U.S. DEPARTMENT OF THE INTERIOR
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A Compilation of Sulfur Dioxide and Carbon Dioxide Emission-Rate Data from Cook Inlet Volcanoes (Redoubt, Spurr, Iliamna, and Augustine), Alaska During the Period from 1990 to 1994

by

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INTRODUCTION

Airborne sulfur dioxide (SO_2) gas sampling of the Cook Inlet volcanoes (Mt. Spurr, Redoubt, Iliamna, and Augustine, fig. 1) began in 1986 when several measurements were carried out at Augustine volcano during the eruption of 1986 (Rose and others, 1988). More systematic monitoring for SO_2 began in March 1990 and for carbon dioxide (CO_2) began in June, 1990 at Redoubt Volcano (Brantley, 1990 and Casadevall and others, 1994) and continues to the present. This report contains all of the available daily SO_2 and CO_2 emission rates determined by the U.S. Geological Survey (USGS) from March 1990 through July 1994. Intermittent measurements (four to six month intervals) at Augustine and Iliamna began in 1990 and continues to the present. Intermittent measurements began at Mt. Spurr volcano in 1991, and were continued at more regular intervals from June, 1992 through the 1992 eruption at the Crater Peak vent to the present.

A correlation spectrometer (COSPEC) was used to measure SO_2 in the Cook Inlet volcanic plumes. The upward-looking COSPEC was mounted in a fixed-wing aircraft and flown below and at right angles to the plume. The first traverse (or orbit) during a measurement was used to determine the size, location and direction of the volcanic plume. In some cases no SO_2 plume was detected by the instrument and a value of zero was reported as the SO_2 rate. Even though SO_2 may have been sensed by the operator's nose (more sensitive than the instrument), a rate of zero was still reported. Typically, three to six traverses were made underneath the plume to determine an average SO_2 burden (concentration multiplied by the pathlength) within a cross-section of the plume. Knowing the burden, the plume width and plume velocity (assumed to be the same as ambient wind speed), the emission rate of SO_2 was calculated. The resultant value of SO_2 is reported after values of more than one standard deviation from the average have been removed. All emission rates are reported in metric tons/day (t/d) above the background level upwind of the volcano. The use of correlation spectroscopy for determining the SO_2 output of volcanoes is well established and the technique has been discussed in detail by a number of investigators (Malinconico, 1979; Casadevall and others, 1981; Stoiber and others, 1983).

Carbon dioxide in the Cook Inlet volcanic plumes was measured by an infrared spectrometer (MIRAN) tuned to the 4.26 micrometers CO_2 absorption band. Volcanic CO_2 is defined as that gas detected within a volcano's plume that is in excess of the concentration of ambient CO_2 in the atmosphere. An external sample tube was attached to the fuselage of a twin-engine aircraft to deliver outside air to the gas cell of the MIRAN. The aircraft was then flown at several different but increasing elevations through the plume. These traverses were at right angles to the plume trajectory and defined plume area and CO_2 concentration in a vertical cross-section of the plume. Plume area, CO_2 density at the mean altitude of the plume, and the plume velocity (assumed to be equal to the ambient wind speed), were then used to calculate the CO_2 emission rate. The resulting calculated CO_2 emission rate is not an average of several measurements (as is the case for SO_2 emission values), but one value. During times of low emission rates and low wind speeds, orbits within a kilometer of the vent were required, which gave low results because of slow instrumental response times. Thus, some CO_2 measurements reported here are indicated to be minimum values. All emission rates are reported in metric tons/day (t/d) above the background level upwind of

the volcano. The use of infrared spectroscopy for determining the CO_2 output of volcanoes is discussed in detail by Harris and others (1981).

DISCUSSION

From March 1990 to October 1994, more than one hundred fixed-wing aircraft flights were made by the USGS in order to measure and characterize gas emissions from the Cook Inlet volcanoes. The dates and interval of measurements of SO_2 and CO_2 emissions at Cook Inlet volcanoes are listed in Table 1. Sulfur dioxide was detected on the majority of these flights. Sixty-four flights were made to Redoubt Volcano, most of which were made during the eruption of 1989-90 (table 1). Sulfur dioxide burden in the Redoubt plume fell below detection limits in May 1991 (fig. 2). Carbon dioxide was measured twice at Redoubt volcano in June of 1990 (fig. 2).and four times from 1992 to 1994. On a few occasions, two or three separate SO_2 gas-measurement flights to Redoubt volcano were made in a single day. In these cases all of the emission-rate values are listed for that day but are considered separate measurements (11, April, 1990 [2 flights]; 15, August, 1990 [3 flights]; 7, September, 1990 [2 flights]). Forty flights were made to Mt. Spurr volcano most of which were made during the 1992 eruption series (table 3). Sulfur dioxide burden at Mt. Spurr volcano (the Crater Peak vent) fell below detection limits in October of 1992 (fig. 3). Carbon dioxide levels were measured from September 1992 to the present at Mt. Spurr volcano (Fig. 3, table 1). Inflight measurements at Mt. Spurr volcano will continue until CO_2 levels are near background levels. Nine flights were made to Iliamna volcano (fig. 4, table 1). Seven flights were made to Augustine volcano (fig. 5, table 1). Carbon dioxide measurements were attempted at Augustine and Iliamna volcanoes during 1993 and 1994, with no gas detected above atmospheric concentrations. Portions of this database have been presented earlier by Casadevall and others (1994) and Doukas and Gerlach (in press).

ACKNOWLEDGMENTS

I acknowledge the efforts of the numerous individuals who contributed to the success of the USGS airborne gas measurement program in Alaska by participating in the gas flights. Funding for this work has been provided by the USGS Volcano Hazards Program and the USGS Global Change and Climate History Program.

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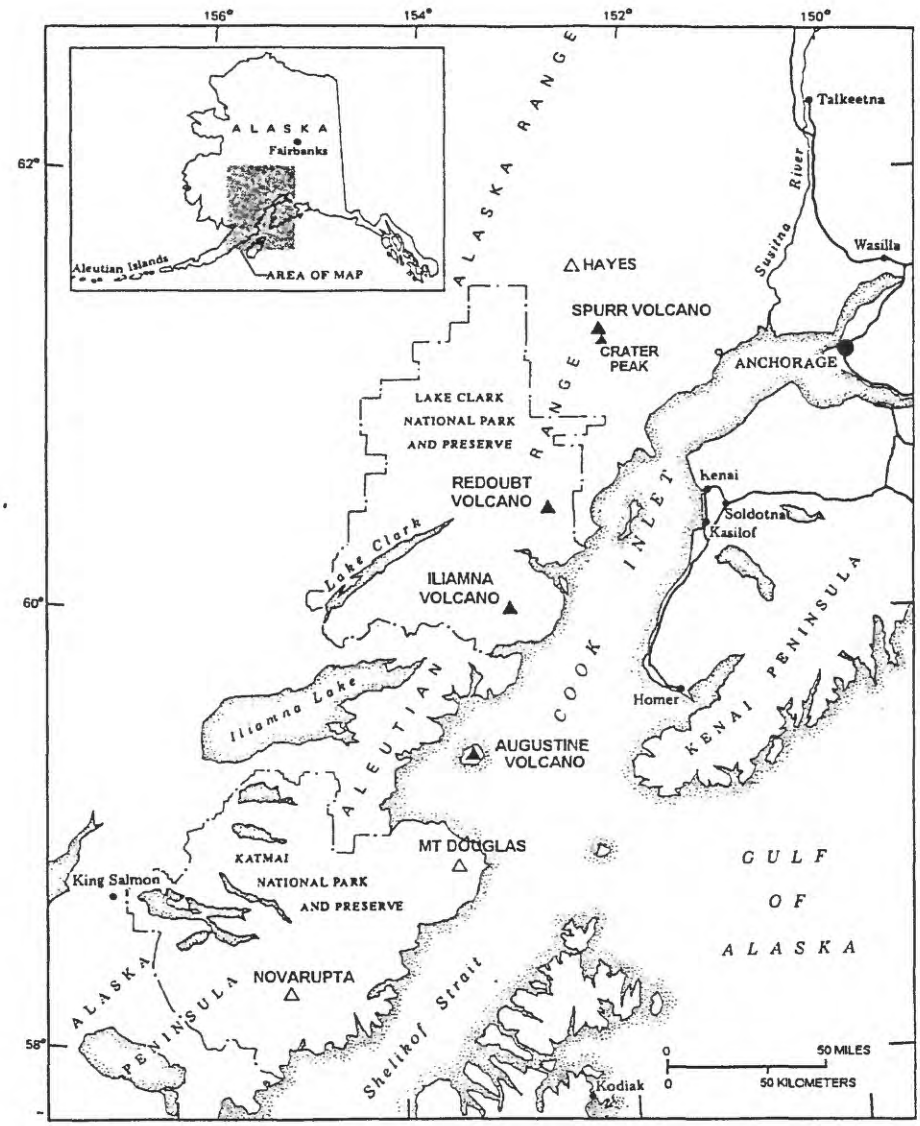

Figure 1. Index map showing the location of the Cook Inlet volcanoes included in this report. Filled triangles = volcanoes of this report; open triangles = location of other nearby volcanoes.

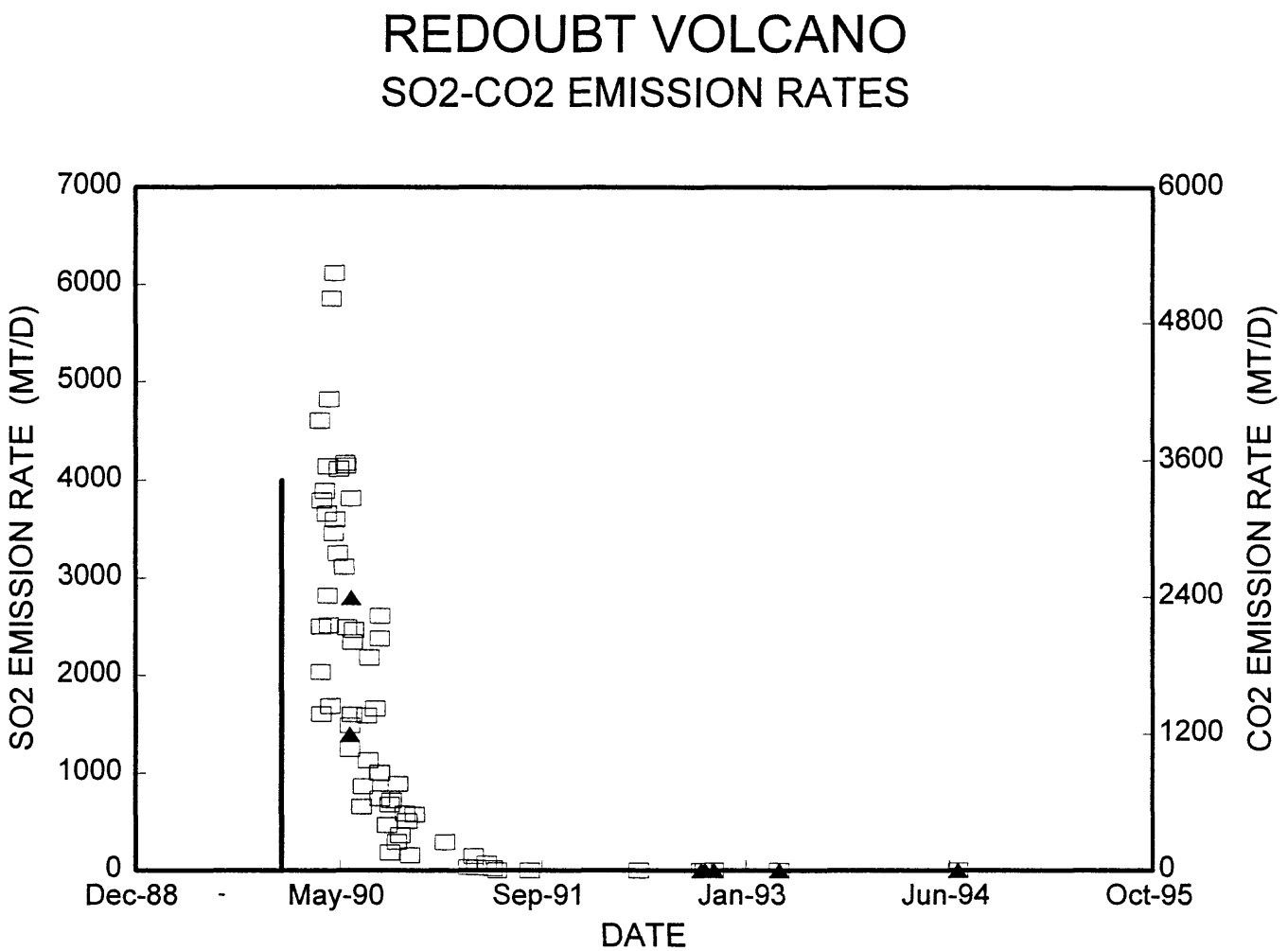

Figure 2. Graph of sulfur dioxide and carbon dioxide emission rates (in metric tonnes per day, MT/D) from Redoubt Volcano, March 1990 to April 1993. Open boxes = average sulfur dioxide emission rate for a single flight; closed triangles = carbon dioxide emission rate; vertical solid line = onset of 1989-1990 eruptions of Redoubt Volcano.

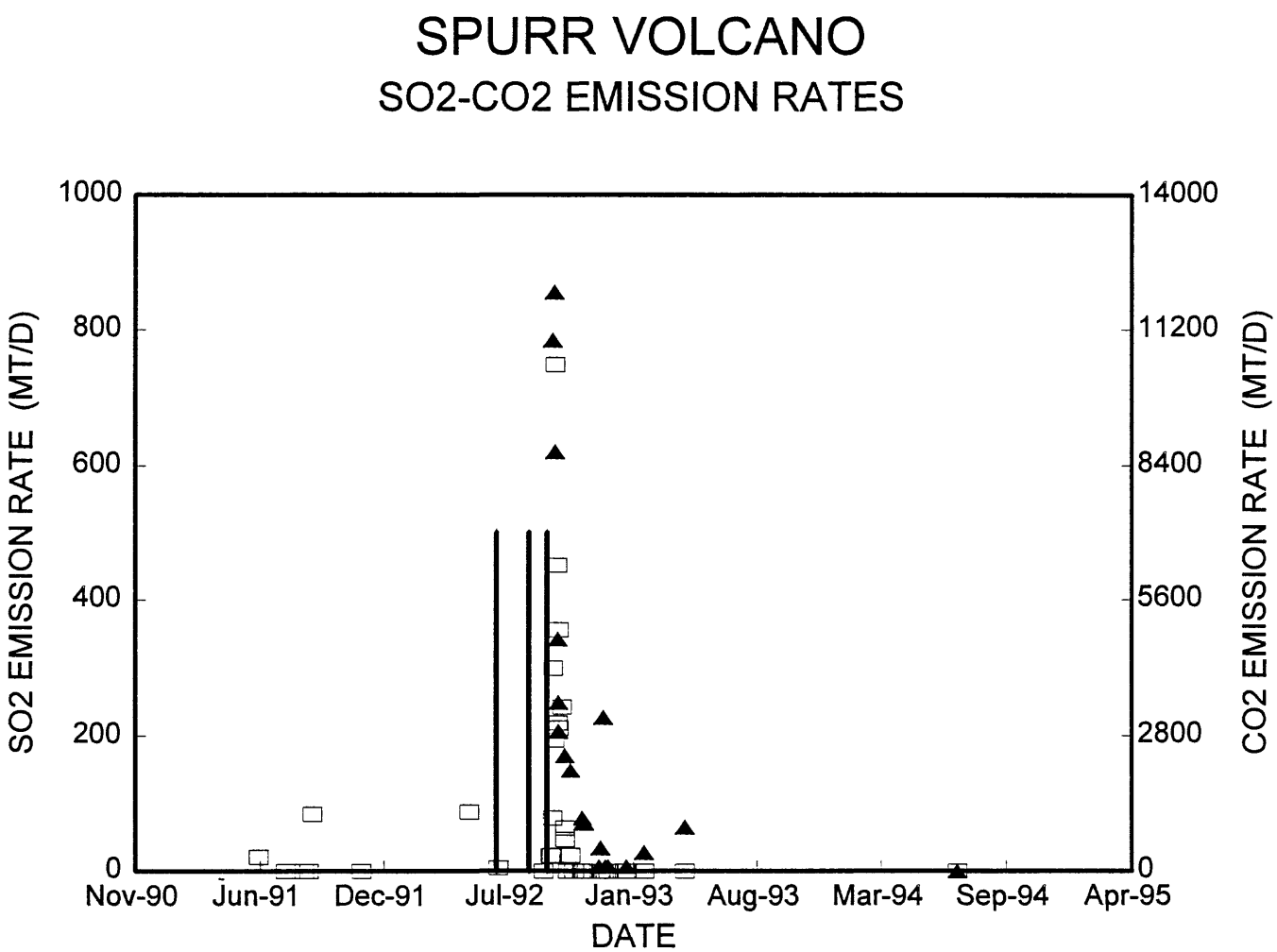

Figure 3. Graph of sulfur dioxide and carbon dioxide emission rates (MT/D) from Spurr volcano, July 1991 to July 1994. Open boxes = average sulfur dioxide emission rate; closed triangles = carbon dioxide emission rate; vertical solid lines = 1992 eruptions of Spurr volcano.

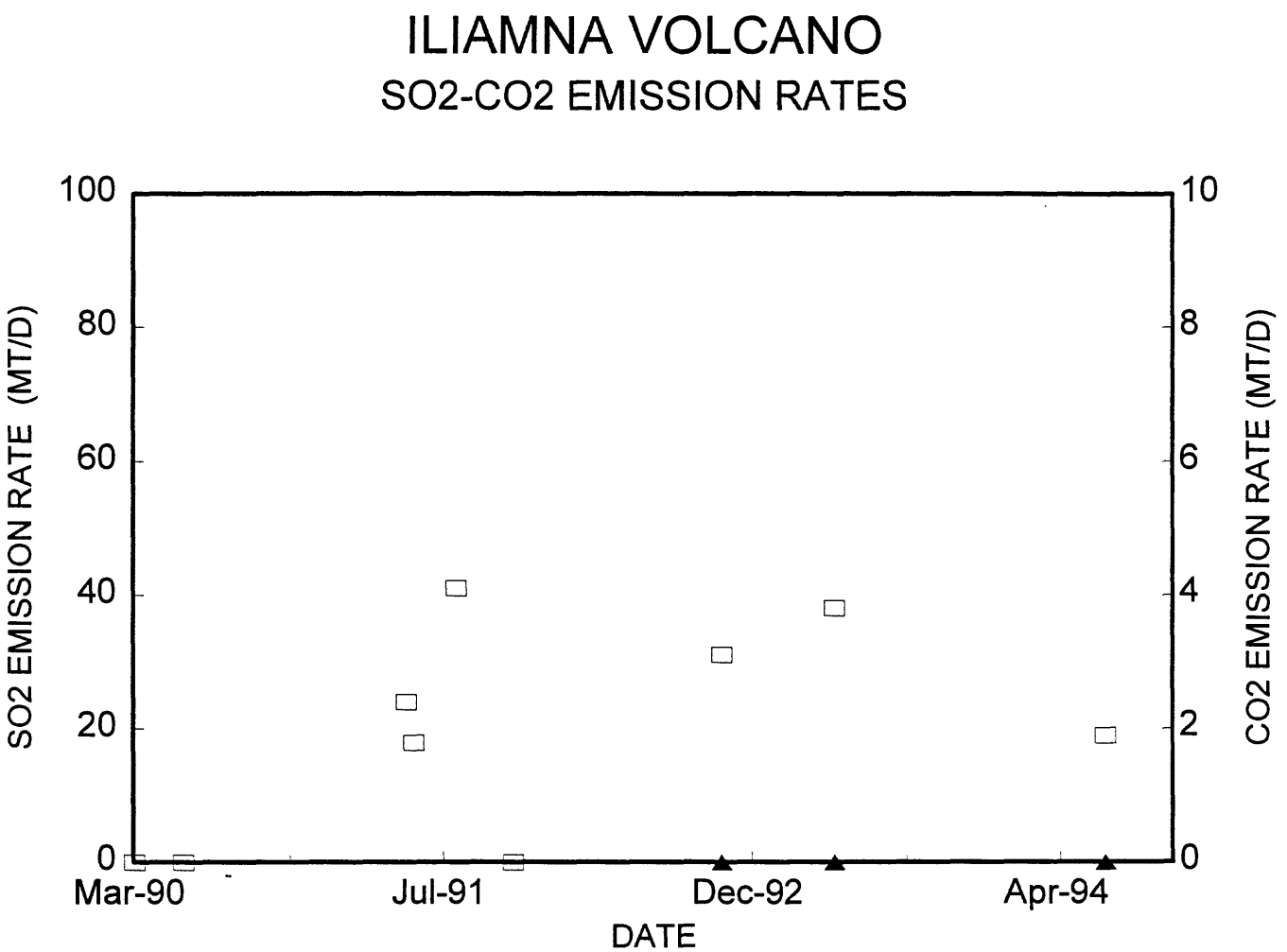

Figure 4. Graph of sulfur dioxide emission rates (MT/D) from Iliamna volcano, March 1990 to April 1993. Open boxes = average sulfur dioxide emission rate; closed triangle = CO_2 emission rate.

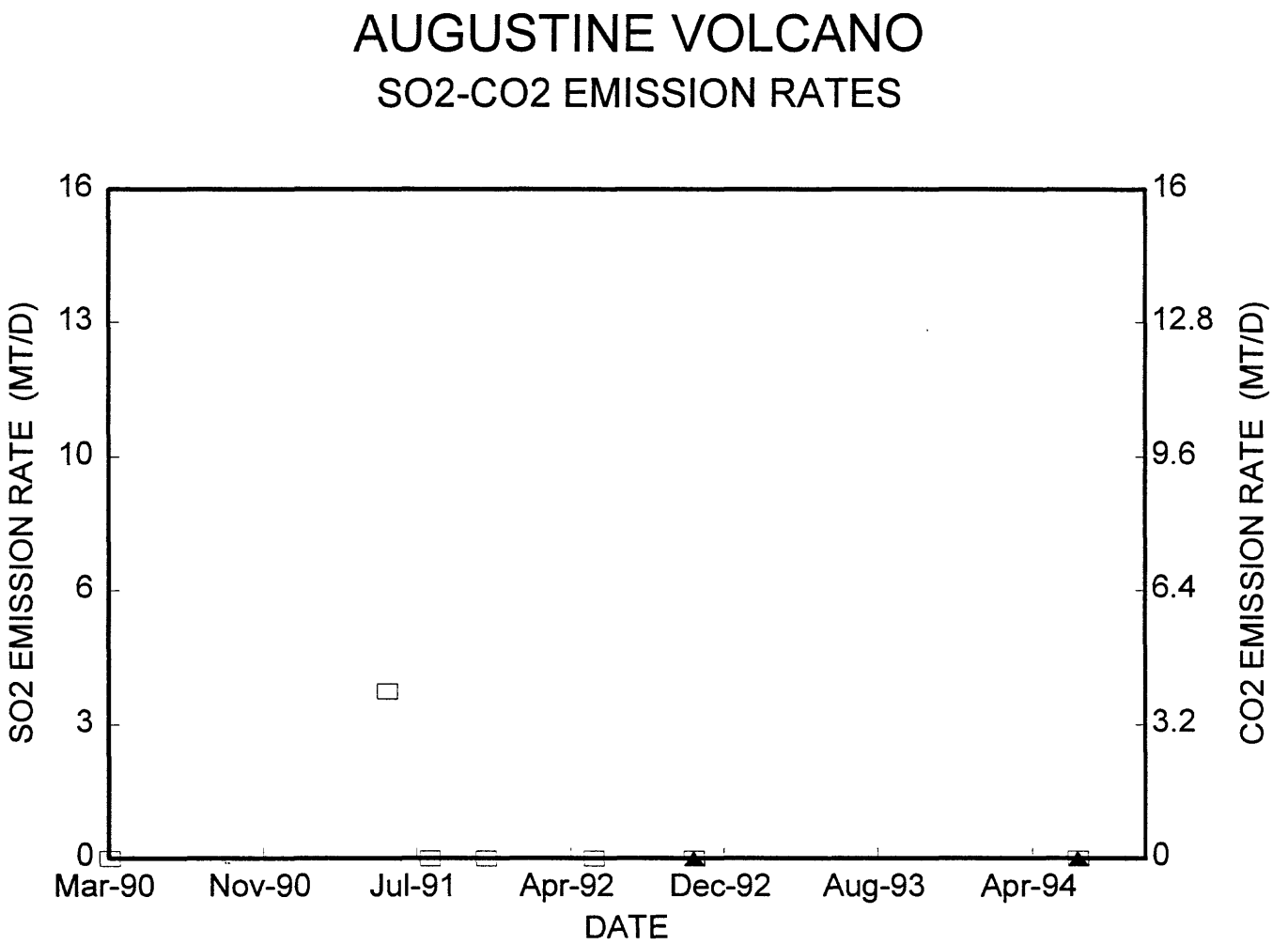

Figure 5. Graph of sulfur dioxide and carbon dioxide emission rates (MT/D) from Augustine volcano, March 1990 to July 1994. Open boxes = average sulfur dioxide emission rate; closed triangle = CO_2 emission rate.

Table 1. Beginning dates of SO_2 and CO_2 measurements at Cook Inlet volcanoes.

Volcano	SO_2-start	number of measurements	CO_2 - start	number of measurements
Redoubt	March, 1990	64	June, 1990	7
Spurr	July, 1991	40	Sept., 1992	25
Iliamna	March, 1990	9	Oct., 1992	3
Augustine	March, 1990	7	July, 1994	2

Table 2. SO_2 and CO_2 Emission Rates From Cook Inlet volcanoes (metric tons per day), number of traverses per flight (n), standard deviation (s.d.) for SO_2; no measurements (n.m.), minimum value (>).

REDOUBT VOLCANO

Date	SO_2 Rate	n	s.d.	CO_2 Rate
20-Mar-90	4609	5	534	n.m.
21-Mar-90	2033	8	261	n.m.
22-Mar-90	1609	6	148	n.m.
23-Mar-90	2502	6	97	n.m.
24-Mar-90	3798	4	182	n.m.
01-Apr.-90	3892	9	1151	n.m.
06-Apr.-90	3662	6	619	n.m.
07-Apr.-90	2819	7	584	n.m.
08-Apr.-90	4145	8	433	n.m.
11-Apr.-90	4826	7	1381	n.m.
11-Apr.-90	2510	8	190	n.m.
14-Apr.-90	1691	8	286	n.m.
17-Apr.-90	5855	8	752	n.m.
22-Apr.-90	3464	8	584	n.m.
25-Apr.-90	6121	8	967	n.m.
27-Apr.-90	3601	8	939	n.m.
03-May-90	3258	6	540	n.m.
04-May-90	4115	9	323	n.m.
19-May-90	3116	9	402	n.m.
20-May-90	4177	9	534	n.m.
22-May-90	4150	10	894	n.m.
25-May-90	2492	11	404	n.m.
01-June-90	1249	6	99	n.m.
02-June-90	1489	4	421	1200
05-June-90	3814	4	261	2400
07-June-90	1601	7	313	n.m.
09-June-90	2340	6	198	n.m.
11-June-90	2462	3	39	n.m.
30-June-90	657	6	100	n.m.
04-July-90	868	6	174	n.m.
12-July-90	1591	9	132	n.m.
16-July-90	1131	6	205	n.m.
19-July-90	2179	6	121	n.m.
03-Aug.-90	1660	6	219	n.m.
13-Aug.-90	1008	5	115	n.m.
14-Aug.-90	2376	6	138	n.m.

TABLE 2. continued

REDOUBT VOLCANO

Date	SO_2 Rate	n	s.d.	CO_2 Rate
15-Aug.-90	1002	6	183	n.m.
15-Aug.-90	742	6	37	n.m.
15-Aug.-90	2609	5	368	n.m.
31-Aug.-90	469	5	161	n.m.
07-Sept.-90	188	4	21	n.m.
07-Sept.-90	680	3	81	n.m.
13-Sept.-90	723	4	78	n.m.
25-Sept.-90	297	6	43	n.m.
28-Sept.-90	897	6	89	n.m.
03-Oct.-90	366	8	21	n.m.
15-Oct.-90	586	4	36	n.m.
21-Oct.-90	510	9	76	n.m.
27-Oct.-90	162	8	36	n.m.
08-Nov.-90	577	8	158	n.m.
23-Jan.-91	297	2	140	n.m.
21-Mar.-91	35	7	10	n.m.
04-Apr.-91	149	9	45	n.m.
10-Apr.-91	29	5	11	n.m.
06-May-91	73	5	25	n.m.
22-May-91	24	4	7	n.m.
31-May-91	0	2	0	n.m.
21-Aug.-91	0	2	0	n.m.
14-May-92	0	1	0	n.m.
14-Oct.-92	0	2	0	0
23-Oct.-92	0	1	0	0
15-Nov.-92	0	1	0	0
24-Apr.-93	0	2	0	0
07-July-94	0	2	0	0

SPURR VOLCANO

Date	SO_2 Rate	n	s.d.	CO_2 Rate
22-July-91	0	1	0	n.m.
21-Aug.-91	0	2	0	n.m.
29-Aug.-91	0	2	0	n.m.
03-Sept.-91	85	2	18	n.m.
22-Nov.-91	0	2	0	n.m.
14-May-92	88	2	10	n.m.

TABLE 2. continued
SPURR VOLCANO

Date	SO_2 Rate	n	s.d.	CO_2 Rate
08-June-91	21	2	4	n.m.
29-June-92	5	5	3	n.m.
10-Sept.-92	0	0	0	n.m.
21-Sep-92	23	5	12	n.m.
23-Sep-92	24	4	7	n.m.
24-Sep-92	79	3	11	n.m.
25-Sep-92	300	4	54	11000
28-Sep-92	194	4	25	12000
29-Sep-92	749	3	75	8700
02-Oct.-92	452	2	0	n.m
03-Oct.-92	220	4	114	4800
04-Oct.-92	212	4	72	3500
05-Oct.-92	356	4	173	2900
10-Oct.-92	243	3	100	n.m
14-Oct.-92	47	3	4	2400
15-Oct.-92	64	2	4	n.m.
16-Oct.-92	105	4	16	>2000
19-Oct.-92	0	1	0	>0
23-Oct.-92	24	2	3	2100
29-Oct.-92	0	1	0	>0
10-Nov.-92	0	1	0	0
11-Nov.-92	0	3	0	0
12-Nov.-92	0	1	0	1100
13-Nov.-92	0	1	0	1000
15-Nov.-92	0	1	0	1000
08-Dec.-92	0	1	0	>1000
11-Dec.-92	0	1	0	>500
15-Dec.-92	0	1	0	3200
18-Dec.-92	0	1	0	>1000
23-Dec.-92	0	1	0	>1000
21-Jan.-93	0	1	0	>1000
18-Feb.-93	0	1	0	>400
24-Apr.-93	0	1	0	>930
07-July-94	0	1	0	0

TABLE 2. continued

ILIAMNA VOLCANO

Date	SO_2 Rate	n	s.d.	CO_2 Rate
20-Mar-90	0	2	0	n.m.
05-June-90	0	2	0	n.m.
31-May-91	24	4	5	n.m.
13-June-91	18	2	4	n.m.
21-Aug.-91	41	3	9	n.m.
21-Nov.-91	0	3	0	n.m.
23-Oct.-92	35	2	6	0
24-Apr.-93	38	2	5	0
07-July-94	19	2	6	0

AUGUSTINE VOLCANO

Date	SO_2 Rate	n	s.d.	CO_2 Rate
20-Mar-90	0	2	0	n.m.
13-June-91	4	3	1	n.m.
21-Aug.-91	0	2	0	n.m.
20-Nov.-91	0	2	0	n.m.
14-May-92	0	2	0	n.m.
23-Oct.-92	0	1	0	0
07-July-94	0	2	0	0

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