Origin of carbonaceous aerosols over the tropical Indian Ocean: Biomass burning or fossil fuels?

T.Novakov,[1] M.O. Andreae,[2] R. Gabriel,[2] T.W. Kirchstetter,[1] O.L. Mayol-Bracero,[2] and V. Ramanathan[3]

[1] Lawrence Berkeley National Laboratory, Berkeley, California

[2] Max Planck Institute for Chemistry, Mainz, Germany

[3] Scripps Institution of Oceanography, La Jolla, California

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Aerosol sources assumed before INDOEX

Organic and sulfate aerosols from:

- Gas-to-particle conversion of secondary oxidation products of organics emitted by the biosphere (vegetation, ocean).
- Emission from industrial and transportation sources.
- Biomass (biofuel) burning.

Black carbon from:

- Biomass burning.

Primary aerosols:

- Soil dust and sea-salt.

Mass concentrations of carbonaceous aerosols over Indian Ocean (hundreds of km from land) are comparable to those in urban Japan, Korea and the U.S.

SITES	**Total C** (µg m^{3})
INDOEX, 1999	
18 February	**6.1**
20 February	**5.7**
25 February	**10.7**
Sapporo, 1982	**9.2**
Seoul, 1994	**17.5**
New York, 1978-79	**8.3**
Los Angeles, 1987	**10.7**
CA Central Valley cities, 1988-89	**11.8**

Differences in fuel types and utilization between developing and industrialized regions are reflected in aerosol concentration and composition

SITES	TC	BC	OC	SO_4^{2-}	SO_4^{2-}/TC
Katmandu, 1982	61.0	17.0	44.0	1.7	0.03
Lahore,1992-93	94.5	17.6	76.9	19.4	0.20
Beijing, 1983-84	64.0	NA	NA	17.2	0.26
Sapporo, 1987-88	6.7	3.3	3.4	4.1	0.61
New York, 1978-79	11.2	4.4	6.8	14.0	1.3
Houston, 1980	6.6	NA	NA	13.8	2.1

Differences in fuels and sources are seen in BC/OC ratios

Source	BC/OC
Forest fires	0.13
Biofuels	0.24
Agri. residue	0.21
Diesel	2.6
Gasoline	0.66

INDOEX concentration ratios are inconsistent with biomass and biofuel burning

Flight or Location	BC/OC	K^+/BC	SO_4^{2-}/BC	D_P (μm)	Refs.
			INDOEX		
Flight 2	1.0 ± 0.1	0.17 ± 0.07	2.5 ± 0.8	<1.3	a
Flight 3	0.93 ± 0.27	0.16 ± 0.04	2.4 ± 0.6	<1.3	a
Flight 10	0.83 ± 0.33	0.11 ± 0.01	2.1 ± 0.7	<1.3	a
			Biomass burning		
Brazil	0.12 ± 0.03	0.52 ± 0.11	0.28 ± 0.13	<4.0	b
Ivory C	0.14 ± 0.08	NA	NA	<5.0	c
			Urban, industrial and rural Pakistan		
Lahore	0.24 ± 0.04	0.23 ± 0.10	1.1 ± 0.1	<10	d

a) This work; b) Ferek et al., 1998; c) Cachier, 1991; d) Smith et al., 1996

INDOEX BC/OC and BC/TC ratios are consistent with ratios in industrialized regions of Asia where the fuels and combustion practices are vastly different from those in Indian Subcontinent

Location	BC/TC	BC/OC	SO_4^{2-}/TC	Refs.
INDOEX average	**0.46±0.07**	**0.90±0.24**	1.0±0.4	a
Urban Southeast Asia				
Sapporo, annual '82	**0.54±0.14**	**1.19±0.37**	0.47±0.08	b
Nagoya, annual '84-86	**0.44±0.03**	**0.80±0.11**	NA	c
Sendai, annual '86-87	**0.37±0.03**	**0.60±0.04**	0.37±0.03	d
Seoul, summer '94	**0.43±0.05**	**0.76±0.1**	NA	e
Marine Southeast Asia				
Hachijo-Jima, winter '91	**0.41±0.07**	**0.70±0.31**	0.91±0.15	f
Chichi-Jima, winter '81	**0.54±0.21**	**1.2±1.4**	1.1±1.6	g

a) This work); b) Ohta and Okita, 1990 (<8 µm); c) Kadowaki, 1990 (<10 µm); d) Hayasaka et al., 1992 (<1 µm); e) Kim et al., 1999 (<2.5 µm); Ohta and Okita, 1984 (<10 µm); Novakov et al., 2000 (<1 µm)

INDOEX OC and BC summary

80% or more of carbonaceous aerosols over Indian Ocean are derived from fossil fuel, not biomass, burning

Average BC/OC ≈ 1

BC and TC (and OC) are highly correlated $R^2 = 0.86$

∴ OC is primary

BC mass absorption cross section = 8.9 ± 3.4 m^2 g^{-1}

BC/OC ratios of over the Indian Ocean and in source regions are different

∴ Changes in composition of carbonaceous aerosols may occur during transport