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Observations of "Arctic Haze" during the "Ptarmigan" weather reconnaissance flights, 1948–1961

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ABSTRACT

114 "Ptarmigan" weather reconnaissance flights over the Alaskan Arctic during 1948–1961 were analyzed for reports of "Arctic Haze" (~400 reports). Arctic Haze can reduce horizontal visibility significantly and is most frequently reported during late winter and spring, but is also found during early winter and summer. Haze is reported everywhere within the Alaskan Arctic at altitudes between the surface and 6 km. Anticyclonic surface pressure conditions are characteristic of Arctic Haze; "clear skies" weather conditions were predominantly present with haze observations during the winter months, "cloudy skies" were predominantly present with haze observations during the summer months. We hypothesize that Arctic Haze has a dual character of origin: it is pollution-derived during winter and early spring, and desert dust-derived during late spring and summer.

1. Introduction

The term "Arctic Haze" was used for the first time by Mitchell (1956) in describing the haze encountered during the "Ptarmigan" weather reconnaissance flights. Mitchell's description of Arctic Haze was based on observations and subsequent discussions between him and several weather officers. They were surprised to find the optical transparency of the arctic atmosphere at times significantly reduced by thick haze layers; this was surprising because up to then the polar regions had been considered as the cleanest regions on earth. A similar phenomenon has not yet been reported from Antarctica. After Mitchell's paper (1956), the phenomenon of Arctic Haze was neglected.

The discovery of high turbidity values in the Alaskan Arctic in spring of 1970 and 1971 (Shaw and Wendler, 1972) led to the rediscovery of Arctic Haze and motivated further chemical studies. Aerosols collected on ground-based filters and analyzed by Neutron Activation Analysis indicated that there seems to be a significant pollution-derived component (i.e., excess sulfate, excess vanadium, carbon), having a late winter/early spring maximum and a minimum during the summer (Rahn and McCaffrey, 1980). There is no evidence of a local source (Rahn, personal communication), Thus, pollutants must have travelled long distances, probably originating from mid-latitudinal sources, involving travel times of about 4–20 days as modelled by Rahn and McCaffrey (1980) and Shaw (1981), as well as based on the interpretation of carbon data (Rahn et al., 1980).

The aerosol collected at Barrow, Alaska is mostly of submicron size and exhibits a hygroscopic character (Bigg, 1980; Shaw, 1983). Bodhaine et al., (1981) and Shaw (1981, 1982a) showed that at Barrow, the aerosol light scattering undergoes a seasonal variation similar to the seasonal variation of the arctic pollution aerosol. Shaw (1982b) observed that during the presence of pollution-derived aerosols at the ground near Fairbanks, haze bands aloft were also present. Therefore, although still very speculative, Rahn and

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Shaw have suggested that Arctic Haze observed during the fifties was a manifestation of anthropogenic pollution in the Arctic.

On the other hand, a field experiment conducted in April/May 1976 at Barrow, Alaska revealed that haze bands observed at about 2 km altitude were composed of crustal particles, in this case having their origin in the eastern deserts of Asia (Rahn et al., 1977; Rahn et al., 1981). Injections of desert dust into the Barrow atmosphere were not considered to occur very often, and indeed our investigation of surface data of spring 1977 and 1978 at Barrow does not find much evidence of enriched crustal components (Raatz, unpublished). The question has yet to be resolved whether or not air samples at the ground are representative for the air aloft, especially under stable atmospheric conditions frequently found in the Arctic.

Thus, we have two sets of data describing the phenomenon of Arctic Haze: on one hand the historical weather reconnaissance flight reports and Mitchell's description of Arctic Haze, and on the other hand, Shaw's and Rahn's description of today's arctic aerosols and their physical and chemical properties.

Unfortunately, the "Ptarmigan" flights ceased in December 1967, and there is no longer a systematic gathering of visual information on the vertical distribution of the arctic aerosol. The purpose of this investigation is to characterize Arctic Haze based on the old reports of the "Ptarmigan" flights and link it to the knowledge of arctic aerosol we have now available. One of the questions to ask is: was the Arctic Haze observed by the "Ptarmigan" flights a visual manifestation of mid-latitudinal pollutants or was it desert dust transported into the Arctic region.

2. The "Ptarmigan" data

The "Ptarmigan" flight reports were obtained on microfilm from the National Climatic Data Center, Asheville, and cover the period January 1949 through December 1967. Table 1 shows that in the beginning, flights were made only 2 or 3 times a week, but later on almost daily. The flight altitude was in most cases close to the 500 mb surface, and in some cases close to the 700 mb surface. Although the flight path patterns were occasionally changed, the flights were always restricted to the Alaskan sector of the Arctic; i.e., approximately within the region defined by the three point: 70N, 160W; 70N. 110E and the North Pole. Haynes (1949) described his experience during one of the "Ptarmigan" flights.

A "Ptarmigan" flight record entry made at 1/2 hour intervals contained the following information: date, time, position, altitude, visibility, wind, cloud amount and types, air temperature, (sometimes) dewpoint, and height of 500 mb or 700 mb surface above ground. Sometimes other information was also given, like turbulence, icing of the aircraft, state of sea underneath, etc., and vertical temperature profiles made by using dropsondes.

Table 1. *Monthly frequency of "Ptarmigan" weather reconnaissance flights*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1949	11	13	15	14	14	15	14	16	13	10	9	0	144
1950	2	9	3	4	8	11	9	13	15	12	10	10	106
1951	2	4	15	24	27	17	17	15	13	16	15	12	177
1952	5	5	9	2	3	13	16	18	22	14	27	28	162
1953	23	23	27	28	31	27	32	30	24	13	21	22	301
1954	14	18	31	32	32	30	32	31	29	29	26	27	331
1955	32	27	33	31	31	30	31	32	31	31	31	31	371
1956	31	29	33	30	32	31	31	31	31	31	32	33	375
1957	25	8	0	0	19	15	20	22	14	27	27	30	207
1958	30	27	11	25	31	31	31	2	30	39	29	31	317
1959	31	27	31	30	31	29	33	31	30	31	31	31	366
1960	31	20	19	16	0	2	5	16	12	11	13	31	176
1961	3	12	31	20	25	30	26	10	37	19	13	15	241
Total	240	222	258	256	284	281	297	267	301	283	284	301	3274

Some of the instrumentation used was described by Vederman and Smith (1950), but we do not have any information on the reliability of the observation procedures and instrumentation. There is also a great deal of uncertainty attached to those visual observations made during the polar night or twilight. For this analysis we are considering only those "Ptarmigan" flight reports in which the occurrence of haze was actually spelled out as a comment, because the coded report on "present weather" conditions does not distinguish between "fog" or "thick dust haze", and on the other hand, in writing out the word "haze" it must have appeared to the observers as something worth mentioning. This restriction reduces our data set to 114 "Ptarmigan" flights. But we are still faced with the problem that a very thin cloud might have been mistaken as a haze layer or that the observer simply missed seeing the haze when it was present, i.e., the data set is subjective. Mitchell (1956), however, noticed that there is a distinct difference between haze and a thin Cirrostratus. Haze has a different color (grey-blue in antisolar directions and a reddish-brown hue in the direction of the sun), diffuse boundaries and is without spectacular optical effects.

3. On the occurrence of Arctic Haze

Presenting the available data of 114 flights, with about 400 haze reports to be analyzed in the form of Table 2, we can already deduce some information on the seasonal and interannual variation of the occurrence of Arctic Haze. One easily can see a seasonal variation with a repeatable spring maximum. Mitchell (1956) did not mention this, perhaps because of the more limited data set he had available. The spring maximum apparently is real, that is, it is not caused by an increased number of flights and therefore an increased number of observations during spring (Table 1). It is possible that the number of occurrences of haze can be higher during the winter, when visual observations are questionable due to the lack of proper illumination. We note that the three months of March, April and May include 62% of all flights with haze reports. Thus, the spring maximum seems to be significant.

The spring maximum of Arctic Haze is to first order in agreement with findings of the seasonal variation of the pollution-derived elements sulfate and vanadium (Rahn and McCaffrey, 1980) found at Barrow, Alaska. Breaking it up into months, May has the maximum of "Ptarmigan" Arctic Haze reports, which seems to be displaced by about 1–2 months with respect to the pollution-derived aerosol which tends to peak in March. There are also a number of haze reports during the summer, which seem to contradict the concept of a pollution-derived haze. During summer, the concentrations of pollution-derived elements are very low, for example, the concentration of vanadium at Barrow is lower by a factor of nearly 50.

A spring maximum, on the other hand, would

Table 2. *Monthly frequency of "Ptarmigan" weather reconnaissance flights with haze reports*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1949	3	4	2	4	0	1	0	2	1	0	2	–	19
1950	1	0	0	2	5	1	0	2	3	4	2	2	22
1951	1	2	4	8	7	2	1	0	1	0	1	0	27
1952	0	0	1	0	0	0	0	0	0	0	0	0	1
1953	0	0	1	2	7	1	3	3	1	0	0	3	21
1954	0	0	5	2	0	1	0	0	0	0	0	1	9
1955	1	0	3	1	3	0	0	0	0	0	0	0	8
1956	0	0	0	1	1	0	2	0	0	0	0	0	4
1957	0	0	–	–	0	0	0	0	0	0	0	0	0
1958	0	0	0	0	0	0	0	0	0	0	0	0	0
1959	0	0	2	0	0	0	0	0	0	0	0	0	2
1960	0	0	0	0	–	0	0	0	0	0	0	0	0
1961	0	0	0	0	1	0	0	0	0	0	0	0	1
Total	6	6	18	20	24	6	6	7	6	4	5	6	114

also be consistent with the idea of a desert dust-derived haze, because spring is the season of desert dust storms in the eastern deserts of Asia (Watts, 1969). Dust concentrations in the atmosphere over Northern Kazakstan and southern Central Asia are high during May through September (Makhon'ko and Rabotnova, 1981). According to Duce et al. (1980) there is a significant transport of continental aerosols out of Asia north of 20° N during the spring and extending into the summer.

Surprisingly, there is an almost equal number of haze observations during the early fifties (except 1952), but after that, the accounts of Arctic Haze drop off and become scarce. The years 1949–1954 represent 87% of all flights with haze report. We have tried to check for the possibility of a change in flight path patterns, flight altitude, use of observers, and change in observation procedures, but these factors have not revealed any significant changes.

For a pollution-derived haze we would expect a monotonic increase of haze occurrence with time associated with increasing anthropogenic activity. It appears unlikely that this drop in haze occurrence could have been caused by a change from coal to oil as the major fossil fuel in Europe (Semb, 1978), because this change occurred during the late fifties and early sixties. We assume that increased consumption of oil in the Soviet Union occurred even later than in Europe, around the mid-sixties, when large discoveries were made (Shabad and Mote, 1977). According to Rahn (1981b), Eurasia is the most important region contributing to the pollution-derived aerosols collected at Barrow.

If Arctic Haze is desert dust-derived a possible explanation would be an increased number of dust storms during the early fifties due to exceptional dryness in Asia. Arao et al. (1979) presented a time series of the number of days with yellow sand over Nagasaki, Japan. Between 1952 and 1955 there is a pronounced increase in the occurrence of yellow sand, flanked by very few low values during the late forties and during the late fifties.

For both possibilities (a pollution-derived haze or a desert dust-derived haze), a change in the effectiveness of removal mechanisms (i.e., clouds and precipitation) along the transport path as well as changes in the transport path itself due to circulation changes could also explain a change in the frequency of Arctic Haze occurrence. Raatz (1981), however, reported a pronounced increase in cloudiness over Barrow which occurred during the mid-forties. Because of the dramatic drop in haze reports, the "Ptarmigan" data from 1962–1967 were not analyzed and are, therefore, not included in this investigation. Reports of Arctic Haze remained very scarce until the end of the record in 1967.

From the frequency of haze reports during one flight we find that Arctic Haze was more widespread over the Arctic during spring than during the rest of the year (Table 3). Note,

Table 3. *Monthly frequency distribution of frequency of haze observations during one flight*

	Numbers of haze observations during one flight															
Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total	Average
Jan.	1	1	2		1			1							6	3.7
Feb.	2	2		1		1									6	2.7
Mar.	2	4	3	3		1		1	2	1			1		18	4.8
Apr.	4	6	1	3	3			1			1	1			20	3.9
May	9	3	3	2	4		1				1	1			24	3.4
June	2	1	1			1	1								6	3.3
July	4	1						1							6	2.3
Aug.	4		1	1	1										7	2.3
Sept.	4	1	1												6	1.5
Oct.	2		1		1										4	2.5
Nov.	3	1		1											5	1.8
Dec.	3						1			1				1	6	5.7
Year	40	20	13	11	10	3	3	4	2	2	2	2	1	1	114	3.5

however, that some of the average number of haze observations during one flight can be misleading, e.g., December, when there were only few data available. For the whole data set, on the average 3.5 haze observations were made during one flight. We also find that Arctic Haze usually seems to be confined to patches, limited to certain areas. This is in agreement with Mitchell's (1956) findings which estimate an average horizontal extent of 800–1300 km. But there were also two cases when Arctic Haze was reported in every flight record, thus covering a distance of about 3200 km.

Fig. 1 shows the frequency of observations of Arctic Haze per quadrants with sides of 4° latitude and 5° longitude. We have made no adjustments for the decreasing size of the quadrants with latitude. At 82° N and 86° N we increased the length of the longitude side to 10° and 20°, respectively, for better visual presentation. There is practically no area where Arctic Haze has not been observed. There seem to be certain areas where Arctic Haze was encountered more frequently, but by studying the most common flight path patterns, those areas of maximal Arctic Haze frequency are found to be those most frequently overflown. Deductions on the spatial distribution of Arctic Haze are, therefore, inconclusive. We noticed, however, that Arctic Haze was almost always reported during anticyclonic surface pressure conditions, most often at the northern periphery of the Beaufort Sea anticyclone. Haze reports were also frequent within the northwestern quadrant of the anticyclone. In mid-latitudes, hazes are often observed during anticyclonic conditions and Arctic Haze does not seem to be different.

40% of all haze observations were specified with an altitude estimate. Arctic Haze was observed everywhere between the surface and 6 km altitude, i.e., below the tropopause (Fig. 2). In most cases, the altitude of the haze was given as, "haze at and below flight level", in other cases the top of the haze layer was estimated. Therefore, it is not too surprising to find the most frequent haze altitude to coincide with the main flight level at 500 mb (5–6 km). A secondary maximum is observed at the other main flight level at 700 mb (2.7–3.0 km). Mitchell (1956) remarked that Arctic Haze was characterized by considerable vertical thickness. It is interesting, however, to note the large number of observations of Arctic Haze occurrence at the 500 mb level, because more recent investigations seem to suggest a haze at lower levels. For example, Holmgren et al. (1974) found an Arctic Haze layer near 2 km altitude, Shaw (1982a) reported haze layers at 1.2 km and between 2 and 3 km, and Rahn et al. (1981) observed bands of haze

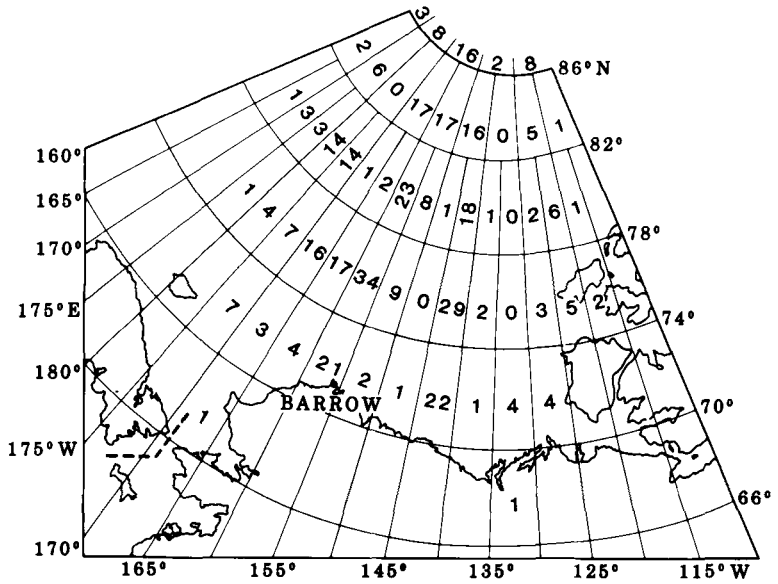

Fig. 1. Spatial frequency distribution of Arctic Haze reports.

between 2 and 2.6 km with evidence of another layer above 3 km. These recent investigations, however, were carried out with small airplanes which could not ascend up to 500 mb.

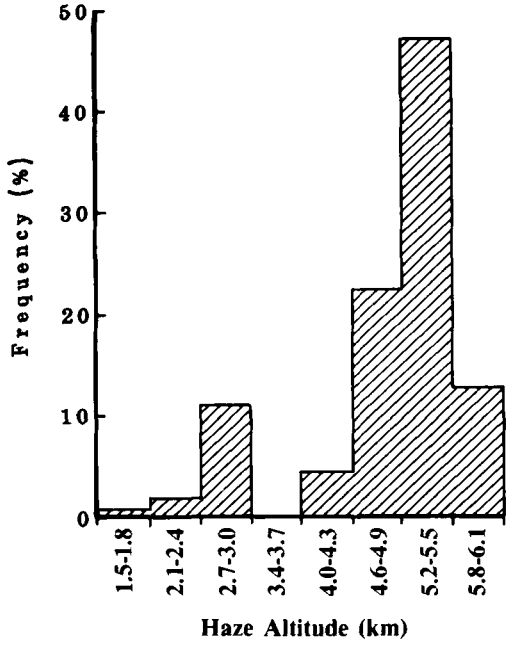

Fig. 2. Frequency distribution of altitude of occurrence of Arctic Haze.

Assuming that haze reports without specified altitude represent low level haze because the observer could not estimate the altitude, we found that during the period November–April there are as many haze reports without specified altitude as during the period May–October. The data set does not suggest, for example, that low-level haze prevails during the winter months and upper-level haze during the summer months.

4. Synoptic conditions during observations of Arctic Haze

Present weather, cloud types and amount were reported for a cylindrical portion of the atmosphere, approximately 50 km in radius about the plane at the time of observation. It has been noted by Mitchell (1956), that Arctic Haze was usually found during otherwise "clear" weather conditions. Mitchell's statement is verified for the period November–April (Fig. 3a). But for the period May–October, Arctic Haze is observed most often during conditions of "continuous layers of clouds" (Fig. 3b). This may only be related to the fact that during the winter arctic skies are usually clear, but are overcast during the summer (Henderson, 1967). On the other hand, it might suggest that clear skies are not a necessary prerequisite for the appearance of Arctic Haze. From the analysis of haze observations at flight level during weather

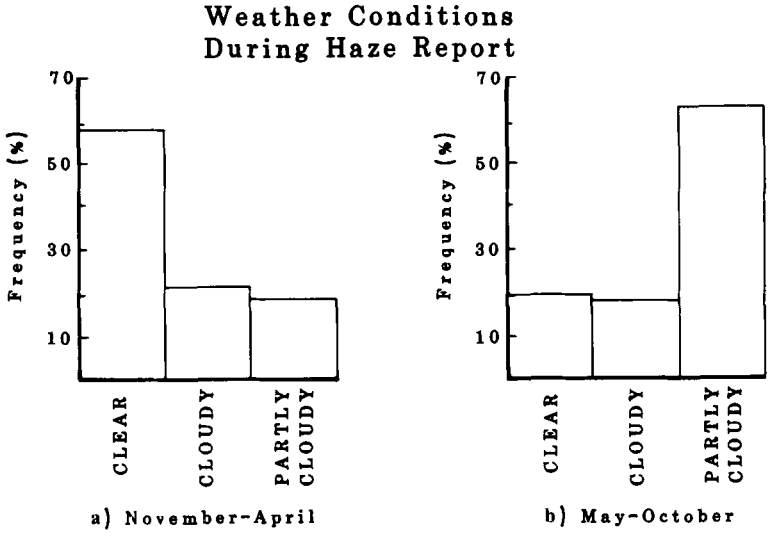

Fig. 3. Frequency of weather conditions during haze reports (a) November–April, (b) May–October.

conditions with clouds, we find that in most cases the haze was at a different altitude than the cloud layers, making it easier to distinguish haze from thin clouds.

If there were clouds present, Arctic Haze was most frequently associated with Cirrostratus clouds. The high percentage of Cirrostratus clouds is surprising, because it does not reflect the normal conditions as indicated by "Ptarmigan" data over the Beaufort Sea (Henderson, 1967) and the data at Resolute (Vowinckel, 1962), where middle layer clouds are more frequent. Voskresenskij and Karimova (1964) note that the number of days with clouds of the upper atmospheric layer has a maximum over the Arctic between the end of the winter and the beginning of spring (March/April). They also mention that the formation of Cirrostratus clouds is usually due to the regular rise of air in the zone of high level fronts. This is consistent with the finding that haze was observed in zones of strong surface pressure gradients which can be associated with fronts aloft.

According to Rahn et al. (1981) pollution episodes at Barrow are associated with northerly winds; clean air usually has its origin in southern latitudes. On the "Ptarmigan" flights, wind was determined by aerial navigation methods and Fig. 4 shows the frequency of wind directions associated with observations of Arctic Haze. It should be kept in mind that the wind was determined at flight level, which is not always necessarily the same at the altitude of the haze layer. Because winds are reported at flight level, which was usually at 500 mb, it is not surprising to find a predominant west wind. During November–April, haze observations frequently coincide with northerly winds, whereas during May–October there are many observations of Arctic Haze with southerly winds.

One of the most obvious features of Arctic Haze is that it restricts horizontal visibility. Horizontal visibility was determined as the maximum distance to which one could see, common to sectors comprising 1/2 or more of the horizon circle in the plane of the flight level. Unfortunately, two different ranges of estimates were used, so that we represent horizontal visibility in categories composed of these two (Table 4). Surprisingly, even under "clear" sky conditions, the horizontal visibility can be reduced appreciably. The effects of haze cannot be eliminated from those due to clouds during conditions of "partly cloudy" or "overcast" skies.

It is difficult to estimate a typical temperature of Arctic Haze because this depends on the type of air mass the haze is in, as well as the altitude of the haze. If, in the case of haze at flight level, we plot altitude of haze versus temperature at that altitude, a correlation is found. The relationship is valid for different "present weather" conditions. The lower the altitude the colder the haze temperature. But it seems that the correlation does not represent a new piece of information. It merely reflects the well-known principle that a pressure surface lies higher if the air column underneath is warmer and vice versa. The range of observed haze temperatures is broad, approximately from −20 °C to −50 °C.

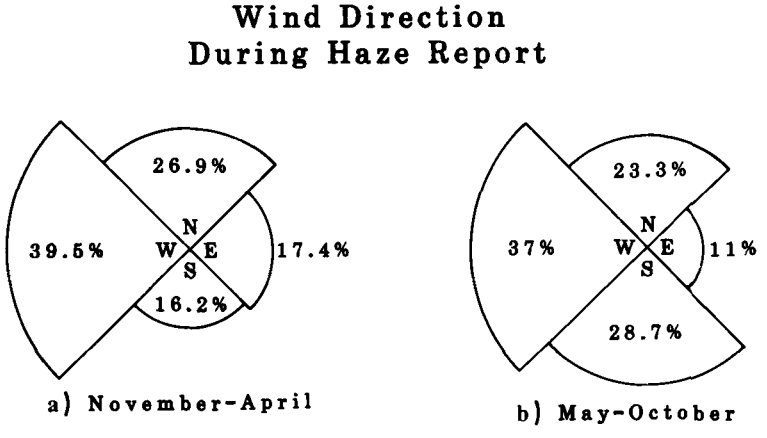

Fig. 4. Frequency of wind direction during haze reports (a) November–April, (b) May–October.

Table 4. *Frequency of visibility range during haze reports and different weather conditions*

	Visibility range (km)				
	<1.8	1.8–5.6	5.6–18.5	18.5–55.6	>55.6
Clear	15*	4	25	44	90
Partly cloudy	0	0	31	20	22
Continuous layers of cloud	6	6	35	31	49

* 13 observations during one flight.

During some of the flights, dropsondes were released to obtain vertical temperature profiles. In most cases, dew point temperatures were not available. We were able to summarize 16 cases of haze report for which both the synoptic conditions and vertical temperature profiles are available. Some cases are also included when the time of dropsonde release did not correspond with the time of haze report, but in these cases the time difference was no more than one hour so probably the aircraft was still within the same air mass. In other cases the dropsonde release was in the vicinity of ground stations (Barrow, Mould Bay), and when both were within the same air mass as revealed by similar temperature profiles, we then obtained the information on the moisture regime from the ground station. A variety of synoptic conditions as well as a variety of vertical temperature profile types are associated with haze reports. No typical Arctic Haze temperature profile is obvious from the data set.

5. On the possible origin of Arctic Haze

Several attempts have already been made to find the source regions of the arctic pollution-derived aerosols. Shaw (1928b) has shown that industrial areas in the Asiatic sector of the Soviet Union can inject pollution aerosols into the Arctic which can be detected at Fairbanks, Alaska. Rahn (1981a) has hypothesized, based on the Mn/V ratio, that Soviet pollution sources might frequently be responsible for the aerosols collected at Barrow, Alaska. Europe has also been suggested as a major source region for injecting pollution aerosols into the Arctic (Rahn, 1981b; Larssen and Hansson, 1979). North America has been suggested as a source as well (Reiter, 1981) although Rahn's (1981b) research indicated that North America is of little importance. The Far East (Japan/Korea) has been assumed to be insignificant as a source for anthropogenic pollution aerosol in the Arctic (Rahn, 1981b), but transport of Gobi desert dust to Barrow has been documented (Rahn et al., 1977; Rahn et al., 1981). We have also attempted to identify transport pathways from possible source areas to the location of the haze observations (Table 5). For the years 1949, 1950, 1951, and 1953, which represent 89 flights, we subjectively identified pathways on the Northern Hemisphere Sea Level and 500 mb charts published by the U.S. Weather Bureau. Admittedly, this is a crude and subjective approach, but it may be useful to gain some rough information about the origin of Arctic

Table 5. *Monthly frequency of occurrence of transport pathways leading to different source regions*

	U.S.S.R.	Europe	America	Far East	Unknown
Sept.	3	1		1	1
Oct.	2	1		1	
Nov.	1	3		1	
Dec.	4	1			
Jan.	2	2			1
Feb.	3	4			
Mar.	3	3			2
Apr.	4	7	2		4
May	1	5	1	7	5
June				6	
July				3	
Aug.	1	1		5	
Total	24	28	3	24	13

Haze. We have classified possible source areas into the following categories: Soviet Union, Europe, North America, Far East, and of unknown origin. The last category "unknown origin" includes all those cases where no pathway could be detected or when two equally strong pathways were present at the same time.

In general, we found that during winter/spring, transport pathways were established on the surface weather maps and quite often supported at the 500 mb level. During the summer, however, transport pathways were usually only suggested at 500 mb. It is known, however, that the arctic atmospheric surface circulation is intense and distinct during the winter, whereas it appears sluggish and indifferent during the summer (Wilson, 1967). It is, therefore, possible that transport of aerosols during winter can occur at low levels, while during summer, the transport would tend to take place at higher levels. The data in Table 5 suggest that there is a seasonal trend as to which source area contributes to the formation of Arctic Haze. During September–April, the Soviet Union is suggested as a source (26% of all cases). The importance of European sources seems to be shifted towards the spring (30% of all cases). There is little evidence that American sources are important in contributing aerosols (3% of all cases). Sources in Far East Asia, which we will assume to be deserts, are, according to Table 5 predominantly responsible for Arctic Haze during the summer (26% of all cases), with little or no contributions from the other source areas.

The month of May appears to be transitional with respect to the haze origin. From December to May, the haze is mostly of pollution origin; from May to August the haze seems to be desert dust-derived. The strong spring maximum as noted in Table 2 seems to be caused by the simultaneous presence of a pollution-derived and a desert dust-derived haze. During April and May 1976, Rahn et al. (1981) noticed pollution episodes and desert dust episodes. Overall, pollution-derived haze was suggested in 59% of all cases, desert dust-derived haze in 26% of all cases and 14% were undetermined.

We hypothesize that the seasonal variation of occurrence of transport pathways leading to different source regions can be explained in the following manner: during the winter the Asiatic anticyclone creates stagnation and temperature inversions over most part of the Soviet Union, thus, "favorable" conditions for the accumulation of pollutants. The continentality of the Soviet Union produces a surface pressure higher than that over the relatively warmer Arctic, such that winds are directed from the Soviet Union to the Arctic (Lydolph, 1977). The transport probably takes place within the surface inversion layer and the aerosols also remain in this layer over the Arctic because the Arctic is characterized by anticyclonic conditions as well (Wilson, 1967). Anticyclonic conditions all along the path inhibit a vigorous mixing and, therefore, explain why pollution aerosols can be sampled at the ground and why haze observed during the winter is most often associated with clear skies. Similar arguments can be made for early spring. The Asiatic anticyclone has extended its influence onto the European continent (Lydolph, 1977). Blocking activity causing meridional exchange between mid-latitudes and the Arctic is at its maximum (Treidl et al., 1981) injecting European aerosols into the Arctic which is under maximal anticyclonic influence (Wilson, 1967).

During winter and spring, the surface circulation of the Arctic is distinct and can allow for transport over long distances. During summer, however, the Asiatic anticyclone has disappeared. The Arctic surface circulation is sluggish and cannot provide efficient transport of pollutants. Instead, cyclonic activity over East Asia raises dust from the surface to higher levels of the atmosphere and with the upper circulation desert dust is transported into the Arctic, unaffected by the prevailing low stratus cloud decks, which are characteristic of arctic skies during the summer. For these reasons, Arctic Haze during the summer is undetectable by ground observers and aerosol samplers.

6. Summary and discussion

The analysis of about 400 haze reports during 114 "Ptarmigan" weather reconnaissance flights over the Alaskan Arctic during January 1949 through December 1961 can be summarized as follows.

Horizontal visibility can be reduced significantly by Arctic Haze during otherwise "clear" weather conditions. If the haze bands contain as much carbon as the near-surface aerosol indicates, the

occurrence of Arctic Haze could lead to a warming of the arctic atmosphere as estimated by Shaw and Stamnes (1978).

Arctic Haze was found everywhere within the Alaskan sector of the Arctic Ocean, usually occurring under anticyclonic pressure conditions. It is, therefore, suggested that Arctic Haze is not, except rarely, a haze caused by moisture released from open leads which are more frequent along the Beaufort Sea coast. Haze layers were found at all altitudes between the surface and 6 km with maximal frequency at the main flight levels (500 mb, 700 mb). The high frequency of haze at these levels is, therefore, most likely an artifact of the data collection. Haze usually appears to be combined with patches of horizontal extent of 800–1300 km. This could be due to the fact that haze is patchy in its own nature or that the flight track traversed different air masses.

Arctic Haze is associated with temperatures between −20 °C and −50 °C and with Cirrostratus clouds as the most frequent cloud type in those cases when clouds were present. The presence of this cloud type might indicate that Arctic Haze is associated with frontal zones.

There is a seasonal variation of the occurrence of Arctic Haze with a repeatable spring maximum. Significantly, more haze is reported in spring than during winter and summer. During the spring maximum, Arctic Haze also appears to be more often reported at different points during one flight, suggesting its presence over large areas of the Alaskan Arctic. Based on the seasonal variation and possible transport pathways of aerosols into the Arctic, we hypothesize that Arctic Haze is predominantly pollution-derived during winter/early spring and desert dust-derived during late spring/summer with May being the transitional month. In addition, the possibility still exists that some of the hazes reported are attributable to local moisture.

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