JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 106, NO. D22, PAGES 28,369–28,370, NOVEMBER 27, 2001

Foreword

> It is hoped that the intensive field phase of INDOEX, which starts today,. . . would help us better understand the complex processes that lead to global warming and sea-level rise.
>
> President Maumoon Abdul Gayoom of Maldives
> (February 15, 1999)

The tropical Indian Ocean is probably the only place in the world where an intense source of anthropogenic trace species, their reaction products (e.g., sulfate, ozone), and continental aerosols from the Northern Hemisphere is directly connected to the pristine air of the Southern Hemisphere by a cross-equatorial monsoonal flow into the Intertropical Convergence Zone (ITCZ). This northeasterly monsoonal flow, persistent during December to March, transports dry and polluted continental air from South and Southeast Asia across the Bay of Bengal and the Arabian Sea over the equatorial Indian Ocean. By providing the confluence of the two contrasting air masses, the ITCZ strengthens the north-south gradients in aerosols and gases. The Indian Ocean Experiment (INDOEX) used these gradients to observe how anthropogenic gases and aerosols are modifying the chemistry and the radiative forcing of the region. Specifically, INDOEX was designed to focus on the following two primary objectives:

The first is to assess the nature and magnitude of the chemical pollution over the tropical Indian Ocean. The reality of the large population density on the Indian subcontinent in close proximity to the ITCZ forces us to think not only about the chemical perturbation of the tropical free troposphere, but also about its role in changing the oxidation power of the global atmosphere.

The second objective is to assess the significance of sulfates, soot, and other continental aerosols for global radiative forcing. In particular, we addressed the following questions: Is the radiative forcing of anthropogenic particles confined regionally to urban and surrounding land areas? Can it spread to remote regions and influence the ocean heat budget and the planetary (clear and cloudy) albedo thousands of kilometers away from the source of the pollution?

INDOEX, conceived by us in the fall of 1994 during an afternoon coffee session at the Scripps Institution of Oceanography in La Jolla, began as a small exploratory field experiment to elucidate how the South Asian pollution is impacting the atmosphere. It quickly grew into a larger activity with the publication of the INDOEX white paper [*Ramanathan et al*., 1995, available at http://www-indoex.ucsd.edu/documents.html], bringing together an interdisciplinary group of atmospheric chemists, aerosol experts, meteorologists, and climate modelers. Its evolution into a major field campaign, with over 250 scientists from about 50 institutions around the world, was catalyzed by several major findings from pre-INDOEX campaigns conducted during 1995 and 1999.

First was the R/V *Malcom Baldridge* cruise from March to April of 1995 [*Rhoads et al*., 1997], which documented the strong gradients in the atmospheric concentrations of carbon monoxide, non-sea-salt sulfate, nitrate, and ammonium across the ITCZ. The oceanic regions where these measurements were made were a few thousand kilometers away from the source regions in South Asia, thus demonstrating the long-range transport of aerosols. Models that used a high-resolution reanalysis of the velocity fields [*Krishnamurti et al*., 1998] also predicted this long-range transport. The INDOEX-India program launched the R/V *Sagar Kanya* every year thereafter to document the spatial and the temporal extent of the INDOEX plume. In the first pre-INDOEX cruise by R/V *Sagar Kanya* during January of 1996, *Jayaraman et al*. [1998] used the large aerosol gradient across the ITCZ to determine the radiative forcing at the surface directly from radiometers. The data, albeit limited in time and range, revealed the potentially large magnitude of the aerosol radiative forcing.

It was clear that a longer time series was needed to make a definitive determination of the aerosol composition, its optical properties, and the radiative forcing. The Kaashidhoo Climate Observatory (KCO) was set up on the tiny island of Kaashidhoo in the fall of 1997, which began collecting chemical, optical, and radiometric data continuously (http://www-indoex.ucsd.edu/KCO.html). The first important finding of KCO was the large seasonal variation of CO, which ranged from about 230 ppbv [nmol/mol] during the northeast monsoon to the background value of about 50 ppbv during the summertime southwest monsoon [*Lobert et al*., 1999]. It established KCO as an ideal site for studying both the pristine and the polluted Indian Ocean.

The first field phase (FFP) of INDOEX was launched in 1998 with KCO and the R/V *Sagar Kanya*. Its major finding [*Satheesh and Ramanathan*, 2000] was the highly absorbing nature of the aerosol (due to black carbon and dust), and because of this absorption, the direct aerosol forcing at the surface was shown to be 3 times as large as that at the top of the atmosphere. It became clear that the aerosol-climate problem was significantly more important than had been envisioned until then. The Indian journal *Current Science* published a collection of the Indian FFP observations in a special issue [*Mitra*, 1999].

The Intense Field Phase (IFP) of INDOEX, conducted between January and March of 1999, provided the first in situ observations of aerosols and air chemistry and led to several major findings reported in this special issue. Detailed descriptions of the IFP missions are given elsewhere (http://www.joss.ucar.edu/indoex/). A summary of the IFP chemical observations is described by *Lelieveld et al*. [2001]. INDOEX papers published prior to this issue are listed at http://www-indoex.ucsd.edu/documents.html. This special issue of the *Journal of Geophysical Research* is the first of two special issues that will carry a collection of original papers describing the results from the IFP.

INDOEX is an international field experiment with participation from Austria, France, Germany, India, Maldives, Netherlands, Sweden, and the United States, with the National Science Foundation as the lead agency. It was truly a rewarding experience to witness the remarkable collaboration between these scientists across national and disciplinary boundaries. The overall findings, however, of INDOEX are quite sobering with regard to the state of the environment over this region. We hope that the data collected by INDOEX will not only

Paper number 2001JD900172.
0148-0227/01/2001JD900172$09.00

serve as a baseline for assessing the changes in the coming decades, but also are useful for averting further environmental degradation.

P. J. Crutzen

Center for Atmospheric Sciences, Scripps Institution of Oceanography
University of California, San Diego, California
Max Plank Institute for Chemistry, Mainz, Germany

V. Ramanathan

Center for Atmospheric Sciences, Scripps Institution of Oceanography
University of California, San Diego, California

References

Jayaraman, A., D. Lubin, S. Ramachandran, V. Ramanathan, E. Woodbridge, W. Collins, and K. S. Zalpuri, Direct observations of aerosol radiative forcing over the tropical Indian Ocean during the January–February 1996 pre-INDOEX cruise, *J. Geophys. Res*., *103*, 13,827–13,836, 1998.

Krishnamurti, T. N., B. Jha, J. M. Prospero, A. Jayaraman, and V. Ramanathan, Aerosol and pollutant transport over the tropical Indian Ocean during the 1996 northeast monsoon and the impact on radiative forcing. *Tellus*, *Ser. B*, *50*, 521–542, 1998.

Lelieveld, J., et al., The Indian Ocean Experiment: Widespread air pollution from South and Southeast Asia, *Science*, *291*, 1031–1036, 2001.

Lobert, J. M., J. Harris, and V. Ramanathan, Trace gases and air mass origin over KCO, INDOEX 1999 (abstract), *Eos Trans. AGU*, *80*(46), Fall Meet. Suppl., F164, 1999.

Mitra, A. P., INDOEX (India): Introductory note, *Curr. Sci*., *76*, 886–889, 1999.

Ramanathan, V., et al., Indian Ocean Experiment (INDOEX) white paper, *C^4 Publ*. *143*, Scripps Inst. of Oceanogr., La Jolla, Calif., 1995.

Rhoads, K. P., P. Kelley, R. Dickerson, T. Carsey, M. Farmer, D. Savoie, and J. Prospero, The composition of the troposphere over the Indian Ocean during the monsoonal transition, *J. Geophys. Res*., *102*, 18,981–18,995, 1997.

Satheesh, S. K., and V. Ramanathan, Large differences in the tropical aerosol forcing at the top of the atmosphere and Earth's surface, *Nature*, *405*, 60–63, 2000.