 February 1998 off Thiruvananthapuram for boundary layer experiments
- on 23 February 1998 off Minicoy for multi-wavelength radiometer experiment
- on 27 to 28 February 1998 near Kaashidhoo.

Some of the results are clear and consistent with expectations, such as a definite North–South gradient in aerosol loading with the concentrations being much lower in the pristine environment south of the ITCZ. One sees also much lower ozone values at surface level in the southern part of the Indian Ocean than in the northern part. Similar gradients in NO_x and CO exist as well. However, there are surprises: (i) pockets of very low and very high ozone concentrations in certain regions that need careful analysis and interpretation; (ii) the intermixture of aerosol intrusion from Indian subcontinent and the Arabian landmass; (iii) the dominant role of soot in surface forcing; and (iv) the pronounced decrease in ozone concentration accompanied by equally drastic increase in water vapour between 300 and 600 mb. Observations of acid rain show that rainwater over Indian Ocean was acidic compared to the predominantly alkaline rainwater over the Indian subcontinent. A result of major significance is the relationship connecting aerosol loading with radiative flux obtained by Jayaraman *et al.* Marine boundary layers heights decreased from 2.5 km at 13°N to 500–600 m at 10°S during the 1997 cruise but were lower in 1998 ranging from 0.5 to 1 km. Observations of methane and carbon dioxide (CO_2) concentration show a distinct latitudinal gradient for CH_4, with higher values near the subcontinent and the ITCZ region, and a surprisingly high value of over 400 ppbv around the equator; the latter could be a result of upwelling of CO_2-rich water mass.

To understand the observed results on atmospheric minor species properly, a preliminary case study was



made by Beig (private communication) of the region under study using the 3-D model developed by Brasseur *et al.* An example of ozone values obtained with this model is shown in Figure 2 and should be compared with the profiles by Mandal *et al.* The theoretical results produce neither the kind of high values seen with ozonesondes nor those in NO_x and CO.

In interpreting INDOEX results, especially those on transport of aerosols and trace species, something not directly addressed but necessary, is an inventory of their emission sources. For SO_2, districtwise inventory of emissions from the Indian subcontinent separately from fossil fuel and biomass burning have been calculated by Bhattacharya *et al.* (private commun). This is shown in Figure 3 for January to March.

INDOEX is an exciting programme, with many surprises anticipated. Climate warming projections as understood now can go through major changes; we provide here only a glimpse of the emerging results, the physical processes that are involved, and the results that are currently available.

1. Jayaraman, A., Lubin, D., Ramachandran, S., Ramanathan, V., Woodbridge, E., Collins, W. D. and Zalpuri, K. S., *J. Geophys. Res.*, 1998, **103**, 13,827–13,836.

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