Atmospheric Sulfur Aerosol Concentrations and Characteristics from the South American Continent

Abstract. *Aerosol samples collected from eight geographically distinct locations in South America during the austral winter of 1976 and summer of 1977 with six-stage cascade impactors show a tropospheric sulfur background concentration of about 50 nanograms per cubic meter of air in the fine-particle mode (< 1 micrometer in aerodynamic diameter). Time-sequence filter samples, taken concurrently at most locations, show an average non-sea spray related sulfur concentration of about 85 nanograms per cubic meter. These concentrations are substantially lower than most published nonurban values for the Northern Hemisphere obtained by similar sampling and analysis techniques and may represent a natural tropospheric background level of aerosol sulfur.*

Concentrations of sulfur as aerosol particulate matter in nonurban eastern U.S. locations are often in excess of 1 μg per cubic meter of air (*1*, *2*). Because most of this S occurs in particles with diameters less than 1 μm, the origin of the sulfur has been attributed to the transformation of gaseous compounds to sulfate. Concentrations in the eastern United States are generally higher than in the less populated western United States and are apparently increasing with time; these findings suggest that anthropogenic SO_2 from fossil fuel combustion is a major source. Since a relationship has been argued between air pollution caused by sulfur oxides and health effects (*3*) as well as ecological effects (*4*), it is of interest to determine quantitatively the extent to which concentrations of pollutants are elevated above natural concentrations. It is difficult to identify regions within the Northern Hemisphere where concentrations may reliably be considered to be natural, owing to the possibility of long-range transport of polluted air to remote Northern Hemisphere regions. Useful estimates of natural aerosol S concentration may be obtained from tropospheric measurements in the Southern Hemisphere, where the continental area in relation to the ocean surface is relatively small, pollution source strengths are comparatively weak, and tropospheric transport from the Northern Hemisphere is inefficient.

The present investigation is a continuation of a study of elemental S concentrations as a function of particle size from various locations on the South American continent (*5*). Sampling was done in July and August 1976 (winter) and January through March 1977 (summer) at the following remote locations in Chile, Argentina, Bolivia, and Brazil (Table 1): three sites near and ~ 30 km northeast and west of San Carlos de Bariloche, Argentina; one site 55 km northeast of Salvador, Brazil, 0.02 to 12 km from the seacoast; three locations in Bolivia—on top of Chacaltaya Mountain (elevation, 5200 m), on the Altiplano, near Patacamaya (elevation, 3800 m), and Zongo, a tropical lowland site (elevation, 1200 m); and five sites near Punta Arenas, Chile, in the Tierra del Fuego region.

We sampled the atmospheric aerosol with single-orifice, six-stage cascade impactors of the Battelle design (*6*) and time-sequence "streaker" filter samplers (*7*), each supported ~ 1 m above ground and held face down so that air was drawn vertically upward into the samplers and positioned to avoid local aerosol sources. At an impactor flow rate of 1 liter/min, spherical particles of unit density are separated into the equivalent aerodynamic diameter ranges (stage 1, > 4 μm; stage 2, 4 to 2 μm; stage 3, 2 to 1 μm; stage 4, 1 to 0.5 μm; stage 5, 0.5 to 0.25 μm; and stage 6, < 0.25 μm) by a Nuclepore backup filter (0.4-μm pore size) which has > 80 percent particle collection efficiency for particles ≤ 0.03 μm in diameter (*8*). The 2.5-μm Mylar impaction surfaces were coated with Vaseline, paraffin, or Apiezon L grease (90 μg/cm^2) to enhance particle retention (*9*). The streaker sampler, a 0.4-μm Nuclepore strip along which a smooth 0.1-cm^2 sucking orifice was drawn at a rate of 0.5 mm/hour, was operated at a flow rate of 0.4 liter/min and afforded 4-hour time resolution when analyzed stepwise with a collimated proton beam. At most sites, miniature vacuum pumps powered by covered lead acid storage batteries were used (*10*). We analyzed the samples by proton-induced x-ray emission (PIXE) for S, Cl, K, Ca, Ti, Fe, Cu, Zn, and Pb (*11*). Great care was taken to limit sample contamination.

In total, 53 impactor samples were collected, 8 winter and 45 summer, comprising 38 observations (duplicated in 15 cases) and 13 streaker samples, each with 12 to 47 contiguous 4-hour time steps. Table 1 presents a comparison of S concentrations for Southern Hemisphere and selected Northern Hemisphere sites taken by cascade impactors and streaker samplers. The data indicate that the nonurban South American concentrations of fine-particle S (< 1 μm in diameter) are generally severalfold lower than the lowest found in nonurban North American locations. In the coastal re-

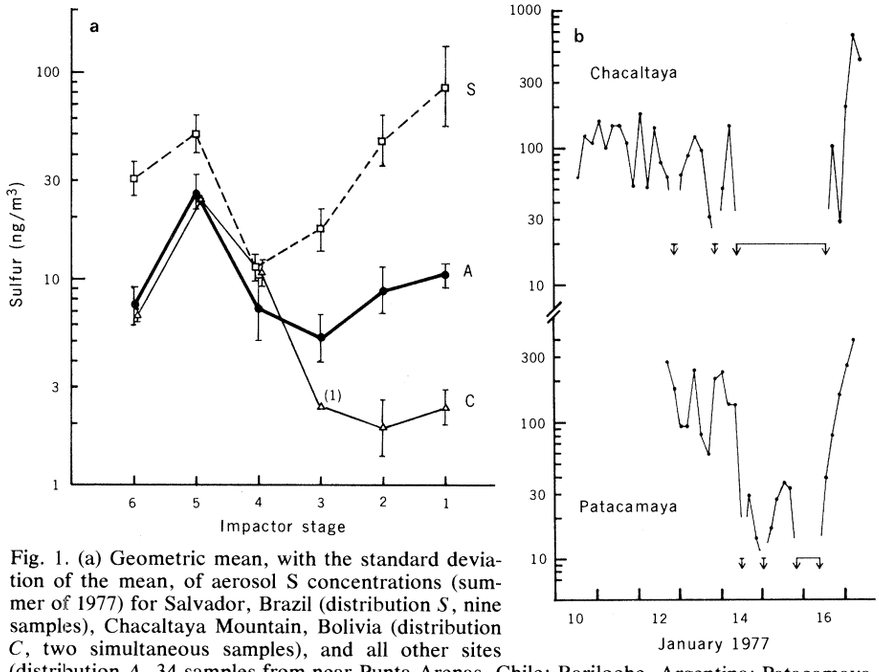

Fig. 1. (a) Geometric mean, with the standard deviation of the mean, of aerosol S concentrations (summer of 1977) for Salvador, Brazil (distribution *S*, nine samples), Chacaltaya Mountain, Bolivia (distribution *C*, two simultaneous samples), and all other sites (distribution *A*, 34 samples from near Punta Arenas, Chile; Bariloche, Argentina; Patacamaya and Zongo, Bolivia; and Manaus, Brazil). The maximum at stage 5 corresponds to particles with aerodynamic diameters between 0.25 and 0.5 μm. (b) Sulfur concentrations in 4-hour time steps of streaker samplers at two remote Bolivian sites: on Chacaltaya Mountain (altitude, 5200 m) and on the Altiplano near Patacamaya (altitude, 3800 m).

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gions a contribution from large-particle sea spray S is present, and for streaker samples a non-sea spray S component has been resolved by means of a regression analysis of S versus Cl (Table 1). The impactor data for inland locations show that S is more highly concentrated on fine particles. The South American summer 1977 impactor data from all but the sites in Brazil show an average fine-particle concentration of approximately 50 ng/m^3. The Salvador, Brazil, fine-particle value of 100 ng/m^3 may include contributions from the intense sea spray in this region and be elevated above the tropospheric S background component. The data from Firminópolis, Brazil, have higher fine-particle S concentrations, due possibly to anthropogenically induced biological contributions, such as seasonal forest burning (*5*). Otherwise, at the remote South American sites the concentrations of fine-particle S are similar throughout the continent and substantially lower than in U.S. locations.

Figure 1a is a plot of the size distribution of S for summer 1977 South American data. On Chacaltaya Mountain, the site possibly most representative of remote tropospheric aerosol, virtually all S is in a fine-particle mode. Distribution *A*, an average for five other locations, exhibits a similarly distinct fine-particle mode but somewhat higher coarse-particle (> 1 μm) S concentrations due in some regions, for example. Punta Arenas, to contributions of sea spray and in others, for example, Manaus and Zongo, to possibly biogenic aerosol (*12*). The Salvador samples (distribution *S*), taken on the coast only when onshore winds occurred, exhibit a relatively intense

Table 1. Comparison of sulfur concentrations. Values listed, except as noted, represent for impactors the geometric means and standard deviations of the geometric means, and for streakers the arithmetic means, of *N* samples, that is, *N* separately analyzed 4-hour time steps of streaker samples and *N* impactor measurements, each with three separately analyzed fine-particle fractions and three coarse fractions. Sources of data: South American summer (this work); South American winter (*5*); Namib Desert (*16*); Samoa (*17*); New Mexico, Colorado, New Hampshire, and Missouri (*10, 18*) [RAMS denotes Regional Air Monitoring System stations (Environmental Protection Agency)]; Florida (*19*); North Atlantic (*20*); Bermuda (*21*); and Sweden (*22*).

Date and location	Latitude and longitude	Streaker		Cascade impactor			
		N	Concentration (ng/m^3)	Sampling time (hours)	*N*	Fine (≤ 1 μm) (ng/m^3)	Coarse (≥ 1 μm) (ng/m^3)
Remote South American sites							
10 January to 9 March 1977 (summer)							
Punta Arenas, Chile (four sites)	53°S, 72°W			66–116	9	52(1.1)	25(1.2)
Cabeza del Mar		46	99*				
Puerto Oazy		47	76*				
San Gregorio		47	75*				
Discordia							
Bariloche, Argentina	41°S, 71°W	16	74	21–25	15	38(1.1)	13(1.2)
Chacaltaya Mountain, Bolivia	16.5°S, 68°W	42	84	171	2†	42(1.0)	5(1.3)
Patacamaya, Bolivia	17.3°S, 68°W	28	101	47–72	4†	44(1.0)	18(1.2)
Zongo, Bolivia	16.1°S, 68°W	12	52	45–48	4†	24(1.2)	21(1.2)
Manaus, Brazil	3°S, 60°W	12	127	20–24	2	83(1.7)	48(1.3)
Salvador, Brazil	13°S, 38°W	23	87*	5–10	9	98(1.1)	162(1.4)
9 July to 2 August 1976 (winter)							
Punta Arenas, Chile	53°S, 72°W			125	2†	11(1.4)	79(1.7)
Firminópolis, Brazil	17°S, 49°W			23–25	6†	132(1.2)	13(1.5)
Other nonurban Southern Hemisphere sites							
November 1976 to February 1977							
Namib Desert, South West Africa	23.5°S, 15°E			108–252	12	160(1.08)	133(1.08)
16 July to 20 September 1976							
Samoa	14°S, 170.5°W			72–120	34†	60(1.8)	87(1.6)
Nonurban North American sites							
13 to 22 April 1976							
Jemez Mountains, New Mexico	36°N, 106°W	111	332	48	10†	185(1.1)	29(1.1)
Squaw Mountain, Colorado	39.5°N, 105°W	57	293	24–74	8†	209(1.2)	18(1.3)
Hubbard Brook, New Hampshire	44°N, 71.5°W			24–48	8†	280(1.1)	21(1.4)
St. Louis, Missouri							
RAMS station 125 (suburban)	38.5°N, 91°W			24–48	7	1010(1.2)	81(1.6)
28 July to 7 August 1976							
Florida (ten sites)	26° to 31°N, 80° to 87°W			24	60		90(1.1)
Northern						1100(1.2)	
Southern						300(1.1)	
5 to 18 December 1976							
Florida (ten sites)	26° to 31°N, 80° to 87°W			24	60		170(1.1)
Northern						800(1.3)	
Southern						400(1.2)	
Other nonurban Northern Hemisphere sites							
7 to 25 August 1976							
Western North Atlantic	33° to 38°N, 65° to 70°W			8–68	26	810 ± 490‡	151 ± 95‡
27 October to 14 November 1973							
Bermuda	32.5°N, 65°W			50–100	10	532(2.6)	377(1.4)
December 1975 to December 1976							
Velen, Sweden	58°N, 13°E			24			
Northwest air (North Sea)					14	62(1.8)	21(1.9)
Southwest air (Britain and West Europe)					12	956(1.5)	146(2.2)

*Concentrations extrapolated to the zero Cl intercept, representing non-sea spray-related S. †Duplicate impactor samples were measured at these locations, that is, *N*/2 independent samples, except at Bariloche, where there are nine independent values. ‡Arithmetic mean and the standard deviation of the arithmetic mean.

coarse-particle contribution from sea spray and a higher fine-mode S concentration; these results suggest that sea spray may contribute to the background tropospheric submicrometer mode as well.

During the winter of 1976 in the Punta Arenas, Chile, region, fine-mode S concentrations were much lower than in the summer of 1977 (*13*). In a 1-week sampling period, the winds were southwesterly and the ground was covered by ~ 30 cm of snow, so that local terrestrial biological and soil contributions were minimal. (During the 2-week sampling period in the summer of 1977, the winds were generally westerly, although for $3^1/_2$ days some calm periods, northerly winds, and easterly winds were recorded.) The winter size distribution shows higher coarse-particle S concentrations than the summer values, perhaps due to a greater sea spray contribution in the higher-velocity southwesterly winds during that season, and fine-particle S concentration of ~ 10 ng/m^3, the lowest value measured in this investigation.

Figure 1b shows the time-sequence streaker data for S at Chacaltaya Mountain and Patacamaya, Bolivia. The two locations, separated by a distance of 100 km and an elevation of 1400 m, display similar time variation patterns in S concentration. Prior to noon on 14 January 1977, S concentrations averaged ~ 100 ng/m^3 or higher. From 14 January until noon on 16 January S concentrations remained below the detection limit of ~ 20 ng/m^3 at Chacaltaya and at nearly the same value at Patacamaya. After this episode, the S concentrations returned to their initial values at both locations; these results suggest large-scale meteorological effects on the observed S concentrations. During the episode of low S concentrations at Chacaltaya, the concentrations of the crustally derived elements such as Fe were also very low, although at Patacamaya larger amounts of Fe were found. Some soil dust may contribute to the aerosol at Patacamaya (*13*).

Local meteorological conditions such as rain or snow at these high elevations do not suggest an explanation for the low concentrations of S observed at both locations from 14 to 16 January. Nor do wind and atmospheric pressure readings from nearby La Paz, Bolivia, exhibit anomalies during this episode. Nevertheless, the chemical data suggest that there occurred during this period a large-scale incursion of air containing atypically low aerosol S concentrations, such as a subsidence of upper tropospheric or stratospheric air. The winter 1976 samples from Punta Arenas may also have been obtained during an atypical episode.

These data from remote locations on the South American continent indicate that fine-particle S concentrations are lower by at least a factor of 4 than corresponding values measured in nonurban western U.S. sites, by similar sampling and analysis techniques, and lower by a factor of 100 than sometimes found in the eastern United States (*1*). A fine-particle mode of S, averaging ~ 50 ng/m^3 (~ 150 ng/m^3 SO_4^{2-} equivalent), is observed with the cascade impactors at continental South American sites. The streaker data give somewhat higher values than the impactors, but the South American streaker values are still approximately one-fourth as large as the corresponding western U.S. samples (*14*). Occasionally higher values may occur, such as in Brazil, possibly due to forest burning (*5*), and lower values may also be observed, for example, the fine-particle mode of S during the winter near Punta Arenas and the January episode at two locations in Bolivia. On the average, aerosol S concentrations are much lower in nonurban South America than values used in previous calculations of the global S cycle (*15*).

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Keeping a Cool Head: Honeybee Thermoregulation

Abstract. *At high ambient temperatures, honeybees regulate head temperature by evaporative cooling of regurgitated honeycrop contents. Thoracic temperature is secondarily stabilized as heat flows from thorax to head by means of passive conduction and physiological facilitation resulting from accelerated blood flow. The mechanism permits flight at the extraordinarily high ambient temperature of 46°C without overheating the head and thorax despite prodigious amounts of heat produced as a by-product of flight metabolism. In contrast, at low ambient temperatures, thoracic rather than head temperature is regulated; no liquid is regurgitated, and the head is heated passively by conduction both in flight and while stationary.*

The common honeybee, *Apis mellifera*, has colonized near-arctic and temperate regions as well as humid tropical and hot desert environments. Honeybees can fly at air temperatures (T_A) as low as 10°C, some 18°C lower than their minimum muscle temperature for flight (*1*) and 8°C below the minimum temperature required for the generation of action potentials (*2*). On the other hand, they also regularly fly in the deserts of southwestern United States at T_A near

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