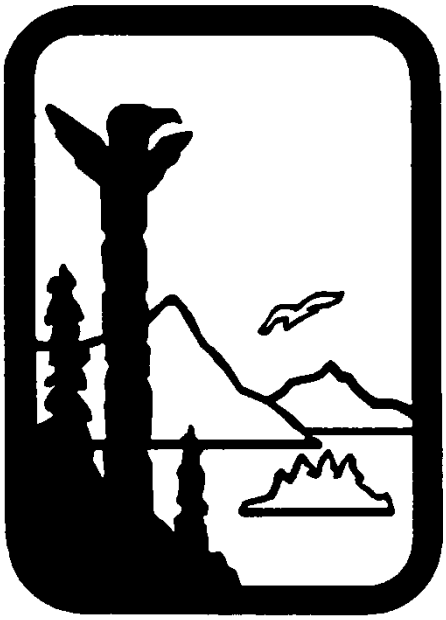
Alaska Department of Environmental Conservation



Amendments to:
State Air Quality Control Plan

Volume III: Appendix III.K.3

Overview of Alaska and Air Quality

Appendix to
Section III. K: Areawide Pollutant Control Program
for Regional Haze

Adopted

February 11, 2011

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Overview of Alaska and Air Quality

Arctic Haze

The scientific knowledge of Arctic haze was first codified by Drs. Rahn and Shaw.[1] Other summations were later made by Dr. Barrie in 1986[2] and by Drs. Shaw and Khalil in 1989.[3]

During the winter, the Arctic atmosphere becomes contaminated with anthropogenic pollution transported primarily from sources in Europe and Russia.[1] This unusual form of regional air pollution is commonly referred to as "Arctic haze." Sulfur oxides and soot are its main ingredients, although many metal and organic compounds can be found in Arctic haze samples.[4] Arctic haze is absent during summer, but begins to appear in the early winter. Photochemical oxidation of sulfur dioxide into sulfate aerosols after polar sunrise and seasonal meteorological conditions cause Arctic haze to reach its peak intensity in March, after which levels sharply decline.

The haze is composed of particles no larger than 2 μm because these particles have low settling velocities and are capable of remaining suspended in the atmosphere for weeks. This allows the particles to travel into the Arctic, which has few local aerosol sources.[5] The size of the Arctic haze aerosols is approximately the same as the wavelength of visible light (0.39-0.76 μm), allowing the aerosol to scatter light and therefore diminish visibility very effectively.

Arctic haze is often layered, a consequence of the small thermal lapse rate of the Arctic atmosphere in the winter. The shallow lapse rate dampens vertical mixing and therefore allows pollution to spread horizontally much faster than vertically.[6] Arctic haze occurs throughout the height of the Arctic troposphere as a result of the tendency of air parcels to move along surfaces of constant potential temperature causing pollution from lower latitudes to enter the Arctic at higher altitudes.[7]

Mitchell first characterized the haze in the 1950s.[8] Mitchell's early observations of pollution in the Arctic air mass were strictly visual; he saw large brown layers of haze. The name "Arctic haze" seemed an obvious and appropriate title, and has since come to be the standard title for the abnormally intense pollution found in the Arctic during winter and spring. Its definition as a visual phenomenon was cemented by the fact that the re-discovery and research into it during the 1970s were carried out with sun photometers.[9,10] However, it must be recognized that the pollution transported into the Arctic is comprised of both gaseous and aerosol components, and that by defining Arctic haze as a visual phenomenon it covers only the aerosol component of that pollution. The distinction is often difficult to make. For example, Khalil and Rasmussen[11] discuss the pollutant gases as "gaseous tracers of Arctic haze" or "trace gases in Arctic haze."

Episodes of high concentrations of aerosol pollution are not always coincident with high concentrations of gaseous pollution. In fact, the two have a slightly offset seasonality, with the gases tending to reach their highest concentrations in January-February due to decreased photochemistry and mixing in the Arctic, while aerosol pollution reaches its

maximum in March-April due to increased airflow from central Eurasia and increased gas-to-particle conversion.

The particulate component of Arctic haze, is mostly comprised of sulfate aerosols, which make up approximately 90% of the haze's mass,[4] and soot.[12] There are also many other elemental constituents, such as lead, arsenic, nickel, copper, cadmium, vanadium, manganese and other metals, nitrate, sodium, magnesium and chloride.[2] Coal burning and metal smelting seem to be the primary contributors to Arctic haze, based on both its composition and the source regions.

The sulfur and nitrogen oxides in the Arctic air mass commonly form sulfuric and nitric acids. Hoff et al.[13] showed that Arctic haze aerosols exist as a spectrum, with acid sulfate aerosols comprising virtually 100% of the aerosol mass below 1 μm, sea salts ($MgCl_2$ and NaCl) comprising virtually 100% of the aerosol mass above 3 μm, and an acidified sea salt mixture existing between 1-3 μm. It is generally assumed in the literature that Arctic haze is mainly anthropogenic. There are many arguments for this, but two of the best use meteorology and isotope ratios. Iversen[14] showed how a high "meridinal index" (defined as a period of significant northward flow) over the North Atlantic coincides with low concentrations of sulfate aerosol at Bjørnøya and Ny Ålesund, while a high value over Europe or Asia coincides with higher sulfate levels.

The isotopic argument comes from Nriagu et al.,[15] who measured $\delta^{34}S$[1] in Arctic sulfate aerosol. According to Nriagu et al., $\delta^{34}S$ for anthropogenic sulfate in east-central North America ranges from 0 to $+5^0/_{00}$; the average $\delta^{34}S$ for sulfate in rainfall in the Soviet Union, $+5.9^0/_{00}$, was taken as an approximate average value for Europe. Sea salt sulfate contains a much higher $\delta^{34}S$, approximately $+20^0/_{00}$. Dimethyl sulfide (DMS), which accounts for the vast bulk of biogenic sulfur,[5] is thought to have a $\delta^{34}S$ less than $10^0/_{00}$, lighter than sea-salt sulfur. The $\delta^{34}S$ observed at Alert oscillates seasonally from a value of $\sim+9^0/_{00}$ in the summer to approximately $+6^0/_{00}$ in the spring. Ny Ålesund and Mould Bay have similar values, although far less detailed time series. The $\delta^{34}S$ ratios gathered by Nriagu et al. suggest that the sulfur collected in March is almost entirely anthropogenic, while the sulfur collected during the summer is substantially influenced by natural and biogenic sources.

Meteorological studies suggest that the pollution comprising Arctic haze comes mainly from Europe and Russia. Barrie et al.[16] used a chemical-transport model to determine the flux of anthropogenic sulfur across the Arctic Circle (66.33ºN) between 0 and 3.5 km altitude from July 1979 to June 1980. By calculating large numbers of back trajectories and matching them with precipitation data, they found that, of the 3.5 Mtonnes (1 Mtonne = 10^9 kg = 1 Tg) of anthropogenic sulfur that entered the Arctic, 52% came from Europe, 42% came from the Soviet Union, and 6% came from North America.

Most Russian pollution enters the Arctic between 20°E and 90°E,[16] indicating that it is transported into the Arctic by the blocking set up by a strong Siberian High, which

[1] The ratio of ^{32}S to ^{34}S in the total in the total inventory of the Earth is 22.22. This sulfur isotope ratio is accepted as an international standard and assigned a value of 0.00. Deviations from this ratio are expressed as $\delta^{34}S$, with units of parts per thousand ($^0/_{00}$).

typically only occurs in the spring.[14] Most of Europe's pollution, by contrast, enters the Arctic between 20°W and 40°,[16] indicating that its pollutants are primarily transported into the Arctic by North Atlantic dipole blockings.

Shaw and Khalil[3] explain the relative absence of pollution from North America and the Orient as a consequence of their positions relative to the oceans. Pollution from China and Japan follows a northeastern track towards the Arctic and encounters the Aleutian Low, which scavenges pollutants from the air. Similarly, pollution from eastern North America encounters the Icelandic Low in the North Atlantic, which scavenges pollution. Pollution from Europe and Russia can move over land, avoiding an encounter with a strong scavenging system. Furthermore, the major industrial centers of Europe lie approximately 10º north of those in the US and the Orient; Russian industry lies yet farther north.

The emission latitude has an enormous impact on the amount of the pollution that enters the Arctic air mass. Iversen[17] found that for sulfur oxides emissions in Europe, every 15° north increased the mixing ratio of sulfur in the high Arctic (80°N) by a factor of 10. This multiplicative factor is highly variable, changing to about 3 for alkanes, 5 for alkenes, and 30 for nitrogen oxides, but it provides the necessary illustration as to the importance of latitude.

Shaw[18] suggested that Norilsk (Russia), might be responsible for generating a substantial portion of Arctic haze. He showed that periods of extreme Arctic haze in Alaska were associated with trajectories that crossed the Norilsk region.

The Kola Peninsula area is also a major source of pollutants into the Arctic. Three major smelters, all located north of the Arctic Circle, inject a combined 500,000 tons of sulfur gases, 64,000 tons of dust, 2,460 tons of nickel, 1,600 tons of copper, and 100 tons of cobalt into the Arctic atmosphere.[19]

In the absence of Arctic haze, visibility in the Arctic is quite high. The greatest possible sea level visual range on Earth is 296 km, and Barrow averages 271 km in June. The average value for March is reduced to 143 km, and episodes of Arctic haze drive the range much lower.[20] Arctic haze often reduces visibility to approximately 30 km in the high Arctic.[2] Barrie also notes that suspended ice crystals frequently accompanied the haze, which further reduces visibility to about 10 km. These ice crystals are probably formed by the nucleation of ice onto acidic aerosols at temperatures below -25° C.

Measurements of the optical scattering coefficient (σ_{sp}) taken at Barrow, Alaska[21] indicated a decrease in Arctic haze between 1982 and 1992. NOAA's Climate Monitoring & Diagnostics Laboratory (CMDL) has since reported that while Arctic haze levels continue to be lower than the values observed in the early 1980s, the reported trend has not persisted during the past five years.[20]

J.R. Wilcox, in his Masters thesis,[22] reanalyzed this data and drew different conclusions. He identified, using the mean scattering measurements for average yearly values, or values for February or April instead of for the month of March, a more regular decrease since 1982.

Results from Ny Ålesund, Norway also suggest a decline. The Arctic Monitoring and Assessment Programme (AMAP) reported[4] that wintertime sulfate concentrations at Ny Ålesund (situated on the Arctic archipelago of Svalbard) had declined roughly 70% between 1980 and 1994. According to AMAP, however, Alert, Canada experienced only a slight decline over the same time period, raising the possibility that the decline might be uneven.

This decline in the severity of Arctic haze has been concurrent with major reductions in pollutant emissions of both sulfate and sulfur dioxide in the source regions, Europe and Russia. The Co-operative Program for Monitoring and Evaluation of the Long-Range Transmission of Air pollutants in Europe (EMEP) reports that Russian emissions of sulfur dioxide west of the Urals have fallen by 61% between 1988 and 1998, while the European Community has seen a concurrent decline of 48%.[23]

Asian Dust

Generally, long-range transport must occur at high altitudes (above 5 km) over an ocean in order to avoid scavenging.[3] Therefore, while the Pacific Ocean usually serves as a barrier to pollution transport, pollution can undergo long-range transport over it if lofted high enough. The transport of desert dust from the Orient is a well-documented phenomenon,[24] and so, increasingly, is the transport of pollution.

One of the first attempts to characterize the origin of Asian dust found that a large haze incident in early May 1976 was caused by desert dust.[25] This conclusion was based on the morphology of the aerosols and their chemical composition, along with consideration of the meteorological situation preceding the appearance of the haze. The dust was almost certainly transported from the Gobi and Taklimakan deserts in Mongolia and northern China. Nearly every spring, high winds loft so much dust that it falls on Japan and Korea like yellow snow. The Japanese refer to the massive dust fall as the "kosa," the Koreans call it the "whangsa." Spring is not only the most active period for dust storms in the Gobi and Taklimakan, but also the period of most active atmospheric transport between the Orient and the Arctic.[24]

Rahn et al.[25] estimated that such a plume could carry an enormous amount of soil into the Arctic; a plume of the intensity observed in 1976 would deliver approximately a half-million tons of soil into the Arctic during a five-day episode, assuming a traveling speed of 80 km/hr. Given that a large plume recently tracked across the Pacific moved at an average velocity of 43 km/hr,[26] Rahn et al.'s estimate may be about double what one would expect.

Since Rahn et al.,[25] the transport of Asian desert dust into the North Pacific atmosphere has been the subject of extensive study.[27,28,29,30,31,32,33,24] These investigations have established that Asian dust events occur in the springtime, usually April, and may reach as far south as Mexico, or as far north as the Arctic. Even Alert, at 82˚N latitude, sees a sharp seasonal elevation of soil dust in April/May.[34]

Cahill[35] found that elemental ratios in dust were similar in Denali National Park and Preserve and Crater Lake National Park, Oregon, during the spring, when both experience peaks in soil aerosol concentrations, indicating that the dust had a common origin. Cahill et al.[36] also showed Asian dust reaching Adak Island, Alaska, and the Poker Flat Research Range, north of Fairbanks, Alaska. These measurements were taken as a part of the Aerosol Characterization Experiment-Asia (ACE-Asia), a multi-national experiment designed to quantify the emissions of dust and other aerosols from the Asian continent into the North Pacific. During this study, the transport of these aerosols across the Pacific and into Alaska and Western United States was observed. Large segments of dust clouds moving east over the Pacific from Asia were observed to peel off and transport northward into the Arctic.[26] Model simulations also predict this phenomenon.[37,38]

Geological evidence suggests that global scale transport of Asian dust has been a long-running natural phenomenon.[27] Chemical analysis of Greenlandic ice cores[39] and Hawaiian soil studies[40,41,42,43] have shown that the chemical and radiological fingerprints of deposited dust were consistent with the composition of the Asian dust sources.

Rahn et al.[25] detected little pollution in the 1976 dust plume, but Chinese sulfur dioxide emissions have since tripled. Unsurprisingly, more recent studies have shown an increase in anthropogenic pollution concurrent with the transport of Asian air during the spring over the Pacific Ocean[44,45,46] and North America.[47] The concentration of sulfate, nitrate, soot, and heavy metal aerosols accompanying these dust plumes will almost certainly increase as China's coal-fired economy rapidly expands over the coming decades.

Aside from the probable increase in obviously anthropogenic pollution, the amount of dust may also be increasing. The dust itself has been implicitly assumed to be an entirely natural phenomenon, but this assumption needs to be examined. The dust storms should be considered at least partially anthropogenic, because human activities are contributing to an expansion of the Gobi desert, which has in turn produced more dust storms.[48] Beijing lies directly in the path of these storms, and therefore the Chinese have anxiously noted the accelerating occurrence of dust storms. Chinese records describe fierce dust storms occurring in Beijing once every seven or eight years in the 1950s. By the 1970s, they occurred every two or three years; and by the early 1990s, they had become an annual problem. By 2000, the problem had become acute; the worst storm in memory continued for many days, blotting out the sun, halting air travel and filling emergency rooms.[48]

The IMPROVE monitoring site in Denali National Park and Preserve actually saw a slight decrease in the severity of dust events reaching Alaska between 1988 and 2000. Perhaps this could be due to changes in transport patterns, but barring a fundamental shift in the seasonal teleconnection between the Gobi and Alaska, the Gobi desert's accelerating expansion ought to eventually cause an increase in the amount of dust entering the Arctic.

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