Atmospheric CO Concentrations on the Greenland Ice Cap

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Measurements of atmospheric CO concentrations were made at Inge Lehmann Station, Greenland (78°N, 39°W), over the period July 23–August 3, 1967. During this period CO concentrations ranged from 0.05 ppm on August 2 to a high of 0.65 ppm on July 29. The period of high concentrations occurring around July 29 coincided with the passage of an air mass which had previously traversed the Great Lakes and northeastern United States. On the basis of these limited observations, it is estimated that arctic air masses passing over Greenland have CO concentrations of between 0.10 and 0.20 ppm; however, concentrations of 0.5 to 1.0 ppm can occur when the air mass has recently traversed heavily populated areas. These Greenland observations are generally comparable with other CO measurements from polar areas.

INTRODUCTION

The discovery of carbon monoxide, CO, in significant quantities in the earth's atmosphere was first reported by *Migeotte* [1949] on the basis of newly detected absorption in the solar spectrum around 4.7μ. These initial observations were later confirmed by several other investigators, and, although there was considerable variation in the estimated atmospheric CO concentration, the identification of CO as a measurable trace constituent of the atmosphere was generally established. *Junge* [1963] provides a useful summary of these initial solar spectra CO determinations. From these data Junge estimated a ground-level concentration range for CO from 0.01 to 0.2 ppm.

Direct measurement of nonurban atmospheric CO concentrations was hampered by lack of suitable instrumentation for these low-background concentrations. An atmospheric CO research program at Stanford Research Institute (SRI) succeeded in developing a field CO analyzer in 1965 that had sufficient sensitivity to measure background CO in remote atmospheres [*Robbins et al.* 1968]. Some of the initial data from the SRI study indicated background CO concentrations in the range 0.03 to 0.8 ppm in remote areas of the United States west coast [*Robbins et al.*, 1968].

This paper presents the results of a CO measurement program conducted on the Greenland ice cap at Inge Lehmann Station, 690 km ENE of Thule AFB. The sampling program covered the period from July 23 through August 3, 1967. Although this is obviously a short period for atmospheric analysis, the results provide some interesting and important information on atmospheric concentrations of CO.

INSTRUMENTATION AND SAMPLING SITE

The SRI CO analyzer used in the Greenland sampling program has been described in detail by *Robbins et al.* [1968], and only a brief description will be given here. The operating principle of the analyzer is the reaction of CO in the sample air stream with a bed of hot mercuric oxide (HgO) followed by the photometric determination of the Hg vapor produced using the strong Hg absorption line at 2537 A. The design of the analyzer and, in particular, of the HgO cell is such that the CO measurement is not affected by the usual atmospheric concentrations of water vapor, H_2, and CH_4. Although the detector is sensitive to reactive organics such as ethylene and acetone, concentrations of these materials are probably unimportant in remote locations such as Greenland where the detector has been used for tropospheric CO background studies. The analyzer is calibrated by metering the escape from a tank of known CO concentration into a CO-free air stream.

The sampling site at Inge Lehman Station (ILS) was about 50 meters north of the small camp facility. This camp was established by the

U. S. Air Force and the Danish Government in 1966 as a seismic monitoring station to determine the seismic properties of a remote ice cap area as part of the USAF Project Blue Ice [*Hjortenberg and Young*, 1967]. The camp site is at 77°57'N and 39°11'W; station altitude is 2200 meters. The ice cap is a uniform snow-covered plain, and the nearest snow-free area is more than 500 km. away. The camp housed a field party of six during this period of CO analyses. Diesel power generators at ILS were a possible interference, but our upwind sampling site and the dominance of northerly winds effectively shielded the site from camp influences. Local vehicles did not operate upwind. The CO analyzer was housed in a small unheated sled-mounted wanigan. The sampler inlet was about 3 meters above the snow surface. Teflon was used for the inlet. We believe that the CO data from this study are truly representative of the low-altitude CO concentrations at this location and that the changes observed represent real CO concentration patterns.

This ice cap sampling program was a severe test of the CO analyzer, and some weak points in its design were revealed. The major problem was excessive drift both in the baseline and in sensitivity. This was attributed to temperature-sensitive electronic components. Consequently, frequent calibration was necessary, and unattended operation for extended periods of time was impossible. Because of the drift problem, the data used in this paper have been limited to those obtained as soon as stable operation was attained after calibration. Thus arbitrary decisions about the nature of any drift were not required. On a qualitative basis it was apparent that changes in CO concentration occurred gradually during the test period. Considering the isolated location, this was certainly expected.

Sampling Results

The data resulting from this analysis of atmospheric CO at ILS are shown in Table 1. These data are plotted versus time in Figure 1. The dotted line (Figure 1) represents an attempt to indicate an average pattern of CO throughout the sampling period without trying to include what seem to be diurnal fluctuations.

These sampling results indicate that CO concentrations of July 23 were relatively low, about

TABLE 1. Atmospheric Carbon Monoxide Concentrations, Inge Lehmann Station, Greenland (77°57'N, 39°11'W), July 23–August 3, 1967

Date	Time	CO Concentrations, ppm	Calibration Time
7/23	0915	0.090	0900
	1100	0.160	1045
	1530	0.130	1500
	1600	0.110	1545
7/24		No data	
7/25	2200	0.275	2145
7/26	1615	0.200	1600
	1730	0.175	1715
	1915	0.130	1900
	1945	0.120	1930
	2100	0.110	2150
7/27	1100	0.210	1045
	1240	0.335	1230
	1500	0.274	1450
	1800	0.210	1745
7/28	1030	0.520	1015
	1400	0.410	1345
7/29	1055	0.380	1050
	1235	0.650	1230
	1430	0.550	1420
	1530	0.510	1520
	1700	0.650	1650
	1915	0.325	1905
	2030	0.290	2040
7/30	1230	0.280	1200
	1600	0.230	1540
	2010	0.180	1940
	2050	0.200	2110
7/31	1315	0.130	1305
	1345	0.150	1350
	1530	0.190	1545
	1930	0.170	1910
8/1	1215	0.220	1200
	1345	0.170	1320
	1530	0.160	1455
	1700	0.160	1645
8/2	1145	0.060	1110
	1300	0.060	1310
	1445	0.075	1435
	1550	0.050	1545
	1930	0.110	1925
	2030	0.115	2020
8/3	1100	0.175	1030

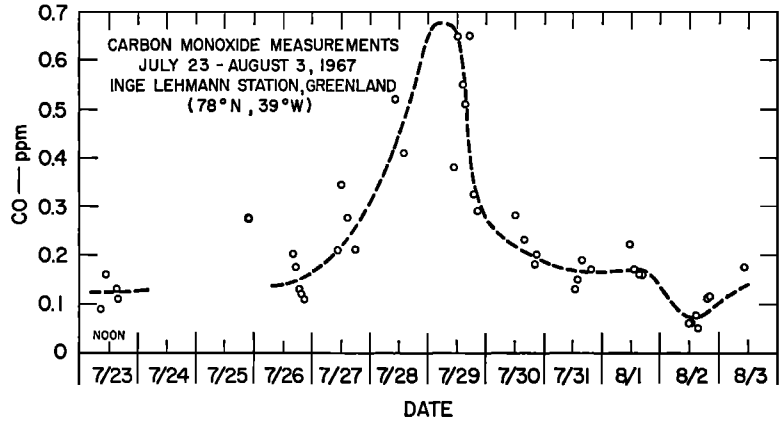

Fig. 1. Atmospheric carbon monoxide concentrations.

0.1 ppm. No data were available for July 24 or for most of July 25 because of analyzer difficulties. However, one reading taken on the afternoon of July 25 seems to be usable. July 26 was a day of relatively low CO concentrations, about 0.15 ppm, and it was followed by two days of significantly higher concentrations, the highest concentrations of the sampling period probably occurring early on July 29. Concentrations of CO then decreased steadily until a value of about 0.13 ppm was reached on July 31, followed by a minimum mean value of about 0.09 ppm on August 2.

This amount of change in CO concentration at such a remote location was not entirely unexpected because in 1965 several glass-flask air samples from the ice cap showed between 0.24 and 0.90 ppm [*Robbins et al.*, 1968]. Nevertheless, on-site instrumental observations of relatively high concentrations of CO are an important confirmation of these earlier data and emphasize the obvious question of the source of this CO.

The most plausible answer at the time the data were recorded and after subsequent study was that this period of high CO concentrations represented the passage across Greenland of an air mass that had become contaminated by previous travel across urban pollution sources in the United States. A trajectory analysis confirmed that the air mass over the station around July 28 had traveled along a trajectory through the Great Lakes and New England areas of the United States. The air mass trajectories for July 24 0000 UT (July 23, 2000 local), July 29 1200 UT (0800 local), and August 3 0000 UT (August 2, 2000 local) are shown in Figure 2. These trajectories are based on geostropic winds at 700 mb from the U. S. Weather Bureau northern hemisphere map series. The figure clearly shows that at the beginning and end of the sampling period, July 24 and August 3, the air masses traversed areas generally north of the Arctic Circle whereas the air mass tra-

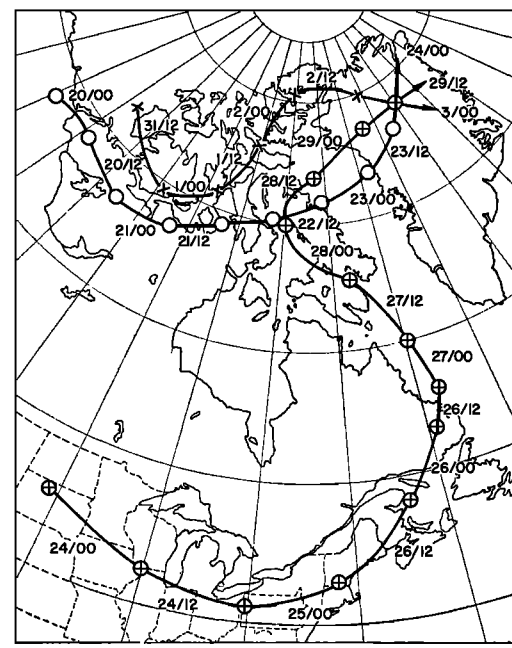

Fig. 2. Air mass trajectories for July 24, July 29, and August 3, 1967.

jectory for July 29 had, on July 24 and 25, passed across the heavily populated northeastern United States. The synoptic situation in the United States at that time was dominated by a very strong trough which moved across the Dakotas, the Great Lakes, and subsequently across New England. On the eastern side of this trough a strong southerly flow developed which provided the type of trajectory shown crossing the ice cap on July 29. On the ice cap this passage of the more moist southerly air mass was clearly evident from snow, clouds, and relatively high temperatures.

Figure 3 shows more trajectory information for this sampling period, namely, the locations of air masses approximately 48 hours before they passed ILS. In this figure the tail of the arrow indicates the location and date before passing ILS. The date and time of passage over ILS is shown along the shaft; however, the shaft does not indicate the actual trajectory of the air mass. As is shown in Figure 3, the low CO concentration air mass of July 24 (00UT) was in the vicinity of 70°N, 89°W, on July 22 (00UT). Beginning with the air masses arriving at ILS on July 27 (00UT) and continuing through July 29 (1200UT), the 2-day trajectory position moved progressively east and south as the southerly flow component became stronger. These more southerly trajectories coincide with the period of increasing CO concentrations shown in Figure 1. The air mass trajectory arriving at ILS on July 30 (00UT) initiated a rapid return to westerly trajectories. Actually, because of a rapidly changing situation off the northwestern coast of Greenland, two alternative trajectories for July 30 (00UT) were justified by the 700-mb patterns; these are indicated in Figure 3. One possible trajectory maintained a strong southerly component as evidenced by only a small westward shift to a 48-hour origin position of 65°N, 71°W, while the alternate trajectory moved to 72°N, 116°W, and is a complete return to an arctic trajectory. After July 30 and through August 3 the arctic trajectory persisted.

Carbon monoxide is a relatively inert gas having an apparent atmospheric residence time of several years; thus it is not surprising that an air mass which crossed areas of heavy contamination would reflect this contamination 5 days later. Nuclear debris, volcanic dust, and forest

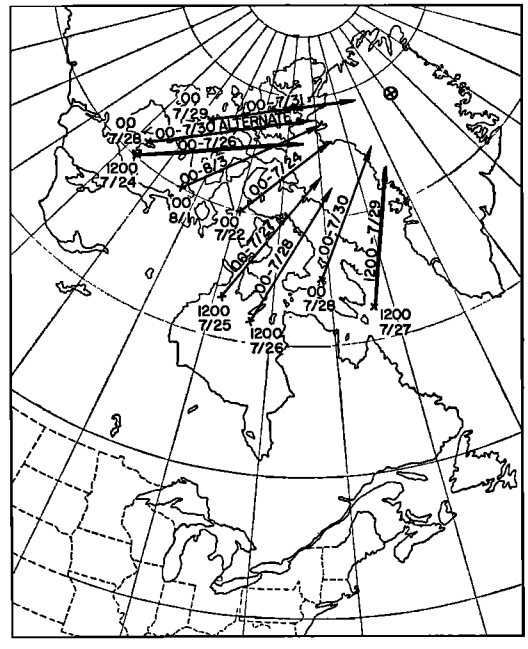

Fig. 3. Locations of air masses 48 hours before they arrived at Inge Lehmann Station.

fire smoke have been traced for much greater periods than this. However, long distance identification of persistent urban air pollutants has apparently not been reported, probably because there are not many sampling sites in operation where such air mass contamination would not be obscured by local pollutant sources. On the basis of these very limited sampling data we conclude that an average concentration of about 0.1 ppm seems indicated for arctic air masses in Greenland, but concentrations can exceed this by at least several-fold where the air mass has had a trajectory over large populated areas.

These data on CO concentrations at ILS are in general agreement with CO data from other polar regions. In Greenland CO data were obtained at Camp Century (77°N, 62°W), 560 km west-southwest of ILS, where four flask samples of air were collected in 1965 and analyzed for CO [*Robbins et al.*, 1968]. In the autumn of 1967, data were recorded for 2½ weeks at Point Barrow, Alaska (71°N, 157°W) [*Cavanagh*, 1968]. In the Antarctic, 16 flask samples were collected aboard the USNS *Eltanin* between 65°S and 77°S and between 168°E and 177°E over the period of January 9 to

January 21, 1967 [*Robbins and Robinson,* 1968].

The CO samples obtained at Camp Century were limited to four 4-liter glass flask samples taken as two pairs of samples on July 3 and 5, 1965. Concentrations were 0.90 and 0.85 ppm on July 3 and 0.24 and 0.32 ppm on July 5. It is believed that these data represent a period of southerly advection such as occurred between July 27 and 29, 1967, at ILS. Both the 1965 and 1967 periods were characterized by strong trough activity in the Great Lakes–Hudson Bay area. The 1965 period was characterized by a heavy snow storm on July 4, indicative of the presence of a moist air mass.

The CO data from Point Barrow were collected between August 24 and September 11, 1967, shortly after the ILS program. The same CO recorder was used in the two studies. At Point Barrow the CO concentrations varied from 0.055 to 0.260 ppm, averaging about 0.090 ppm. Concentrations generally varied no more than 0.02 ppm on any given day. There was no indication of any regular diurnal cycles or of any major advection of a contaminated air mass during the test period. The 0.09-ppm average value at Point Barrow is somewhat lower than the results obtained in Greenland for air masses with trajectories from within the Arctic Circle, i.e., July 23, 29, August 1–3, 1967; however, the data are obviously sparse.

In January 1967, 16 flask samples of air were obtained in the Antarctic during a cruise of the USNS *Eltanin.* The sampling area was generally north of McMurdo base in the Ross Sea. The results seemed to show a gradual increase in CO concentration southward from about 0.02 ppm at 65°S, 177°E, on January 9, 1967, to 0.08 ppm at 76°S, 174°E, on January 20, 1967. There was some scatter in the results, but, as was mentioned above, the trend toward increasing concentrations southward into the Antarctic was quite evident. At latitudes in the Antarctic comparable to Point Barrow and ILS in the Arctic, south of 70°S, CO concentrations for the 12 available samples ranged from 0.06 to 0.12 ppm and averaged 0.08 ppm.

Thus from these limited data it appears that in both the Arctic and Antarctic CO concentrations of about 0.1 ppm might be considered typical. The data for ILS show, however, that in Greenland CO concentrations can be strongly influenced by advection from large urban centers at lower latitudes. This would probably also be the case in the Scandinavian and Siberian arctic regions. However, the Antarctic data seem to indicate that the situation may be more complex than simple air mass advection; in the Antarctic there are essentially no population or pollution sources, yet the polar CO concentrations were comparable. No explanation is available at present.

The ILS data also seem to indicate considerable diurnal variation, the concentration range exceeding 0.1 ppm on several occasions.

Judging from the data shown in Table 1 and Figure 1 for July 23, 27, 30, and August 1, maximum daily concentrations seem to occur around noon or in the early afternoon. Observations on July 31 indicate an evening maximum, and the August 2 data do not indicate any pattern. The diurnal patterns were not related to any known instrumental or operational parameters. A correlation with atmospheric stability may be indicated here since the higher CO concentrations did occur in midday. Similar diurnal cycles of both temperature gradients and humidity have been observed on the Greenland ice cap [*Robinson and Ludwig,* 1967]. However, other than this indication of apparent correlation, there is no obvious physical mechanism which can be shown to produce such a cycle.

Conclusions

The data on CO concentrations in Greenland clearly show that CO produced in lower latitude population areas is readily observable when the lower latitude contaminated air masses move into the Arctic. Concentrations of CO in northern Greenland have exceeded 0.5 ppm under such situations. Furthermore, the CO data from Point Barrow and Greenland indicate that a background concentration of 0.1 to 0.2 ppm is apparently characteristic of the North American arctic region. European and Asian arctic areas would probably show similar concentration patterns.

Acknowledgments. This research was supported by the U. S. Public Health Service under grant 1 R01 AP 00558-01. Operations in Greenland would have been impossible without the suport of the U. S. Air Force Project Blue Ice and the Arctic Institute of North America. Their interest and assistance are gratefully acknowledged.

References

Cavanagh, L. A., Concentrations of carbon monoxide and organic gases in arctic atmospheres, Final Report, *SRI Project PRU-6689, Office of Naval Research Contract N00014-67-C-0515,* April 1968.

Hjortenberg, E., and D. D. Young, Jr., Survey of seismic noise on the Greenland ice cap, *Research Review Office of Aerospace Research, U. S. Air Force, 6*(7), 19-24, July 1967.

Junge, C. E., *Air Chemistry and Radioactivity,* Academic Press, New York, 1963.

Migeotte, M. V., The fundamental band of carbon monoxide at 4.7μ in the solar spectrum, *Phys. Rev., 75,* 1108–1109, 1949.

Robbins, R. C., K. M. Borg, and E. Robinson, Carbon monoxide in the atmosphere, *J. Air Pollution Control. Assoc., 18,* 106–110, 1968.

Robinson, E., and R. C. Robbins, Evaluation of CO data obtained on Eltanin cruises 27, 29, and 31, *Antarct. J. U. S., 3,* 194–196, 1968.

Robinson, E., and F. L. Ludwig, Atmospheric water vapor measurements on the Greenland ice cap, *Polar Meteorol. Tech. Note. 87, WMO-No. 211, T.P.111,* 1967.

(Received October 17, 1968;
revised December 12, 1968.)