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**Summertime nitrate aerosol in the upper troposphere
and lower stratosphere over the Tibetan Plateau
and the South Asian summer monsoon region**

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Supplementary Material

Table S1. Observed concentrations of aerosols in South Asia

Site name	Period		Sample type	Concentration ($\mu\text{g m}^{-3}$)					Reference
				Sulfate	Nitrate	Ammonium	OC	BC	
NCO-P, Nepal (28°N,87°E)	2006-2008	Jun-Sep	PM ₁₀	0.50	0.37	0.00	0.9		Decesari et al. (2010)
		Oct-Nov		0.50	0.00	0.08	1.4		
		Dec-Feb		0.22	0.08	0.14	1.2		
		Mar-May		1.48	0.66	0.52	2.4		
Langtang, Nepal (28.13°N, 85.60°E)	1998-2000	Oct-Jan	PM _{2.5}	0.27±0.24	0.04±0.07	0.15±0.15	3.4		Carrico et al. (2003)
		Feb-Mar		1.41±1.30	0.78±1.00	0.54±0.56	0.8		
		Jun-Sep		0.20±0.45	0.09±0.36	0.08±0.17	1.8		
Nagarkot, Nepal (27.72°N, 85.52°E)	1998-2000	Oct-Jan	PM _{2.5}	2.5±2.2	0.8±1.7	1.2±1.3	14		Carrico et al. (2003)
		Feb-May		3.8±1.0	1.2±1.8	1.5±1.0	2.0		
		Jun-Sep		0.8±1.2	0.08±0.18	0.25±0.29	6.3		
Rongbuk Glacier, China (28.02°N, 86.96°E)	2003	Sep	TSP	0.41	0.14				Ming et al. (2007)
Manora Peak, India (29.4°N 79.5°E)	2004	Dec	TSP	2.56±1.27	0.50±0.33	0.52±0.37	4.9±1.3	1.36±0.99	Rengarajan et al. (2007); Pant et al. (2006)
Manora Peak, India (29.4°N 79.5°E)	2005-2006	Feb-Mar	TSP				11.6±5.9		Ram et al. (2008)
		Apr-Jun					8.6±2.7		
		Jun-Jul					5.7±0.2		
		Sep-Nov					10.8±6.7		

		Dec-Mar					11.0±2.3		
Hisar, India (29.2°N 75.7°E)	2004	Dec	TSP	12.68±6.23	13.34±6.64	6.33±4.24	33.0±17.9		Rengarajan et al. (2007)
Mt. Abu, India (24.6°N 72.7°E)	2000-2002	Jan-Apr	TSP	3.08	0.43				Rastogi and Sarin (2005)
		Sep-Dec		2.71	0.74	0.73			
Mt. Abu, India (24.6°N 72.7°E)	2005-2006	May-Jun	TSP				3.5±2.7		Ram et al. (2008)
		Jul-Aug					2.2±0.7		
		Sep-Nov					4.9±2.2		
		Dec-Mar					3.6±2.8		
Mumbai, India (19.4°N, 72.8°E)	1999	Jan-Feb	PM ₁₀	7.3±2.6	4.7±1.7				Venkataraman et al. (2002)
		Feb-Mar		6.2±1.0	6.0±3.0				
	2001-2002	Mar-Apr					9.5		Chowdhury et al. (2007)
Pune, India (18.5°N, 74°E)	1998	Mar-Apr	TSP	2.98	2.91	2.14			Momin et al. (1999)
	2005	Dec-Feb	TSP					7.38	Safai et al. (2007)
		Oct-Nov						6.04	
		Mar-May						3.25	
Jun-Sep						1.31			
Agra, India (27.15°N 78°E)	1992-1993	Dec-Mar	TSP	14.7	8.37	6.52			Kulshrestha et al. (1998)
Ahmedabad, India (23.0°N, 72.6°E)	2000-2002	Jan-Apr	TSP			0.05			Rastogi and Sarin (2005)
		Sep-Dec				0.48			
Ahmedabad, India	2003-2005	Dec-Mar	TSP					5.5±2.8	Ganguly et al.

(23.0°N, 72.6°E)		Apr-May						2.2±1.0	(2006)
		Jun-Dec						1.5±0.8	
		Oct-Nov						7.3±3.7	
Ahmedabad, India (23.0°N, 72.6°E)	2002	Jun	TSP	3.38	0.73		7.20		Rastogi and Sarin (2009)
		Jul		4.27	0.43		5.00		
		Aug		4.90	0.60		5.40		
Dhaka, Bangladesh (24°N, 90.6°E)	2001	Apr	TSP	11.3	3.63	1.86	45.7		Salam et al. (2003)
Kayamkulam (KLM), India (9.17°N, 76.5°E)	2004	Feb	TSP	6.4	2.4				Nair et al. (2006)
Tellicherry (TLY), India (9.17°N, 76.5°E)	2004	Feb	TSP	9.8	3.6				Nair et al. (2006)
Kumbla (KUM), India (12.63°N, 74.92°E)	2004	Feb	TSP	10.5	7.2				Nair et al. (2006)
Dandebag (DAN), India (14.88°N, 74.01°E)	2004	Feb	TSP	2.4	0.5				Nair et al. (2006)
Ainapur (AIN), India (16.83°N, 75.77°E)	2004	Feb	TSP	3.5	2.0				Nair et al. (2006)
Maslakhurd (MSK), India (17.79°N, 76°E)	2004	Feb	TSP	4.3	2.3				Nair et al. (2006)
Satwar (SAT), India (17.7°N, 77.51°E)	2004	Feb	TSP	5.6	3.6				Nair et al. (2006)

Shadnagar (SHD), India (17.00°N, 78.18°E)	2004	Feb	TSP	7.0	2.3				Nair et al. (2006)
Ananthpur (ANA), India (14.61°N, 77.64°E)	2004	Feb	TSP	5.8	1.9				Nair et al. (2006)
Navani (NAV), India (11.38°N, 78.13°E)	2004	Feb	TSP	5.4	1.6				Nair et al. (2006)
Kuttikkanam (KUT), India (9.57°N, 76.97°E)	2004	Feb	TSP	10.1	3.2				Nair et al. (2006)
Vazhathoppu (VAZ), India (9.01°N, 76.89°E)	2004	Feb	TSP	8.8	2.9				Nair et al. (2006)
Thenmala (TML), India (8.97°N, 77.01°E)	2004	Feb	TSP	4.7	1.0				Nair et al. (2006)
Trivandrum, India (8.55°N, 77°E)	2003-2005	Mar-May	TSP	4.9±0.5	1.6±0.3	1.2±0.4			George et al. (2008)
		Jun-Nov		3.9±0.3	1.8±0.2	0.2±0.03			
		Dec-Feb		6.2±0.5	1.5±0.1	1.6±0.3			
Trivandrum, India (8.55°N, 77°E)	2005	Jun	TSP					2.00	Nair et al. (2012)
		Jul						1.19	
		Aug						2.07	
Kanpur, India (26.4°N, 80.3°E)	2004	Dec	PM ₁₀	14.9±3.3	15.7±5.58	8.76±4.3			Tare et al. (2006)
	2004	Dec	TSP					12.3	Tripathi et al. (2005)
Kathmandu, Nepal (27.7°N, 85.3°E)	2004-2005	Sep	PM _{2.5}	1.75					Adhikary et al. (2007)
		Oct		1.93					

		Nov		1.25					
Darjeeling, India (27°N, 88.25°E)	2005	Jun	PM _{2.5}	0.51	1.10				Chatterjee et al. (2010)
		Jul		0.32	0.90				
		Aug		0.38	0.39	0.06			
Darjeeling, India (27°N, 88.25°E)	2008	Jun	TSP					0.90	Chatterjee et al. (2012)
		Jul					1.09		
		Aug					0.76		
Kaashidhoo, India (4.97°N, 73.47°E)	1999	Feb-Mar	TSP	6.08					Verma et al. (2012)
Hanimadhoo (6.78°N, 73.18°E)	2004-2005	Jun	PM _{2.5}	1.18			0.09	0.01	Ramanathan et al. (2007); Adhikary et al. (2007)
		Jul		1.10			0.16	0.03	
		Aug					0.52	0.03	
Mt. Yulong, China (27.1°N, 100.2°E)	2010	Jan-Feb	TSP	1.78	0.58	0.37			Zhang et al. (2012)
Mangalore, India (12.82°N, 74.93°E)	2000	Feb-Mar	TSP	3.6	1.7	1.0			Hegde et al. (2007)
		Apr-May		1.7	0.31	0.64			
Delhi, India (28.62°N, 77.22°E)	2001-2002	Mar-Apr	PM _{2.5}				37.8		Chowdhury et al. (2007)
		Jun-Jul					16.1		
		Oct-Nov					57.4		
		Dec-Jan					95.8		
Delhi, India (28.62°N, 77.22°E)	2006-2007	Dec-Feb	TSP					25.5	Bano er al. (2011)
		Mar-May						9.4	
		Jul-Sep						7.7	

		Oct-Nov						13.7		
Kolkata, India (22.57°N, 88.03°E)	2001-2002	Mar-Apr	PM _{2.5}					18.8	Chowdhury et al. (2007)	
		Jun-Jul					7.8			
		Oct-Nov					17.6			
		Dec-Jan					146.7			
Chandigarh, India (30.7°N, 76.8°E)	2001-2002	Oct-Nov	PM _{2.5}					20.1	Chowdhury et al. (2007)	
		Dec-Jan					33.6			
Bay of Bengal (13.09°N, 80.30°E)	2003	Feb	TSP					2-8	Sudheer and Sarin (2008)	
	2006	Mar-Apr	TSP					0.3-5.5		
Kathmandu, Nepal (27.7°N, 85.3°E)	2004-2005	Aug	PM _{2.5}					2.29	0.47	Adhikary et al. (2007)
		Sep					1.61	0.69		
		Oct					2.23	0.83		
Kathmandu, Nepal (27.7°N, 85.3°E)	2009	Jun	TSP					5.3	Sharma et al. (2012)	
		Jul					3.0			
		Aug					3.2			
Lahore, Pakistan (31.57°N, 74.37°E)	2005-2006	Dec-Jan	TSP					21.7	Husain et al. (2007)	
Goa University, India (15.42°N, 74.98°E)	1999	Dec-Feb	TSP					3.0±0.7	Leon et al. (2001)	
		Mar					1.5±0.7			
Dharwar, India (15.42°N, 74.98°E)	1999	Feb	TSP					3.0	Leon et al. (2001)	
Bangalore, India (13°N, 77°E)	2001	Nov	TSP					4.2 ± 0.03	Babu and Moorthy (2002)	

Shadnagar, Inland (17.03°N, 78.18°E)	2002	Feb	TSP					2.21	Jayaraman et al. (2006)
Kharagpur, India (22.5°N, 87.3°E)	2007	Jun	TSP					2.20	Nair et al. (2012)
		Jul						2.08	
		Aug						1.97	
Karachi, Pakistan (24.8°N, 67.0°E)	2006	Apr	TSP					4.0	Dutkiewicz et al. (2009)
		Nov						10.1	
	2007	Jan	TSP					9.1	
Hyderabad, India (17.5°N, 78.5°E)	2003	Jun	TSP					4.27	Latha and Badrinath (2005)
		Jul						4.38	
		Aug						5.18	

References

- Adhikary, B., Carmichael, G. R., Tang, Y., Leung, L. R., Qian, Y., Schauer, J. J., Stone, E. A., Ramanathan, V., and Ramana, M. V.: Characterization of the seasonal cycle of south Asian aerosols: A regional-scale modeling analysis, *J. Geophys. Res.*, 112, D22S22, doi:10.1029/2006JD008143, 2007.
- Babu, S. S., and Moorthy, K. K.: Aerosol black carbon over a tropical coastal station in India, *Geophys. Res. Lett.*, 29, 2098, 2002.
- Bano, T., Singh, S., Gupta, N., Soni, K., Tanwar, R., Nath, S., Arya, B., and Gera, B.: Variation in aerosol black carbon concentration and its emission estimates at the mega-city Delhi, *Int. J. Remote Sens.*, 32, 6749–6764, 2011.
- Carrico, C. M., Bergin, M. H., Shrestha, A. B., Dibb, J. E., Gomes, L., and Harris, J. M.: The importance of carbon and mineral dust to seasonal aerosol properties in the Nepal Himalaya, *Atmos. Environ.*, 37, 2811–2824, 2003.
- Chatterjee, A., Adak, A., Singh, A. K., Srivastava, M. K., Ghosh, S. K., Tiwari, S., Devara, P. C., and Raha, S.: Aerosol chemistry over a high altitude station at northeastern Himalayas, India, *PloS one*, 5, e11122, 2010.
- Chatterjee, A., Ghosh, S. K., Adak, A., Singh, A. K., Devara, P. C., and Raha, S.: Effect of Dust and Anthropogenic Aerosols on Columnar

- Aerosol Optical Properties over Darjeeling (2200 m asl), Eastern Himalayas, India, PloS one, 7, e40286, 2012.
- Chowdhury, Z., Zheng, M., Schauer, J. J., Sheesley, R. J., Salmon, L. G., Cass, G. R., and Russell, A. G.: Speciation of ambient fine organic carbon particles and source apportionment of PM_{2.5} in Indian cities, *J. Geophys. Res.*, 112, D15303, doi:10.1029/2007JD008386, 2007.
- Decesari, S., Facchini, M., Carbone, C., Giulianelli, L., Rinaldi, M., Finessi, E., Fuzzi, S., Marinoni, A., Cristofanelli, P., and Duchi, R.: Chemical composition of PM₁₀ and PM₁ at the highaltitude Himalayan station Nepal Climate Observatory-Pyramid (NCO-P)(5079 m asl), *Atmos. Chem. Phys.*, 10, 4583–4596, 2010.
- Dutkiewicz, V. A., Alvi, S., Ghauri, B. M., Choudhary, M. I., and Husain, L.: Black carbon aerosols in urban air in South Asia, *Atmos. Environ.*, 43, 1737–1744, 2009.
- Ganguly, D., Jayaraman, A., and Gadhavi, H.: Physical and optical properties of aerosols over an urban location in western India: Seasonal variabilities, *J. Geophys. Res.*, 111, D24206, doi:10.1029/2006JD007392, 2006.
- George, S. K., Nair, P. R., Parameswaran, K., Jacob, S., and Abraham, A.: Seasonal trends in chemical composition of aerosols at a tropical coastal site of India, *J. Geophys. Res.*, 113, D16209, 2008.
- Hegde, P., Sudheer, A., Sarin, M., and Manjunatha, B.: Chemical characteristics of atmospheric aerosols over southwest coast of India, *Atmos. Environ.*, 41, 7751–7766, 2007.
- Husain, L., Dutkiewicz, V. A., Khan, A., and Ghauri, B. M.: Characterization of carbonaceous aerosols in urban air, *Atmos. Environ.*, 41, 6872–6883, 2007.
- Jayaraman, A., Gadhavi, H., Ganguly, D., Misra, A., Ramachandran, S., and Rajesh, T.: Spatial variations in aerosol characteristics and regional radiative forcing over India: Measurements and modeling of 2004 road campaign experiment, *Atmos. Environ.*, 40, 6504–6515, 2006.
- Kulshrestha, U., Saxena, A., Kumar, N., Kumari, K., and Srivastava, S.: Chemical composition and association of size-differentiated aerosols at a suburban site in a semi-arid tract of India, *J. Atmos. Chem.*, 29, 109–118, 1998.
- Latha, K. M., and Badarinath, K.: Seasonal variations of black carbon aerosols and total aerosol mass concentrations over urban environment in India, *Atmos. Environ.*, 39, 4129–4141, 2005.
- Leon, J.-F., Chazette, P., Dulac, F., Pelon, J., Flamant, C., Bonazzola, M., Foret, G., Alfaro, S., Cachier, H., and Cautenet, S.: Large-scale

- advection of continental aerosols during INDOEX, *J. Geophys. Res.*, 106, 28427–28428, 28439, 2001.
- Ming, J., Zhang, D., Kang, S., and Tian, W.: Aerosol and fresh snow chemistry in the East Rongbuk Glacier on the northern slope of Mt. Qomolangma (Everest), *J. Geophys. Res.*, 112, D15307, doi:10.1029/2007JD008618, 2007.
- Momin, G. A., Rao, P. S. P., Safai, P. D., Ali, K., Naik, M. S., and Pillai, A. G.: Atmospheric aerosol characteristic studies at Pune and Thiruvananthapuram during INDOEX programme–1998, *Curr. Sci.*, 76, 985-989, 1999.
- Nair, P. R., George, S. K., Sunilkumar, S., Parameswaran, K., Jacob, S., and Abraham, A.: Chemical composition of aerosols over peninsular India during winter, *Atmos. Environ.*, 40, 6477–6493, 2006.
- Nair, V. S., Solmon, F., Giorgi, F., Mariotti, L., Babu, S. S., and Moorthy, K. K.: Simulation of South Asian aerosols for regional climate studies, *J. Geophys. Res.*, 117, D04209, doi:10.1029/2011JD016711, 2012.
- Pant, P., Hegde, P., Dumka, U., Sagar, R., Satheesh, S., Moorthy, K. K., Saha, A., and Srivastava, M.: Aerosol characteristics at a high-altitude location in central Himalayas: Optical properties and radiative forcing, *J. Geophys. Res.*, 111, D17206, doi:10.1029/2005JD006768, 2006.
- Ram, K., Sarin, M., and Hegde, P.: Atmospheric abundances of primary and secondary carbonaceous species at two high-altitude sites in India: Sources and temporal variability, *Atmos. Environ.*, 42, 6785-6796, 2008.
- Ramanathan, V., Li, F., Ramana, M., Praveen, P., Kim, D., Corrigan, C., Nguyen, H., Stone, E. A., Schauer, J. J., and Carmichael, G.: Atmospheric brown clouds: Hemispherical and regional variations in long-range transport, absorption, and radiative forcing, *J. Geophys. Res.*, 112, D22S21, doi:10.1029/2006JD008124, 2007.
- Rastogi, N., and Sarin, M.: Long-term characterization of ionic species in aerosols from urban and high-altitude sites in western India: Role of mineral dust and anthropogenic sources, *Atmos. Environ.*, 39, 5541–5554, 2005.
- Rastogi, N., and Sarin, M.: Quantitative chemical composition and characteristics of aerosols over western India: one-year record of temporal variability, *Atmos. Environ.*, 43, 3481–3488, 2009.
- Rengarajan, R., Sarin, M., and Sudheer, A.: Carbonaceous and inorganic species in atmospheric aerosols during wintertime over urban and high-altitude sites in North India, *J. Geophys. Res.*, 112, D21307, doi:10.1029/2006JD008150, 2007.
- Safai, P., Kewat, S., Praveen, P., Rao, P., Momin, G., Ali, K., and Devara, P.: Seasonal variation of black carbon aerosols over a tropical urban city of Pune, India, *Atmos. Environ.*, 41, 2699–2709, 2007.

- Salam, A., Bauer, H., Kassin, K., Mohammad Ullah, S., and Puxbaum, H.: Aerosol chemical characteristics of a mega-city in Southeast Asia (Dhaka–Bangladesh), *Atmos. Environ.*, 37, 2517–2528, 2003.
- Sharma, R. K., Bhattarai, B., Sapkota, B., Gewali, M., and Kjeldstad, B.: Black carbon aerosols variation in Kathmandu valley, Nepal, *Atmos. Environ.*, 2012.
- Sudheer, A., and Sarin, M.: Carbonaceous aerosols in MABL of Bay of Bengal: Influence of continental outflow, *Atmos. Environ.*, 42, 4089-4100, 2008.
- Tare, V., Tripathi, S., Chinnam, N., Srivastava, A., Dey, S., Manar, M., Kanawade, V. P., Agarwal, A., Kishore, S., and Lal, R.: Measurements of atmospheric parameters during Indian Space Research Organization Geosphere Biosphere Program Land Campaign II at a typical location in the Ganga Basin: 2. chemical properties, *J. Geophys. Res.*, 111, D23210, doi:10.1029/2006JD007279, 2006.
- Tripathi, S., Dey, S., Tare, V., and Satheesh, S.: Aerosol black carbon radiative forcing at an industrial city in northern India, *Geophys. Res. Lett.*, 32, 2005.
- Venkataraman, C., Reddy, C. K., Josson, S., and Reddy, M. S.: Aerosol size and chemical characteristics at Mumbai, India, during the INDOEX-IFP (1999), *Atmos. Environ.*, 36, 1979–1991, 2002.
- Verma, S., Boucher, O., Reddy, M., Upadhyaya, H., Van, P., Binkowski, F., and Sharma, O.: Tropospheric distribution of sulphate aerosols mass and number concentration during INDOEX-IFP and its transport over the Indian Ocean: a GCM study, *Atmos. Chem. Phys.*, 12, 6185–6196, 2012.
- Zhang, N., Cao, J., Ho, K., and He, Y.: Chemical characterization of aerosol collected at Mt. Yulong in wintertime on the southeastern Tibetan Plateau, *Atmos. Res.*, 107, 76, 2012.