VARIATIONS OF THE MARTIAN CO_2 ABUNDANCE WITH MARTIAN SEASON

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Abstract. All previous published equivalent widths of the Martian CO_2 bands including the 1967 apparition coverage at McDonald Observatory are reduced to CO_2 abundances using the same curve of growth parameters. The corresponding CO_2 partial pressures (assuming a pure CO_2 atmosphere), along with the regression curves of the north polar cap, are presented as functions of Martian heliocentric longitudes, L_s. A correlation is noted between the maximum CO_2 abundance and minimum north cap diameter and the decrease in CO_2 abundance when the northern polar haze begins to reform. Preliminary results of the 1969 apparition coverage at McDonald Observatory are also presented.

The CO_2 abundance is most easily determined from the 0.87 μ and 1.05 μ bands and practically all ground-based measurements have been made with these bands. The first such observations, dating from 1963 and 1965, happened to be limited to brief periods; hence, it was simply not possible to detect any seasonal variation in CO_2 abundance. During 1967 the seasonal coverage was extended an additional four months, primarily by our observations at McDonald Observatory.

Our present program at McDonald Observatory is to obtain as long a baseline as possible in Martian season to measure any seasonal variation in the atmospheric constituents of Mars, primarily the CO_2 abundance and the water vapor content. Numerically, Martian season can be represented as heliocentric longitude, L_s. Whenever telescope time on the 107-inch reflector or 82-inch Struve reflector is available (between other observations or during twilight or daytime hours), spectrographic observations of the CO_2 bands between 0.87 μ and 1.22 μ are made.

Many different abundance observations have been made since 1963. Table I contains all published abundances and corrected abundances which have been obtained by reducing the respective equivalent widths under the same conditions (broadening factors, temperature, band strengths, and atmospheric composition). These abundances were determined using the same curve of growth analysis which provides the 'best fit' CO_2 abundance and surface pressure. (For a more complete and detailed description of the procedures and computer programs used, see Barker (1969).) For simplicity, the results for a pure CO_2 atmosphere will be presented, although the trends are similar in nature when a fixed pressure-abundance product is assumed.

It is straightforward to convert from CO_2 abundances to CO_2 partial pressures. The partial pressures corresponding to spectra taken at McDonald Observatory during the 1967 apparition are shown in Figure 1 as a function of Martian season, or L_s. (L_s is defined as 0° at the northern spring equinox.) The polar cap measurements were by Capen (1966, 1969) of the Jet Propulsion Laboratory with several telescopes, including the 82-inch Struve reflector. Figure 2 combines all previous measurements

Sagan et al. (eds.), Planetary Atmospheres, 196–202.

TABLE I

CO_2 abundances determined during 1963, 1965, and 1967 apparitions

Author	Plate number	L_s (°)	Published CO_2 abundance (m-atm)	Corrected CO_2 abundance (m-atm)	CO_2 partial pressure (mb)
Kaplan *et al.* (1964)	—	76	50 ± 20	43 ± 10	3.1 ± 0.7
Kliore *et al.* (1966)	—	139	90 ± 20	90 ± 20	6.7 ± 1.4
Belton and Hunten (1966)	—	—	68 ± 26	72 ± 15	5.3 ± 1.2
Owen (1966)	C4365	82	56	56 ± 11	4.1 ± 0.8
	C4367	82	65	65 ± 13	4.8 ± 1.0
	C4368	82	62	62 ± 12	4.7 ± 0.9
	C4376	84	65	65 ± 13	4.8 ± 1.0
	C4381	85	52	52 ± 10	3.8 ± 0.7
Spinrad *et al.* (1966)	C4290	47	93	93 ± 33	6.9 ± 2.4
	C4298	49	82	80 ± 46	5.9 ± 3.6
	C4304	49	88	90 ± 14	6.6 ± 1.0
	C4347	59	118	129 ± 43	9.5 ± 3.2
	C4387	110	111	121 ± 46	8.9 ± 3.4
	C4392	110	110	115 ± 41	8.5 ± 3.0
	C4396	112	125	140 ± 15	10.2 ± 1.1
	C4406	114	111	120 ± 42	8.8 ± 3.1
	EC4037a	72	112	134 ± 63	9.9 ± 4.7
	EC4037b		64	73 ± 23	5.4 ± 1.7
	EC4090	81	70	74 ± 64	5.4 ± 4.8
	EC4120a	84	98	95 ± 61	7.0 ± 4.5
	EC4120b		61	67 ± 37	4.9 ± 2.7
	EC4272a	112	51	74 ± 64	5.5 ± 4.7
	EC4272b		45	42 ± 23	3.1 ± 1.7
	EC4287a	122	111	114 ± 46	8.4 ± 3.4
	EC4287b		51	75 ± 68	5.5 ± 5.0
Belton *et al.* (1968)		120–122	75–77	71 ± 19	5.3 ± 1.5
Giver *et al.* (1968)		131–135	61	58 ± 10	4.3 ± 0.8
Carleton *et al.* (1969)		110–122	83 ± 11	83 ± 11	6.1 ± 0.8
Munch (1969)		120	76 ± 9	81 ± 18	6.0 ± 1.3
Owen (1968)	—	120	75 ± 15	—	—

of the CO_2 partial pressure given in Table I with the 1967 McDonald data. The following conclusions can be tentatively drawn from the data.

The maximum CO_2 abundance occurs at L_s values, when the north polar cap has finished the major portion of its annual shrinking; and as the northern polar cap begins to reform as a polar haze in the Martian autumn, the CO_2 abundance drops significantly to a minimum near $L_s = 220°$. Our 1969 observations of the CO_2 abundance are filling in the region from $L_s = 140°$ to 300°. (A mean correction for elevation differences based on the 1967 radar data of Pettengill *et al.* (1969) has been applied to the 1967 McDonald data and the result is to slightly increase the scatter in the partial pressures, but the conclusions remain the same.)

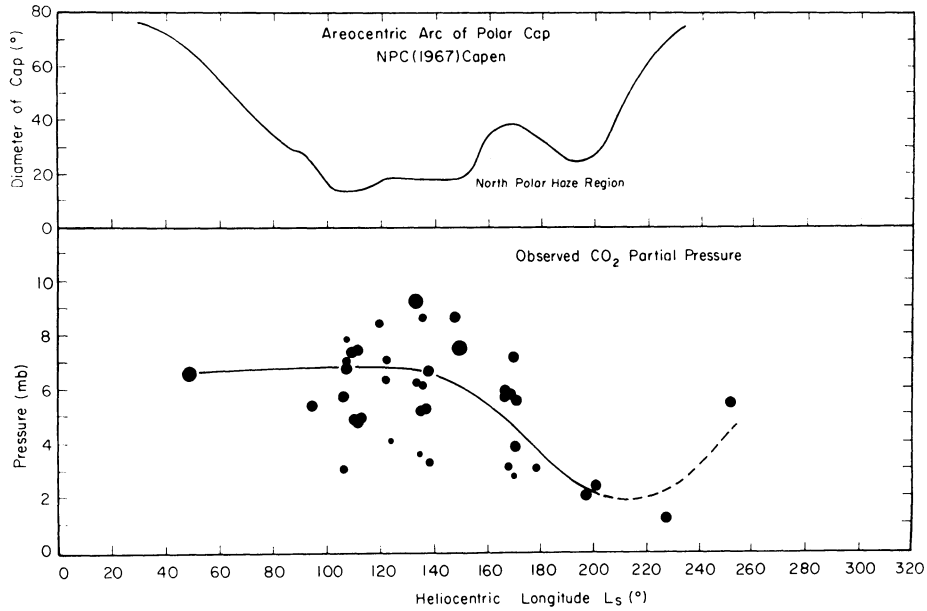

Fig. 1. Regression curve for north polar cap in 1966–67. CO_2 partial pressures obtained from 1967 McDonald spectra as a function of L_s. Barker (1969).

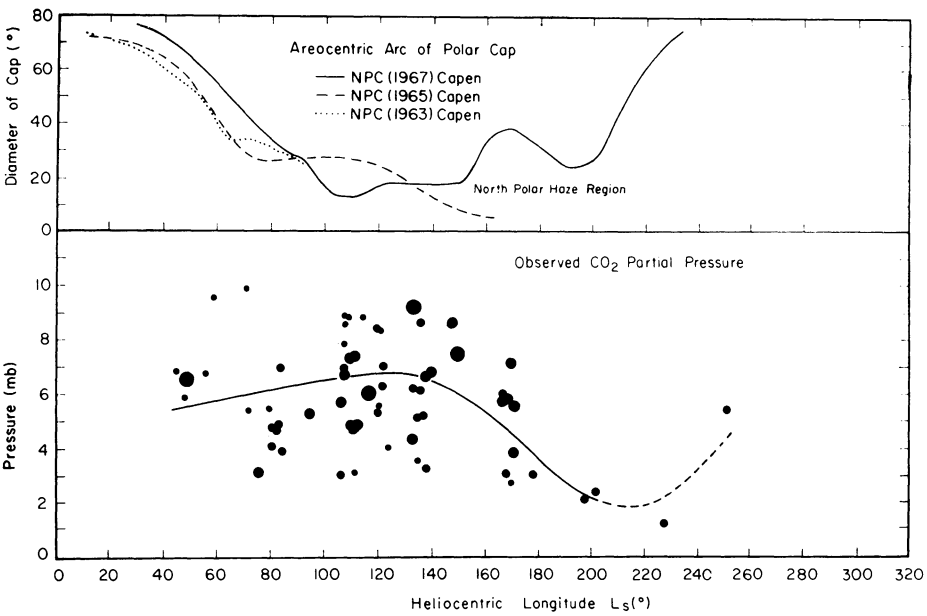

Fig. 2. Regression curves for north polar cap and all CO_2 partial pressures obtained during the 1963, 1965, and 1967 Martian apparitions.

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Our Mars observations at McDonald Observatory during the 1969 apparition began at an L_s of 56° (October 1968) and will continue in 1970. The 1969 McDonald spectral coverage of Mars in the 0.87, 1.03, 1.05, and 1.2 μ CO_2 bands as a function of L_s is shown schematically, with each dot referring to a usable spectrum in Figure 3. The 8700 Å bands were recorded on hypersensitized IV-N emulsions at 2.0 to 4.0 Å/ mm. The 1 μ bands were observed with the RCA Carnegie infrared image tube at a dispersion of 3.6 Å/mm and a resolution of 0.15 Å.

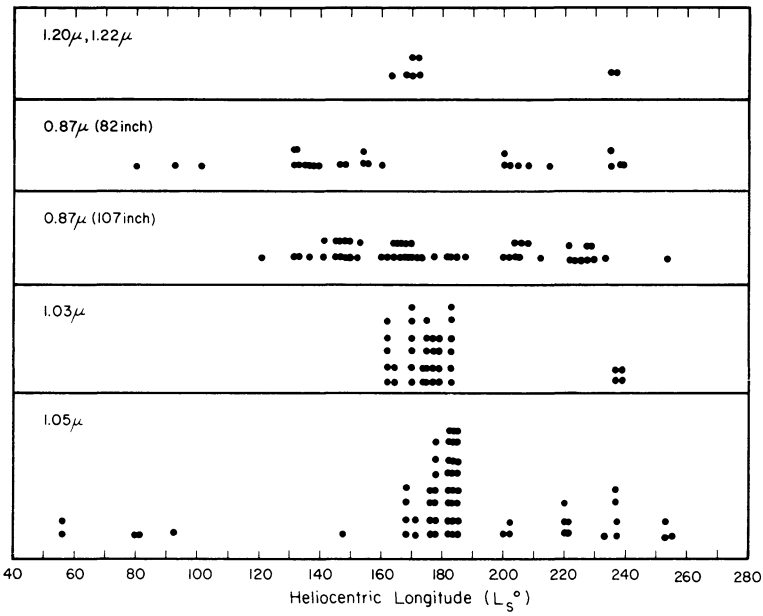

Fig. 3. 1969 McDonald coverage of the 0.87, 1.03, 1.05, and 1.2 μ CO_2 bands. Each dot represents a usable spectrum.

Because of the press of observing time and very recent reduction of most of the data, only a few representative spectra have been reduced by this time for presentation. The CO_2 abundances and corresponding partial pressures (assuming a pure CO_2 atmosphere), appear in Table II. The CO_2 partial pressures are shown in Figure 4, along with Capen's (1969) measurements of the north polar cap that have been reduced at the present time. These partial pressures have been obtained from spectra of the full planet and represent the mean value over the meridional strip accepted by the spectrograph slit. The filled square refers to a mean of ten 1.05 μ spectra taken within 2° of L_s near opposition.

The trend is similar to that observed in 1967, and indicates a possible decline toward a minima beyond an L_s of 200°. Only further observations and a complete reduction of the spectra will show the actual minima. The presented data were obtained prior to the middle of August. Many spectra have been taken since then, and we plan to follow Mars into early 1970, which corresponds to L_s values of 300 to 320°.

One must take into account the effect of the Martian topography which transits

TABLE II

CO_2 abundances determined during 1969 apparition from full planet spectra

Coudé No.	L_s (°)	L_{cm} (°)	ω (m-atm)	CO_2 partial pressure (mb)
	0.87 μ band			
5902	79.8	283	151 ± 32	11.1 ± 2.3
6147	132.6	224	132 ± 40	9.8 ± 3.0
6152	134.5	170	141 ± 26	11.6 ± 1.9
6163	145.9	306	106 ± 16	7.8 ± 1.2
6166	146.7	290	134 ± 33	9.9 ± 2.4
6185	153.6	181	142 ± 39	10.4 ± 2.9
6194	154.1	174	131 ± 43	9.7 ± 3.2
76	167.9	264	99 ± 34	7.3 ± 2.5
77	168.0	300	104 ± 26	7.7 ± 2.0
6393	199.1	82	96 ± 24	7.4 ± 1.7
6406	203.9	8	110 ± 30	8.1 ± 2.2
146	211.8	254	115 ± 30	8.5 ± 2.2
	1.05 μ band			
Coudé No.	L_s (°)	L_{cm} (°)	ω (m-atm)	CO_2 partial pressure (mb)
5903	79.8	336	103 ± 23	7.6 ± 1.9
6175B	147.9	270	35 ± 9	2.8 ± 0.7
6251	168.9	261	56 ± 11	4.1 ± 0.8
6269A	170.5	162	97 ± 15	7.2 ± 1.3
6358	181.7	157	40 ± 9	2.9 ± 0.7
6359A	181.7	10	93 ± 24	6.9 ± 1.9
6359C	181.7	40	134 ± 35	10.0 ± 2.8
6363A	182.2	334	93 ± 28	6.9 ± 2.2
6363B	182.2	348	57 ± 14	4.2 ± 1.1
6363C	182.2	3	99 ± 19	7.3 ± 1.6
6364A	182.2	18	95 ± 23	7.0 ± 1.8
6364C	182.3	48	81 ± 26	6.0 ± 1.9
6371A	182.8	321	127 ± 27	9.4 ± 2.2
6371B	182.8	335	72 ± 17	5.3 ± 1.4
6403	201.5	32	90 ± 18	6.6 ± 1.5
6404	201.5	65	34 ± 5	2.4 ± 0.5

under the spectrographic slit during the exposure. No correction for mean topographic differences has been applied at this time to the CO_2 partial pressures shown in Figure 4. In fact the central meridian values, L_{cm}, for the three low partial pressures shown in Figure 4, correspond to central meridians where highlands were indicated in the central regions of the Martian disk by Woszczyk and Belton (see papers presented during this symposium). An attempt will be made to remove the effect of elevation differences when the results of Woszczyk and Belton appear in final form. The

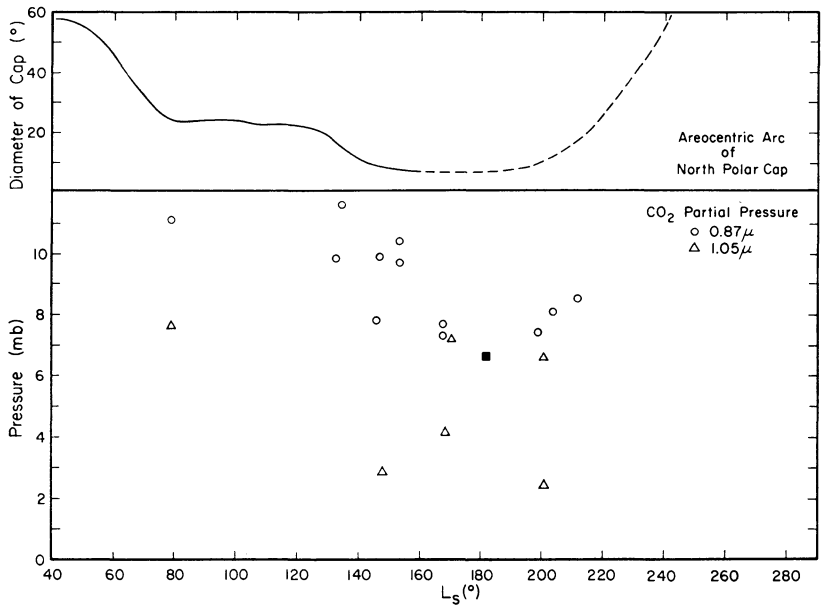

Fig. 4. Regression curve for north polar cap and some CO_2 partial pressures obtained during the 1969 Martian apparition.

radar topographic profiles of Pettengill *et al.* (1969) and Rogers *et al.* (1969) will also be used in this correction procedure. The effect of topographic differences may be so large that it may be impossible to assign a total CO_2 abundance to the Martian atmosphere at a given seasonal date without a thorough knowledge of the topography for the entire planetary surface.

Such a phenomenon as the CO_2 partial pressure variation was predicted by Leighton and Murray (1966) based on their CO_2 polar cap model. They predicted a double-sine wave variation over the Martian season based on the assumption that the polar caps were primarily composed of CO_2 and the total atmospheric CO_2 abundance is determined by the season and extent of the polar caps. Their variation is similar in shape, but the magnitude of the variation is smaller and the minima in the CO_2 partial pressure occurs at an L_s of 160°. The aim of this long-range program is to develop a complete set of data, which can be used to test models of the polar cap composition such as Leighton and Murray's.

Summary

Since CO_2 is the major constituent of Martian atmosphere (probably 70% or greater), any variation in the CO_2 partial pressure must constitute a proportional variation in the total atmospheric pressure. Based on the spectra reduced up to the present, we believe that the CO_2 abundance varies by a factor of two; thus, presumably the Martian surface pressure varies by almost a factor of two, and this variation is correlated with the waxing and waning of the polar caps or Martian season.

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