PEER REVIEW OF MORE STRINGENT AIR POLLUTION EMISSION LIMITATIONS: MUNICIPALITY OF ANCHORAGE

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1. INTRODUCTION

The Municipality of Anchorage (MOA) proposes to adopt emission limitation provisions in the Anchorage Clean Air Ordinance that are more stringent than EPA or ADEC regulations. Two of these would set limits on wood-burning devices, specifically:

- A new 20% opacity limitation for wood-fired boilers, fireplaces, wood and coal stoves and other similar solid-fuel heating appliances. The limits would not apply during the first 20 minutes after initial firing or when the appliance is the sole source of heat.
- Require all outdoor wood-fired boilers (OWBs) to meet EPA Phase 2 OWB emission certification limits and meet setback and stack height requirements. This provision was adopted by the MOA Assembly in 2009.

MOA has the authority under AS 46.14.010 (Emission Control Regulations) to establish emission standards for its local air quality program that are more stringent than the corresponding federal or State standards, but to do so it must:

(1) find in writing that exposure profiles and either meteorological conditions or emissions unit characteristics in the State or in an area of the State reasonably require the ambient air quality standard, or emission standard to protect human health and welfare or the environment;

(2) find in writing that the proposed standard or emission limitation is technologically feasible; and

(3) prepare a written analysis of the economic feasibility of the proposal.

MOA must also follow the procedure in AS 46.14.015 (Special Procedure For More Stringent Regulations) that requires the department to submit the findings to a peer review by independent parties and to make the written findings available to the public at locations around the State.

I was selected as an independent party to review the written finding with respect to the <u>impacts and effects of meteorology and wood smoke from space heating</u>. I have examined the Peer Review Draft[*] of the written finding entitled: *Basis for More Stringent Air Pollutant Emission Limitations Proposed for the Anchorage Municipal Code* to determine whether MOA has met the requirements of AS 46.14.010 (c)(1) and (d) with regard to the meteorological conditions that contribute to elevated $PM_{2.5}$ concentrations and exceedances.

[*] Hereinafter referred to as the Finding.

This report provides my written comments and opinion on the Finding. Section 2 presents the peer review of the Finding with respect to meteorology. Section 3 presents a summary and my opinion, which is that MOA has met its obligations under the Alaska statutes by demonstrating that meteorological conditions in the Anchorage area reasonably require the proposed $PM_{2.5}$ emission limitation on wood-fired and other solid-fuel heating devices.

2. PEER REVIEW OF MOA FINDING WITH RESPECT TO METEOROLOGY

The MOA Finding addresses the need and basis for more stringent emission standards in three areas: (1) Exposure profiles, meteorological conditions and emissions unit characteristics reasonably require more stringent emission standards; (2) the emission limits proposed are technologically feasible; and (3) the proposed emission limitations are economically feasible. The following review examines the first of these areas. It is presented in the form of five questions and my answers.

1. Has MOA correctly identified the meteorological factors that lead to strong temperature inversions in Anchorage?

Yes. It has long been known that Alaskan cities are prone to high levels of winter air pollution due to their Arctic location. Dr. Carl S. Benson – now Faculty Emeritus at the Geophysical Institute (University of Alaska Fairbanks) – conducted some of the early research on climatic and meteorological factors causing Arctic air pollution. In one paper, he describes the meteorological challenge as follows:

> *"… the two requirements for air pollution are: 1) the availability of pollutants, and 2) a restriction in the volume of air which dissolve these pollutants. Conditions controlling the latter requirement vary widely from place to place because they depend on meteorologic and topographic factors. The most stable atmospheric conditions occur under and within inversion layers.*
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> *"… temperature inversions form at ground level when there is a net loss of heat from the earth's surface by outgoing longwave radiation.[*] The radiative balance between the surface and the air aloft causes this cooling to proceed upward in the air as described in detail by Wexler (1936). These inversions become especially well developed at night over snow surfaces and are common both day and night in parts of the Arctic and Antarctic.*
>
> *"The rate of change of temperature within the inversion layer, i.e., the 'steepness,' or 'strength,' of the inversion, is also important because the*

[*] Dry air is highly transparent to infrared ("longwave") radiation and Arctic atmospheres are often very dry. In radiative cooling, infrared radiation emitted by the Earth's surface carries heat out to the deep-cold of outer space.

stability of the air increases with it. The steepness of radiative inversions increases as topographic features restrict low level air motion. Thus, the strongest inversion measured at the South Pole was 9.65°C/100 m at 2315 GMT on 21 April 1958; this is a strong inversion, but the inversions measured during cold spells at Fairbanks are among the steepest in the world with values of 10 to 30°C/100 m common in the first 50 to 100 m. These different ranges of values can be attributed to topography. The South Pole area is essentially a flat plateau; Fairbanks is surrounded by hills on three sides which permits stagnant air to form at low levels similar to the situation in the Los Angeles Basin." (Benson 1970, p. 9)

Fairbanks, located inland in central Alaska, has perhaps the most severe meteorology of any major city in the world. Anchorage, located on the southern Alaska coast, does not have meteorology as severe, but from time-to-time each winter it faces the same combination of short days with very low daytime solar radiation and clear skies that permit rapid radiative cooling of the surface, leading to a surface-based temperature inversion. In this stable condition with low (or no) winds at the surface, concentrations of air pollutants – including carbon monoxide (CO) and fine particulate matter ($PM_{2.5}$) – can build to high levels.

2. *Under what circumstances do these meteorological conditions occur in Anchorage?*

Surface-based temperature inversions are an episodic phenomenon in Anchorage, rather than the prevailing condition as in Fairbanks. During much of the winter, Anchorage is under the influence of a persistent low pressure system in the Gulf of Alaska. Southerly or southeasterly air flows bring relatively warm, moist marine air into coastal areas, moderating surface temperatures and producing frequent cloudy weather. From time to time, high pressure systems located over central and northern Alaska build to sufficient strength that a northerly flow of cold, dense arctic air pushes the marine influence away from the coast. The northerly flow is also effective in trapping pollutants against the mountains that enclose the Anchorage "bowl" to the east and south.

When this occurs in the middle of winter, Anchorage experiences an episode of colder surface temperatures and radiative cooling under clear skies that creates a surface-based temperature inversion with low (or no) winds. The lower atmosphere has poor "ventilation" and pollutants do not easily disperse vertically or horizontally. Because the surface air temperature is also very cold, source emission rates are highest as natural gas, fuel oil, wood and other fuels are burned at increased rates for space heating.

During calendar years 2010, 2011, and 2012 Anchorage had seven days with 24-hour average $PM_{2.5}$ concentrations greater than 30 ug/m^3.[*] Each of these days had a strong northerly flow extending kilometers above the surface with generally cold surface temperatures, clear (or clearing) skies and a surface-based temperature inversion with calm winds.

[*] The Federal standard is 35 ug/m^3 above which the air is classified as Unhealthy for Sensitive Groups.

3. *Can CO be used as an indicator of inversion strength and wintertime pollution potential as in the Finding?*

Yes. As Benson noted, "*a restriction in the volume of air which dissolve these pollutants*" is required for pollutant concentrations to build to high levels. MOA used data on ambient CO concentrations in selected cold climate cities as an indicator of relative inversion strength and wintertime pollution potential. Anchorage was shown to have the highest short-term average CO values of the cities compared, from which MOA inferred that it has strong wintertime inversions. CO concentrations are also useful surrogates for the pollution potential from wood-burning devices because both pollutants are emitted near ground level and the atmospheric mechanisms of trapping are the same. Like $PM_{2.5}$, CO emissions are highest when it is cold and ambient concentrations are highest when the surface inversion is strong and winds are low. My review presents direct measures of inversion strength that support the CO-based comparisons in the Finding.

4. *Are meteorological conditions in Anchorage more severe than in other cold-winter cities in the Lower 48 States?*

Yes, winters in Anchorage are more severe than in all but a few cold-winter cities in the Lower-48 as evidenced by Figure 2 and Table 2 in the Finding (Finding, p. 5). Here, we will compare Anchorage with both Fairbanks and three wintertime $PM_{2.5}$ non-attainment areas in the Lower-48 States:

- **Salt Lake City, UT**. Salt Lake City and nearby communities form a cluster of $PM_{2.5}$ non-attainment areas in the northwestern portion of Utah. These locations, at higher elevations in the arid West, are analogous to Alaskan cities in that they can experience surface temperature inversions due to radiative cooling.
- **Pittsburg, PA**. Pittsburg and nearby cities form a cluster of $PM_{2.5}$ non-attainment areas in the western portion of the State. Terrain is a prominent factor here; the Pennsylvania air agency notes that the tall ridges and deep river valleys characteristic of this area are effective in trapping emissions within the valleys.
- **Seattle-Tacoma, WA**. Pierce County is classified as a $PM_{2.5}$ non-attainment area based on monitor readings in South Tacoma. The Seattle-Tacoma metropolitan area has a marine climate and experiences a type of inversion, in which warm, moist marine air flows over colder air at the surface.

For <u>surface temperature</u> (Exhibit 1), Fairbanks is much colder than any of the other cities in the comparison due to its inland location near the Arctic Circle. Anchorage, located at high latitudes but on Cook Inlet off the Gulf of Alaska, is not nearly as cold as Fairbanks but is consistently colder than the Lower-48 cities. The record low temperature in

Anchorage is 4°F colder than the record low in Salt Lake City and substantially colder than the record lows in the other cities. Winter temperatures in Anchorage are intermediate between Fairbanks and the next two coldest cities (Salt Lake City and Pittsburgh). Seattle-Tacoma has a mild climate by comparison. Like Fairbanks, Anchorage experiences more days below freezing (more than one-half of the year) than any of the Lower-48 cities. These results are consistent with the heating degree day comparisons presented by MOA (Finding, p. 5).

Exhibit 1. Comparison of Temperatures in Anchorage, Fairbanks and Three Winter Non-Attainment Areas in the Lower-48 United States

	Fairbanks, AK	Anchorage, AK	Salt Lake City, UT	Pittsburgh, PA	Seattle-Tacoma, WA
Record Minimum Temperature	-62°F	-34°F	-30°F	-22°F	0°F
Coldest Monthly-Average Minimum Temperature in Winter	-17°F	11°F	22°F	22°F	36°F
Average Number of Days below Freezing (Annual)	222	191	121	120	29

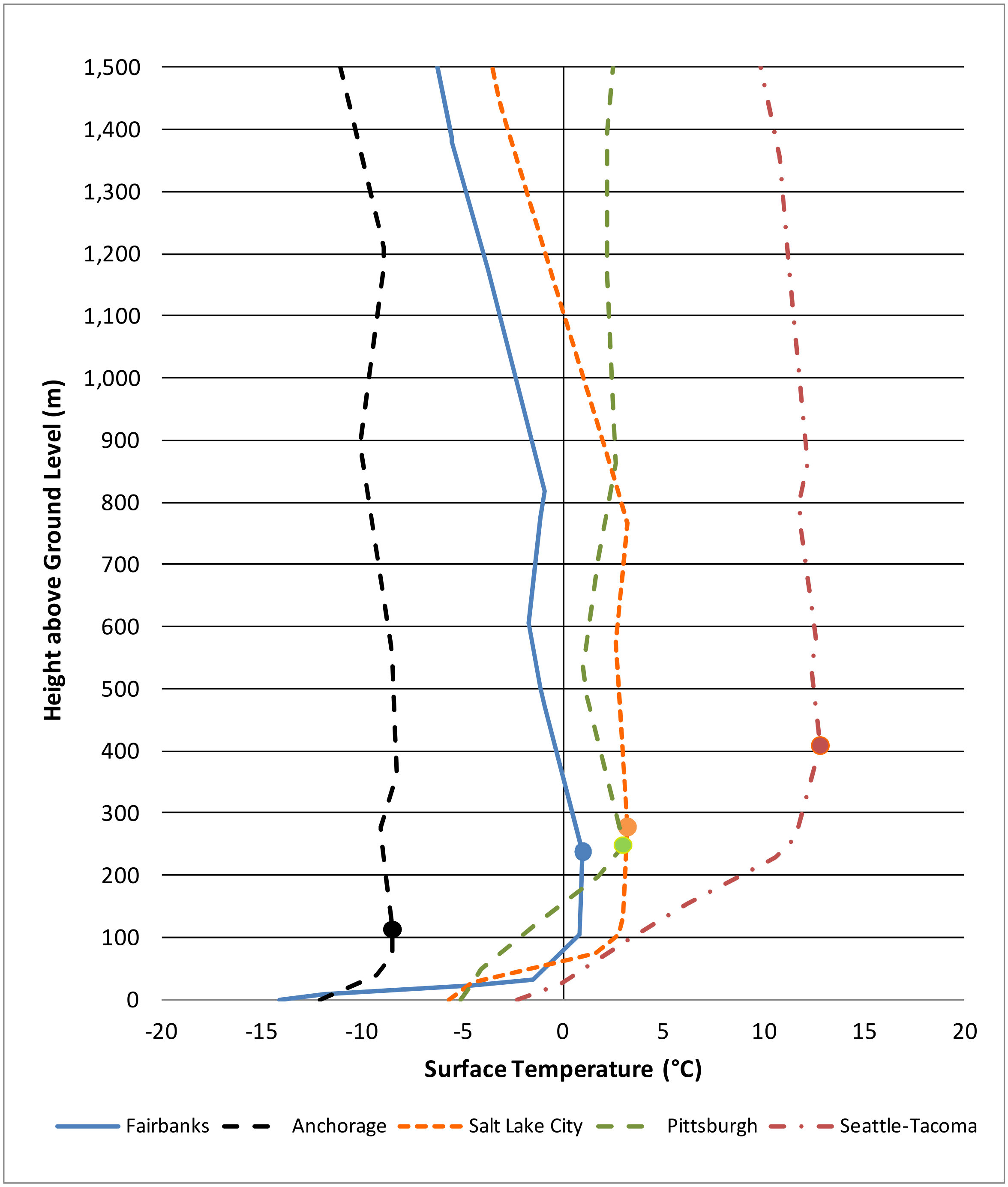
Source: Comparative Climate Data – United States. Golden Gate Weather Services http://ggweather.com/ccd/.

For inversion strength, upper air soundings for the past winter (2012-2013), taken by the National Weather Service (NWS) at airports located in or near each city, were reviewed to identify specific examples that are representative of the strongest inversions typically experienced. The 02 December 2012 data selected for Anchorage is one of the seven high $PM_{2.5}$ days during 2010-2012. Exhibit 2 plots the air temperature profiles for the selected soundings. Exhibit 3 presents supporting data for the plot and additional information regarding inversion strength and frequency of occurrence.

In the plot of air temperature profiles (Exhibit 2), a surface inversion is noted by the rightward slope of the temperature line from the surface to the top of the inversion (marked by filled circles). The more horizontal the line, the more quickly the air warms above the surface and the stronger is the inversion. The surface temperatures are coldest for Fairbanks and Anchorage. The temperature inversions are strong in all of the cities, but none can match Fairbanks, where the air warms more than 10°C in the first 50m.

Exhibit 2. Comparison of Inversion Strength in Anchorage, Fairbanks and Three Winter Non-Attainment Areas in the Lower-48 United States.

Representative strong inversions were selected from NWS upper air soundings during the period October 2012 through March 2013. Air temperature profiles are plotted versus height above ground to allow direct comparison across areas. The top of the surface inversion is marked with a filled circle.



For the comparisons presented below (Exhibit 3), the average lapse rate is computed from the temperature difference between the surface and the top of the inversion. On this measure, the Fairbanks inversions are about twice as strong as those in the other cities. The inversions in the other cities, including Anchorage, are of comparable strength.

The surface lapse rate is computed between the surface and a height of 20-30m. Here, the difference among the cities is dramatic. The surface lapse rate in Fairbanks exceeds 25°C/100m, a value that is seldom seen anywhere in the world, while it is at or below 10°C/100m for all of the other cities. Among the other cities on the selected days, Anchorage has the second highest surface lapse rate behind Seattle-Tacoma.

During the 2012-2013 Winter, Anchorage had surface inversions of 10°C/100m or more on 5 different occasions and a strongest inversion of 15°C/100m. These are very strong inversions, if not as strong as Fairbanks; in fact, they are as strong as the strongest inversion at the South Pole cited by Benson.

Exhibit 3. Supporting Data for Soundings Selected From Winter 2012-2013

	Fairbanks, AK	**Anchorage, AK**	**Salt Lake City, UT**	**Pittsburg, PA**	**Seattle-Tacoma, WA**
Date	03 Feb 2013	02 Dec 2012	8 Feb 2013	8 Jan 2013	19 Jan 2013
Sounding					
Time (GMT)	12Z	12Z	12Z	12Z	12Z
Location (IATA code)	FAI	ANC	SLC	PIT	UIL
Inversion Height (m)	283	113	278	247	405
Average Lapse Rate (°C per 100m)	6.3	3.2	3.2	3.3	3.7
Surface Lapse Rate (°C per 100m)	27.5	7.0	4.4	2.5	9.6
Winter 2012-2013 Statistics					
Frequency of Inversion (% of days during winter)	64%	45%	40%	38%	24%
Longest Inversion Period (consecutive days)	11	11	2	7	1

Inversions are clearly more frequent in Alaska, being present nearly two-thirds of the time in Fairbanks during the past winter. As on other measures, Anchorage is not as extreme but still experiences inversions nearly one-half of the time and more frequently that the Lower-48 cities. Further, inversion conditions can persist for extended periods in both Fairbanks and Anchorage, the longest during the past winter being 11 days. Of the other cities, only Pittsburgh comes close with a longest episode of 7 days, while Salt

Lake City and Seattle-Tacoma had longest episodes of 2 and 1 days. The latter is more typical in the Lower-48 States, where inversions can set up overnight but will usually breakdown the next day when sunshine heats the ground. Inversions that set up in Fairbanks and Anchorage during mid-winter can persist for many days.

From these many comparisons, we see that the wintertime meteorology of Anchorage is more severe than most locations in the Lower-48. Although selected cities may come close on an individual measure, Anchorage is generally colder and experiences surface inversions as strong as or stronger than the Lower-48 cities. Its climate is intermediate between the extreme of Fairbanks and the cold-winter cities in the Lower-48.

5. *Why does the meteorology experienced in Anchorage imply the need for more stringent emission standards for certain wood-fired heating devices?*

Research into the wintertime $PM_{2.5}$ problem in Fairbanks has shown that wood smoke is "… the major source of $PM_{2.5}$ throughout the winter months in Fairbanks, contributing between 60% and nearly 80% of the measured $PM_{2.5}$ at the four sites." (Ward 2012, abstract) The MOA Finding reports the results of research in Anchorage that revealed "… the contribution of biomass burning to the emissions of airborne organic PM in winter was much greater than previously thought. … the average contribution from wood burning to emissions of organic PM was 67%." (Finding, p. Appendix 2-7)

Washington State has determined that "… [w]ood smoke is the main source of the high levels of $PM_{2.5}$. It makes up 56 percent of Washington's wintertime $PM_{2.5}$" (Washington 2007). Other States across the country have reached similar conclusions implicating wood smoke as a major (sometimes the major) wintertime source of fine particulates. For this reason, Washington State enacted an opacity limit for OWBs as have other communities including Ft. Collins, CO and BAAQMD (SF Bay Area). (Finding, Table 3) MOA's OWB opacity limit is modeled on the Washington State regulation with the added provision that it does not apply when the appliance is the sole source of heat.

It is well-established that exposure to fine particulates increases the risk of heart and lung disease[*]. Given this and the direct connection between wood-burning devices and fine particulates, efforts to limit wintertime $PM_{2.5}$ levels must take steps to reduce wood smoke emissions. Because Anchorage has stronger and more persistent temperature inversions and higher home heating demands than most locations in the Lower-48, MOA has good reason to go beyond the EPA standards in adopting regulations on wood-burning devices that are comparable to, or more stringent, than those in adopted in Washington State, Ft. Collins, CO and the SF Bay Area.

[*] See http://www.epa.gov/pm/health/ for more information on the health effects of fine particulate matter.

3. SUMMARY AND OPINION

The climate and topography of Anchorage create recurring periods each winter when a strong surface inversion is present. The combination of cold temperature, a strong surface inversion, and calm winds causes fine particulates to accumulate in the air near the surface. Cold surface temperatures lead to high rates of fuel consumption and emissions of fine particulates, with wood-burning space heating devices being an important source. A strong surface inversion prevents vertical dispersion of pollutants, while calm winds prevent horizontal dispersion. In these conditions, $PM_{2.5}$ concentrations build over time and can approach the 24-hour standard.

In my opinion, MOA has demonstrated that meteorological conditions in the Anchorage area justify the proposed $PM_{2.5}$ emission limitation on wood-fired heating devices. Therefore, MOA has met its obligations under AS 46.14.010 (c)(1) and (d).

4. REFERENCES

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