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Project Summary

Meteorological Factors Responsible for High CO Levels in Alaskan Cities

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High latitude communities frequently have severe air pollution problems. The usual cause is the release of moderate amounts of pollutants into the atmosphere with extremely poor dispersion which, in turn, is a direct result of the high latitude radiation balance. Winter is characterized by short days and low solar elevation. At locations north of 60°N, midwinter day light may vary from 0 to just under 6 hours, and at noon the sun, if it rises at all, is lower in the sky than it would be 45 minutes after sunrise in Los Angeles. The result is a ground-based nighttime inversion which continues through peak traffic hours (throughout the day in some places), coupled with a complete lack of photochemical reactions. Downtown mixing heights as low as 10 m, combined with speeds less than .5 m sec^{-1}, have been measured in Fairbanks. If development in high latitudes is to proceed rationally, these meteorological conditions must be understood, and models developed which take account of them.

This Project Summary was developed by EPA's Environmental Research Laboratory, Corvallis, OR, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The region north of 60° latitude in the western hemisphere is not heavily developed, but severe air pollution problems exist even in relatively small settlements. Fairbanks, Alaska (64°50'N) is the best studied example of high-latitude air pollution, but Anchorage, (61°10'N) also has a severe carbon monoxide problem. As development increases in northern regions, it is important that the meteorological conditions leading to these high pollution levels be understood. In particular, the physical and chemical consequences of the high-latitude regime of solar radiation must be recognized.

High-Latitude Meteorology

The 24-Hour Night Regime

The most critical factors behind the poor winter dispersion conditions found in many high-latitude cities are the very low values of incoming solar radiation and the tendency for cities to be in locations sheltered from winds. With this radiation regime, nocturnal inversion conditions can occur 24 hours a day. If warm clouds are present, or if winds are high enough to force turbulent mixing, inversion strengths may be low and normal lapse rates may even occur. However, surface inversions are present in over 80% of *all* soundings taken in Fairbanks during December and January. Nominal solar times on these soundings are 2 am and 2 pm; actual release times may be as much as an hour earlier.

The effect of nocturnal inversions on pollutant levels has been studied at lower latitudes, where they also result in significant pollution episodes even though they occur at times when emissions are relatively low. At latitudes poleward of 61°N, for at least a few days each year, the potential for polar-night inversions is continuous. The long periods of possible inversion development produce lapse rates which may be continuously inverted to as high as 2 km. At Fairbanks, near-ground inversion strengths away from town commonly exceed 10°C/100 m when winds are light and skies are clear, and at times exceed 30°C/100 m in the lowest 30 m of the atmosphere, and 200°C/100 m in the first two meters. Complex stepped temperature structures are common. Furthermore, these intense ground inversions continue through the hours of maximum CO emissions. Our studies show that Anchorage inversions (measured near the shore of Cook Inlet) may also persist throughout the day in the latter half of December, with inversion strengths of as much as 10°C/100 m. These inversions are even steeper farther inland. The result is that even relatively small, non-industrial settlements such as Fairbanks and Anchorage are subject to high CO levels.

The Short Daily Warming Regime

As the noon solar elevation exceeds 3½°, some warming begins to occur at midday on clear days, and as the season progresses, dispersion conditions near noon improve steadily. Based on the observed situation at Anchorage, a 7° noon solar elevation angle could result in a 5°C rise in surface temperature at noon on a clear, calm day. This, however, does not guarantee that a ground inversion fails to persist through the day. As an example, Figure 1 shows a series of 1 am and 1 pm temperature soundings for Anchorage starting about a week befor the winter solstice. The two number after each date are the 1-hour mean C(level in ppm and the temperature i degrees Celsius at the most polluted c the Anchorage monitoring sites, Bensoı and Spenard. Note that the Benson an Spenard site temperature is generall lower than the airport temperature, i spite of heat island effects, so the inver sion persistence is probably more pro nounced inland.

By January, the 100-meter inversion a the Anchorage airport (which is ver close to the coastline near the tip of th peninsula) usually, though not always vanishes or becomes very weak at 1 pn compared with its 1 am value, which car still approach 10°C/100 m. There is

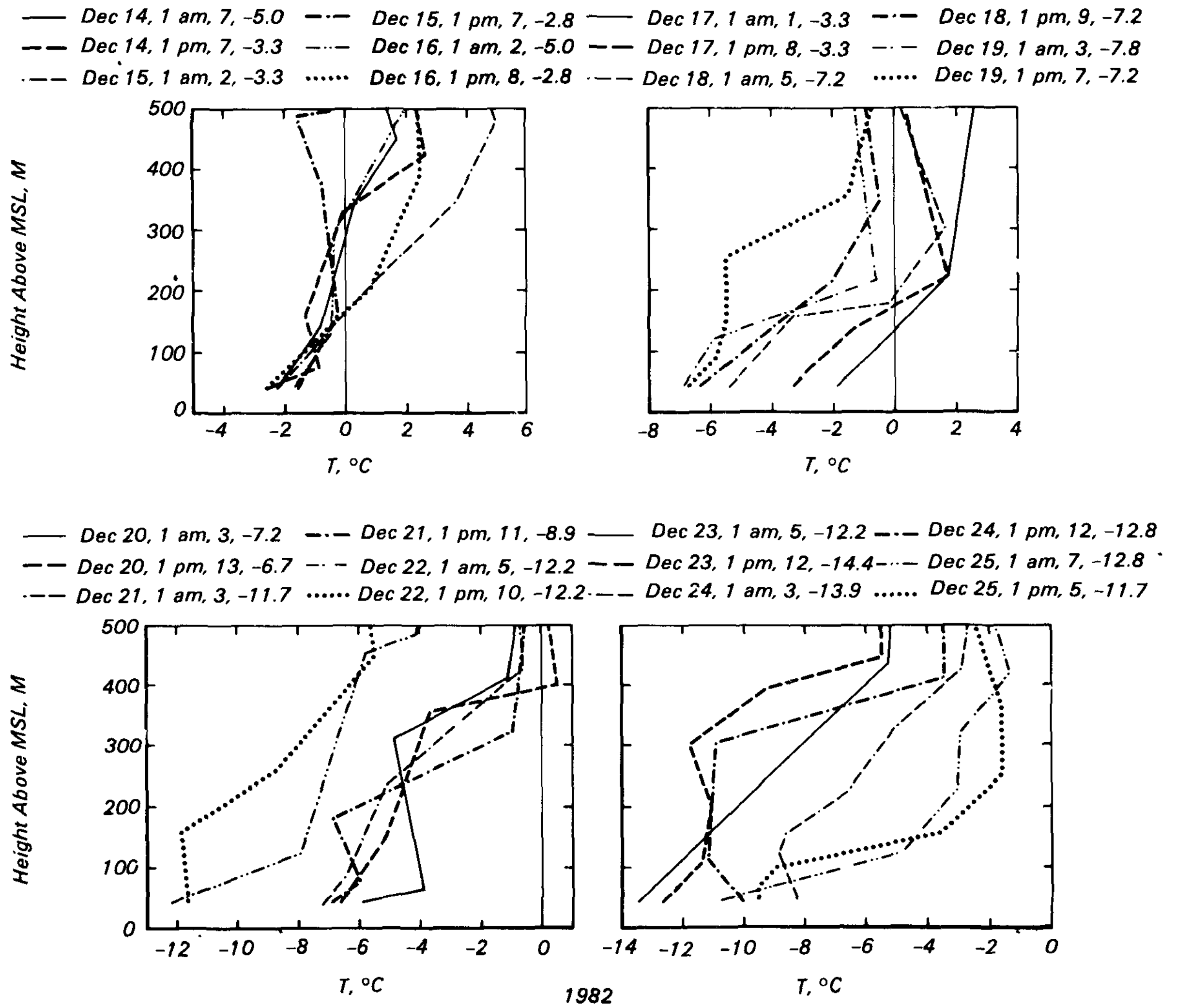

Figure 1. *Anchorage airport soundings for 12 days around the winter solstice, showing persistence of the nocturnal inversion through the dayligh hours. The two numbers following each date and time give the 1-hour mean CO (ppm) and the temperature (°C) at Benson and Spenarc (an Anchorage shopping area) at the time of the sounding. Note that there is little systematic difference in inversion strength between 1 am and 1 pm.*

however, good reason to believe that inversions persist farther inland. Daily maximum temperatures at the CO monitoring sites are often lower than daily minimum temperatures at the airport, and mean hourly CO levels for December at urban monitoring sites in Anchorage show no midday minimum (Figure 2, Benson and Spenard). Rather, the pattern consists of a sharp rise during the commuter peak from 7-8 am, fairly steady CO values through the day, and a second sharp rise around 5 pm. A residential site (Garden Site, Figure 2) does show a drop in CO near noon, but this may represent no more than the local traffic pattern.

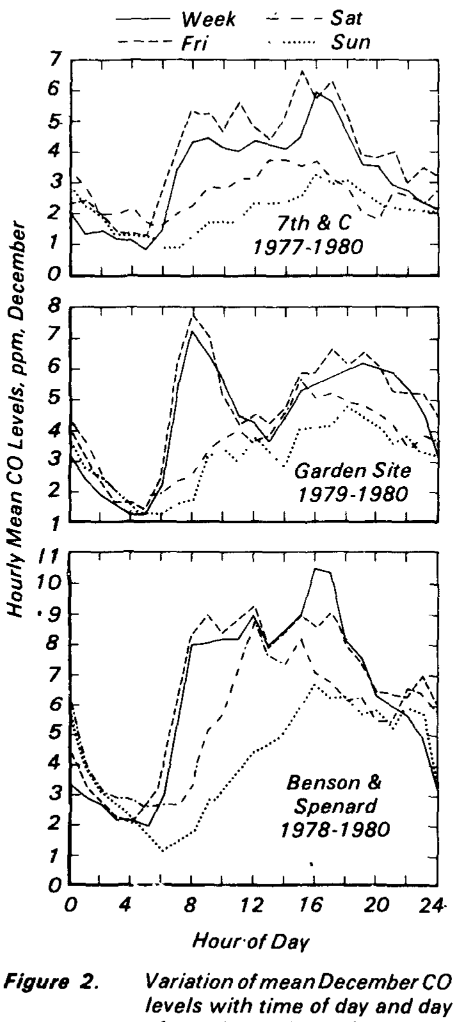

Figure 2. *Variation of mean December CO levels with time of day and day of week at three Anchorage locations. 7th and C is an area of downtown office buildings not too far from the coast, Benson and Spenard is on a heavily travelled artery in a shopping district, and Garden Site is in a church parking lot in a quiet residential area.*

By February, when the noon solar elevation angle at Anchorage is about 15°, a distinct and well-developed midday minimum in CO levels is present and the improved mixing is beginning to overlap the evening traffic peak (Figure 3), delaying the corresponding CO peak. An intermediate stage, which has been observed in February in Fairbanks, involves relatively good dispersion near noon, with the nighttime inversion remaining strong through the morning commuter peak and becoming reestablished before the evening rush hours. This situation has led to alert levels of CO (15 ppm or more) in Fairbanks.

Urban Modification of Nocturnal Inversions

Substantial heat islands are known to be associated with high latitude cities of moderate size. These heat islands are the surface expression of weakening of the nocturnal inversion by anthropogenic heating. Tethered balloon measurements of the temperatures in the lowest 100 m of the atmosphere just north of Fairbanks and within 200 m of the CO monitoring site were carried out in December 1981. Hourly CO values during three pairs of ascents made under polluted conditions are shown in Figure 4; the data obtained during the ascents are shown in Figures 5-7.

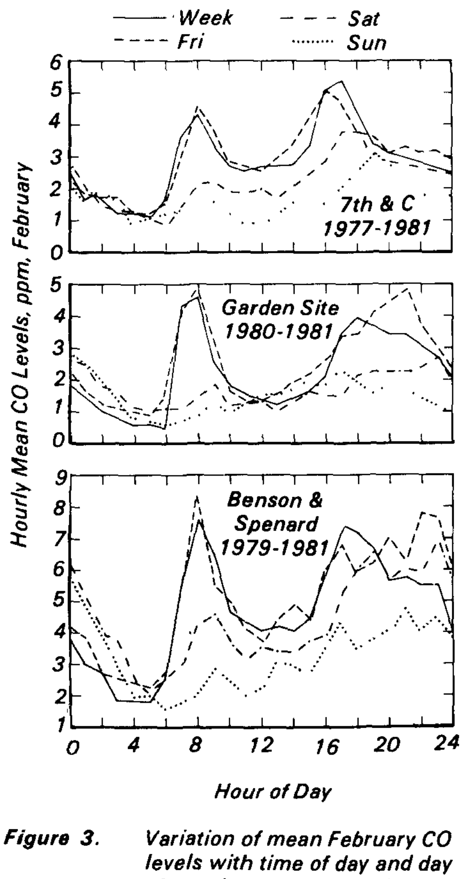

Figure 3. *Variation of mean February CO levels with time of day and day of week at three Anchorage locations. 7th and C is an area of downtown office buildings not too far from the coast, Benson and Spenard is on a heavily travelled artery in a shopping district, and Garden Site is in a church parking lot in a quiet residential area.*

Our preferred interpretation of this information is that vertical mixing was probably complete through the isothermal layer (30 m on December 15, 10 m on December 22 and 6 m on December 23). Although the highest CO level was not measured during the time of the shallowest isothermal layer, the most rapid increase in CO was. Wind minima were observed above the isothermal layers, another indication that these represent mixing layers. Relatively warm city temperatures above the isothermal layer to the heights of 30-40 meters are ascribed to partial mixing due to updrafts

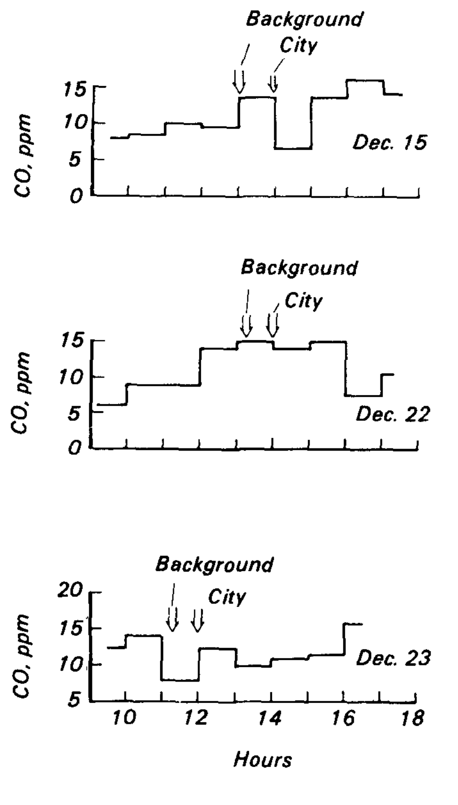

Figure 4. *CO levels around the tethered balloon ascents. Width of arrows shows the time over which the ascents took place.*

generated along warm building walls. (The majority of buildings in Fairbanks do not exceed 10 to 15 meters in height, and the tallest is only 35 m.) Temperature differences between urban and rural sites above 40 m can be readily explained by gravity waves of some 15 m amplitude, which are known to be common in the Fairbanks area.

Neither CO levels nor rural inversion strength during the ascents represent worst-case conditions. Previous measurements have shown background lapse rates as great as 30°C/100 m for the lowest 30 m, and 3 recent years of Fairbanks data (1979-80, 1980-81 and 1982-83) give an average of 4 days a year with more than 15 ppm CO on an 8-hour average. (The ascent days had maximum 8-hour averages of 12-13 ppm.) A mixing height of 10 m and a windspeed of 0.5 m sec^{-1} should therefore be considered generous estimates for worst-case modeling of pollutants from surface sources in Fairbanks. Repeated visual observation of well-layered smoke below street lights 12 m high provides independent evidence for a mixing height of no more than 10 meters. Until bett[illegible] measurements become available, thes[illegible] values should be considered to app[illegible] generally to continental sites north [illegible] 60°N when low windspeeds prevail. Us[illegible] of models unable to handle such lo[illegible] mixing heights and windspeeds cann[illegible] be expected to give meaningful results [illegible] high latitudes.

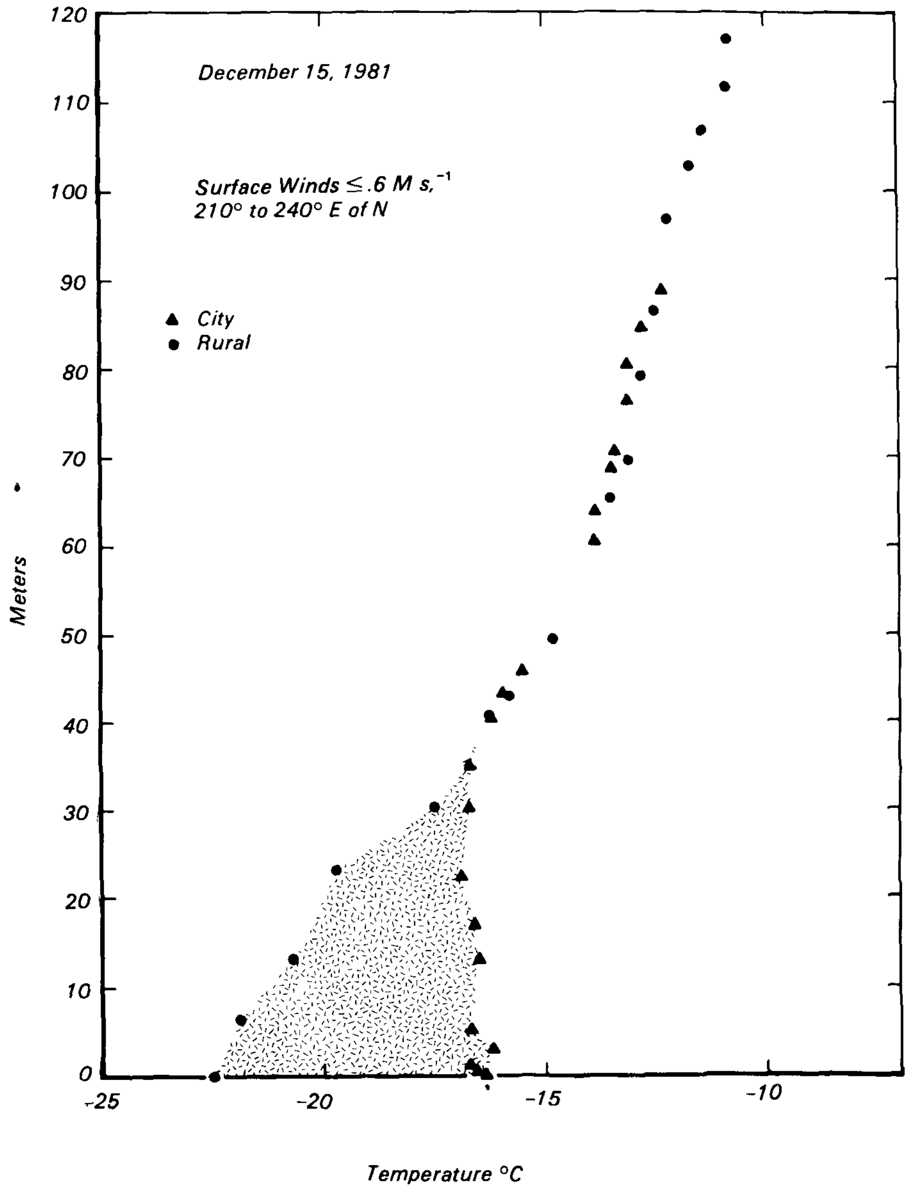

Figure 5. *Comparison of rural and downtown lapse rates at Fairbanks, Alaska, during an episode of high CO on December 15, 1981. "Rural" sounding was taken at a wildlife refuge just north of Fairbanks; "city" sounding was taken in a parking lot within 200 meters of the CO monitor.*

Modification of Nocturnal Inversions by Topography

Local factors, such as the degree o[illegible] shelter from regional winds, can significantly affect both the strength and persistence of surface inversions. I[illegible] Fairbanks, several episodes of CO level above 15 ppm have been associated wit[illegible] winds adequate for good dispersion sout[illegible] of town (including the airport) while stagnation conditions prevailed in the cit[illegible] itself. In Anchorage, the weathe[illegible] observations are taken at the airpor[illegible] which is located on a point jutting out int[illegible] Cook Inlet, with substantial oceani[illegible] exposure. Rawinsonde data from this sit[illegible] do not represent the near-surface ai[illegible] structure over the city. As an example, w[illegible] used a tethered balloon to measure [illegible] surface inversion strength of 10°C/10[illegible] m at the Bus Barn, 10 km inland from th[illegible] airport, while the airport had norma[illegible] lapse rates (Fig. 8). Temperature distributions across Anchorage suppor[illegible] the idea that this is a normal situation; the CO monitoring sites (which should be within the Anchorage heat island) can be as much as 10°C colder than the airport. Therefore, it seems clear that careful observation of local topography is essential before assuming that a nearby weather station can be used to give valid estimates of winds or vertical stability at a site even a very short distance away.

Capping Inversions

Anchorage can develop strong inversions overlying superadiabatic layers from 50 m to more than 200 m in depth when cold continental air crosses Cook Inlet before arriving at the airport. However, CO levels during these episodes are high only when there is evidence that ground inversions are present at the CO monitoring sites or if traffic concentrations are extraordinary (e.g., 2 pm Christmas Eve, 1982, Fig. 1). If temperatures at the CO monitoring sites are not depressed by several degrees relative to those at the airport, CO levels remain at or below normal when the airport lapse rate is normal for the first 50 m. This is an additional argument that actual mixing layers during high CO episodes in Anchorage, as in Fairbanks, are very shallow.

Although capping inversions do not presently lead to high pollutant levels in Anchorage, their presence is a warning against excessive release of pollutants from tall stacks, either in Anchorage or on the other side of Cook Inlet.

Winds: Variability in Time and Space

In many high latitude regions, wind speeds are normally high enough to prevent development of steep surface inversions, although the weaker overall inversions may still persist. Such areas include many island and exposed coastal areas as well as upland areas further inland. These sites, however, are subject to the obvious problems of drifting snow and high wind chill. Furthermore, river travel was common when many settlements were founded so that a large fraction of the population is concentrated in sheltered valley bottoms, such as in Fairbanks and Whitehorse. Even relatively exposed sites, such as Anchorage, are subject to occasional periods when wind speeds are low enough to permit the formation of ground inversions.

The few measurements available in Anchorage show the existence of persistent shears. Figure 9 documents a period of three days with light winds (mostly 2-3 m sec^{-1} or less) and a substantial horizontal shear; the three sites are in a triangle less than 10 km on a side. Previous studies have documented similar shears in Fairbanks

Synoptic Situations

The clear skies and low wind speeds conducive to the formation of nocturnal inversions are commonly seen under anticyclonic situations. In Fairbanks, anticyclones do in fact appear to dominate periods of poor air quality. Coastal cities such as Anchorage and Juneau, however, are rarely under the influence of anticyclones in winter, and high CO episodes at Anchorage are normally associated with easterly geostrophic winds. The city is located just ENE of the abrupt mountain front of the Chugach Range, and relatively calm, clear conditions leading to nocturnal inversions appear to be due to the shielding effect of the mountains. Eight-hour CO levels exceeding 9 ppm also have been observed when the core of a dissipating low-pressure system was located directly over Anchorage. In these cases, very light and variable winds were associated with thin, high or broken cloud cover.

Air Pollution Forecasting

Evaluation of the forecasting of CO levels by the Fairbanks North Star Borough indicated that alert situations (15 ppm or more for an 8-hour average) were being persistently underforecast. Part of the problem was traced to poor communications between the NOAA Weather Service and the Borough forecasters. As a result of our study, the Borough now provides current CO levels to the Weather Service as one input for the dispersion forecasts that are then provided to the Borough by the Weather Service

Our study also identified several meteorological situations likely to be associated with very high CO levels. Two have already been mentioned: winds forecast (correctly) for the airport which did not extend to the more sheltered downtown area, and coincidence of the evening rush hour with rapid reestab-

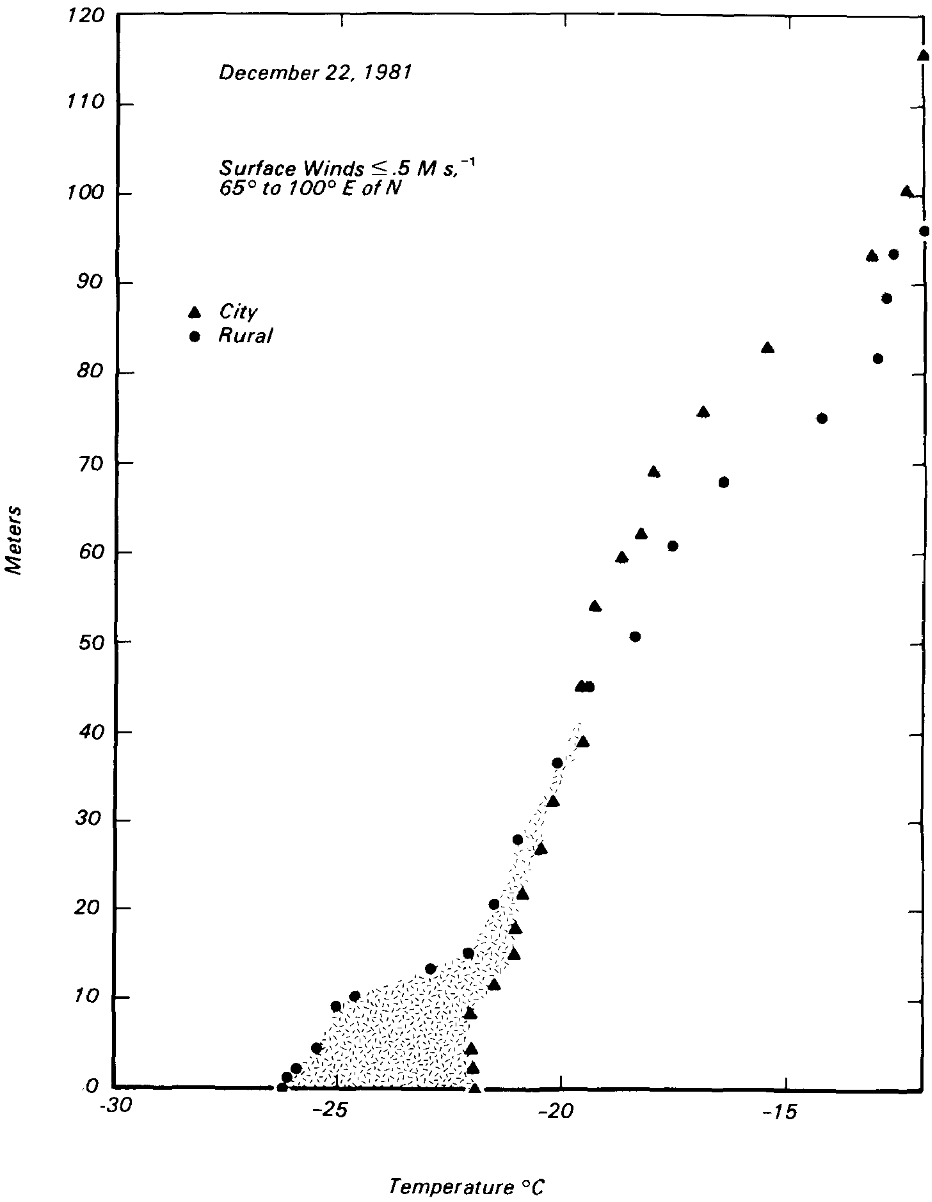

Figure 6. *Comparison of rural and downtown lapse rates at Fairbanks, Alaska, during an episode of high CO on December 22, 1981. "Rural" sounding was taken at a wildlife refuge just north of Fairbanks; "city" sounding was taken in a parking lot within 200 meters of the CO monitor.*

lishment of a ground inversion after sunset in February. Additional conditions responsible for CO levels over 15 ppm were episodes of warm air advection and calm periods with a thin or high cloud cover.

Conclusions

Winter air pollution episodes at high altitudes are due to the persistence of intense nocturnal inversions through the hours of maximum release of pollutants near the surface. Coldstart CO emissions and high energy demands during cold, dark winters contribute to the problem, and any solution will depend on controlling these emissions. However, the fundamental problem remains that the high latitude winter atmosphere is so stable that only minute quantities of pollutants can be dispersed.

Relocation of cities to windier sites would reduce air pollution but cause severe problems with snow drifting (a major difficulty now on the windswept North Slope of Alaska and parts of northern Canada) and wind chill. Furthermore, even generally windy sites have calm days. Anchorage has problems with wind storms as well as air pollution (not simultaneously!) in winter. However, any industry with air pollution potential should only be considered for upland sites with high frequencies of winds over 6 m sec^{-1}, and then be approved only after tracer studies.

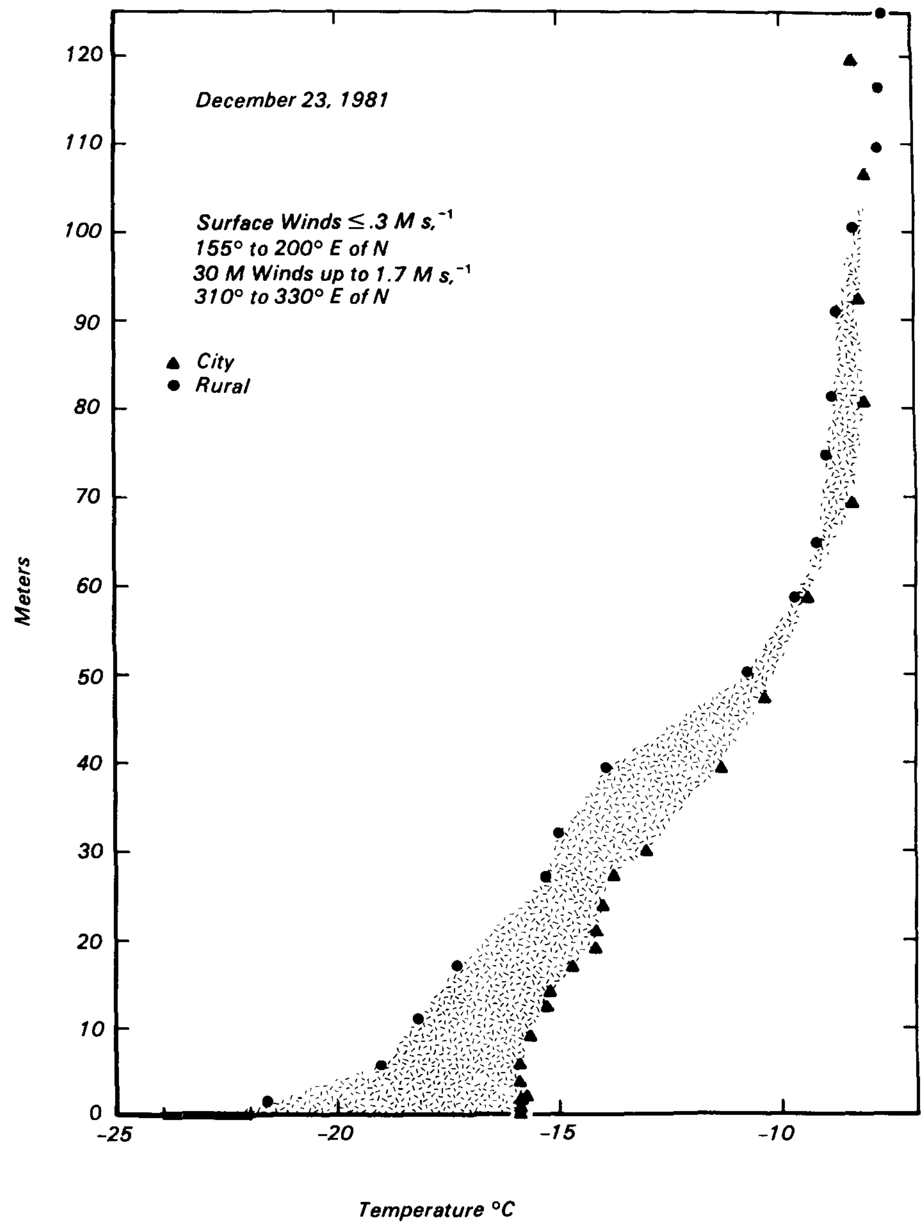

Figure 7. Comparison of rural and downtown lapse rates at Fairbanks, Alaska, during an episode of high CO on December 23, 1981. "Rural" sounding was taken at a wildlife refuge just north of Fairbanks; "city" sounding was taken in a parking lot within 200 meters of the CO monitor.

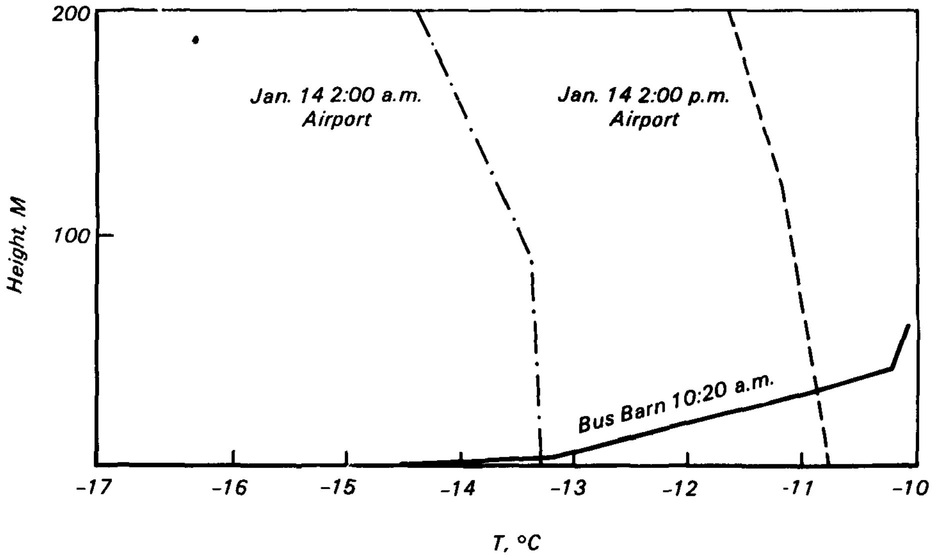

Figure 8. Comparison of lapse rates at the Anchorage airport and the Bus Barn, 10 km inland, January 14, 1983.

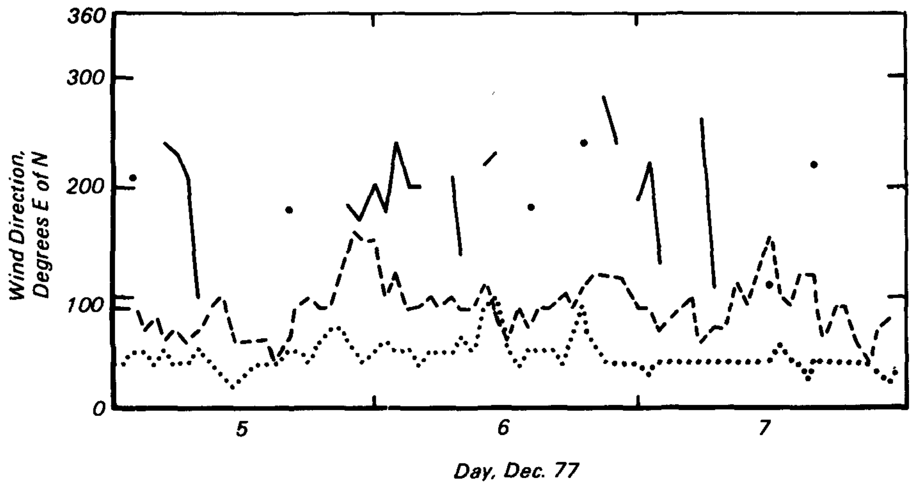

Figure 9. Hourly wind directions from three sites in Anchorage over a 3-day period with low wind speeds. Solid line airport (tip of peninsula), dashed line 7th and C (northeast of airport), dotted line Tudor and Lake Otis (east of airport and southeast of 7th and C). The airport anemometer had a higher starting speed than the other two, hence more missing data.

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***James C. McCarty** is the EPA Project Officer (see below).*
The complete report, entitled "Meteorological Factors Responsible for High CO Levels in Alaskan Cities," (Order No. PB 85-115 137; Cost: $11.50, subject to change) will be available only from:
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