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ARCTIC HAZE: A CHEMICAL, PHYSICAL, OPTICAL
AND METEOROLOGICAL STUDY

A Progress Report and Research Proposal to the
Office of Naval Research
Arctic Program

1 August 1976

GRADUATE SCHOOL OF OCEANOGRAPHY
UNIVERSITY OF RHODE ISLAND
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after. The origin of the dust was proposed as deserts in eastern Asia ↗

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**ARCTIC HAZE: A CHEMICAL, PHYSICAL, OPTICAL
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PROPOSAL

TITLE: Arctic Haze: A Chemical, Physical, Optical and Meteorological Study
DATE: 1 August 1976
AGENCY: Arctic Program, Office of Naval Research

Submitted

by

GRADUATE SCHOOL OF OCEANOGRAPHY

UNIVERSITY OF RHODE ISLAND

KINGSTON, RHODE ISLAND

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Proposed Starting Date: 1 October 1976

Duration of Program: 12 Months

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Statement of Submission

The following progress report and renewal proposal, "Arctic Haze: A Chemical, Physical, Optical and Meteorological Study", is hereby submitted to the Office of Naval Research, Arctic Program, for consideration as a research grant. Because of the pressure of time between the field program upon which the progress report is based (April-May 1976) and the target date for renewal (1 October 1976), the proposal is being submitted without final approval or related paperwork from the University of Alaska. In every other respect, including scientific justification and plans for the work, the proposal is complete. The basic budget of the University of Alaska has already been approved by their business office, however, the minor changes introduced at the University of Rhode Island during the final preparation of this proposal should cause no difficulties whatsoever. All necessary documents from the University of Alaska will be forwarded to ONR as soon as possible.

This proposal is not being submitted to any other agency for financial support.

Abstract

The original eight-month pilot study of Arctic haze (persistent diffuse aerosol bands found in the Arctic troposphere) over Alaska has shown conclusively that aircraft sampling of the haze aerosol followed by chemical analysis of the particles collected is a powerful tool for deducing the source of the haze. The haze aerosol of April-May 1976 seems to have been crustal in composition, i.e. natural rather than anthropogenic. Very rough trajectory analysis has suggested that the Asian deserts may have been the source of this haze.

We propose here a two-part follow-up study which will further examine the characteristics and origin of Arctic haze. The first of these parts, a one-year ground-level sampling program at Barrow and Fairbanks, will seek to determine the seasonal frequency of occurrence of the Alaskan haze bands by following the chemical composition of the Alaskan ground-level aerosol. Correlations between its composition and its source areas will be sought by trajectory analysis. The second part of the study (April 1977) is a follow-up field program in which the aerosol bands themselves will be intensively sampled both at various heights and as a function of particle size. As before, the radiation characteristics of the haze aerosol will be simultaneously monitored. Use of a Super DC-3 for the airborne sampling should allow more and longer samples to be taken at a greater variety of altitudes than was possible in the pilot study. The aircraft study should yield critical information about: the composition of the haze next year as compared to this year (to confirm its recurrent crustal nature),

the vertical profile of chemical composition through the haze layers (which may not be the same for large and small particles), and about their composition as a function of particle size (to see whether the smaller-sized haze-producing component has the same source as the larger-sized bulk mass of the aerosol). In addition, a laboratory investigation of the detailed chemical composition of various soils as a function of particle size, with particular attention to the 1-10 μ m fraction of various soils (our best guess as to the true precursor of the Alaskan and other crustal aerosols), will be begun. The composition of "crustal" aerosol (including Arctic haze) does not correspond to that of any known crustal material; a study of crustal material by particle size may show why. A useful by-product of this investigation might also be specific indicator elements or groups of elements from various arid regions of the world.

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I. Progress Report: February 1976 - July 1976

A. Scientific background, goals of the study, and summary of results

"Arctic haze" is a general term for turbid layers of air which are seen regularly over the Arctic Ocean north of Alaska during all periods when the weather there is clear. Arctic haze was first noticed by weather officers who flew the "Ptarmigan" weather missions over the Arctic Ocean about 20 years ago (Mitchell, 1956). Because the clearest periods in the Alaskan Arctic are during the spring, most reports are from this season. Otherwise, its seasonal occurrence is unknown. Its observation so far has been entirely visual. It is found as broad diffuse layers hundreds to thousands of miles in horizontal dimension and at nearly all levels in the troposphere. Although it is invisible from the ground, horizontal visibility through a haze layer may be restricted to as little as 3-8 km. Its color is grey-blue in the antisolar direction and reddish-brown in the solar direction. It has none of the optical effects of ice crystals such as sun pillars, halos, etc., which would seem to rule out thin cirrostratus clouds as the explanation. Rather, one is more reminded of urban haze. Indeed, the color effects of Arctic haze suggest that its particles are 1 μ m or smaller in radius, i.e. true atmospheric aerosols. Curiously, the haze has seldom been reported over land, e.g. Greenland.

From 1956 until 1972 Arctic haze was a forgotten phenomenon. Then in 1972 radiation measurements conducted by the Geophysical Institute of the University of Alaska in the AIDJEX pilot study revealed unexpectedly high turbidities in the Arctic atmosphere, which were again confirmed during the AIDJEX lead

experiment in 1974 (Holmgren et al., 1974). For these flights over the pack ice north and northwest of Barrow, Alaska, it was found that much of the anomalous turbidity was associated with distinct haze layers at altitudes of only a few kilometers. These layers had all the properties of the previously reported Arctic haze and appeared to be the same phenomenon.

In the spring of 1975, Dr. Glenn E. Shaw of the University of Alaska and Dr. Kenneth A. Rahn of the University of Rhode Island discussed this phenomenon in some detail and concluded that a combination of radiation and chemical measurements on the haze aerosol could prove to be a very powerful tool in investigating its origin and composition, with a particular eye toward whether it was anthropogenic or natural. Joint flights into the haze would be made, where its position would be delineated by radiation measurements and then sampled by a series of filters and analyzed for various elements at the University of Rhode Island, using neutron activation as the principal analytical tool.

The current research contract, entitled "Arctic Haze: Natural or Pollution?" (ONR Contract No. N00014-76-C-0435), is the outgrowth of these plans. It was funded in February 1976 by the Office of Naval Research to the University of Rhode Island (Kenneth A. Rahn, Principal Investigator) and to the University of Alaska (Glenn E. Shaw, Principal Investigator) for a period of eight months. Its purpose was twofold: (1) to study some of the chemical, physical, and optical properties of Arctic haze over Alaska by performing an aircraft-based pilot study, using the resulting information to attempt to deduce its source or source

type, particularly whether it was natural or anthropogenic; and (2) to attempt to learn the seasonal frequency of haze events over Alaska by initiating a year-long study of the chemical composition of the ground-level aerosol there, and by comparing this information with the appropriate meteorological situation to gain some understanding of the source areas of the haze aerosol and of its transport mechanisms into the Alaskan Arctic Basin.

This project has proceeded as planned. A five-week aircraft sampling program was conducted over the North Slope of Alaska, using the Naval Arctic Research Laboratory (NARL) as base. This program included condensation nucleus counts, radiation measurements, and samples for chemical and physical analysis in the laboratory. It seems to have been highly successful and will be discussed in detail below. At the time of this writing, the equipment for the ground study is being assembled, and the study itself will begin during September 1976.

The following is a brief summary of the more important results of the study so far. They will be discussed in detail in Section IE.

(1) Layers of Arctic haze were definitely seen over Barrow in April and May 1976. Their clarity and intensity varied from day to day, but there was little doubt that the same phenomenon was being observed as had been reported earlier (Mitchell, 1956; Holmgren et al., 1974). The layers were seen at the same altitudes as before and had the same overall appearance as in previous years.

(2) A single, long-period haze event was observed over Barrow. During the month-long sampling period the concentrations of several

indicator elements in the haze aerosol (Al, Mn, etc.) increased smoothly by more than an order of magnitude, then dropped off suddenly at the end of the period. Rather than varying greatly from day to day, there was a cycle time of about three weeks for the haze event to run its course.

(3) The layers were equally detectable by condensation-nucleus counts (number of particles per cc of air) or by optical techniques (changes in solar intensity through the layer). There was a general correspondence between concentrations of individual elements in the haze layer and its intensity as measured by particle counts or turbidity, but at least in one instance this correlation failed completely.

(4) The haze bands were definitely found over the continent. This finding is something of a departure from the earlier information (Mitchell, 1956), which suggested that the bands were found only over the ice. On one occasion the haze bands were traced by aircraft all the way to the Brooks Range, and may well have extended from the other side, because at the time the winds aloft were southerly.

(5) The haze layers showed a general association with southerly winds aloft, especially for the periods just before the haze events. Haze layers also appeared to be associated with dry air masses, the lower boundary of which decreased in height with time during the period of the haze event.

(6) The composition of the haze layers was crustal (i.e. probably natural), rather than anthropogenic. This conclusion is based on V/Al and Mn/Al ratios as determined by neutron activation

analysis, and will be checked later by atomic absorption analysis for Pb in the same samples. The V/Al ratio is a very sensitive indicator of pollution contributions to the aerosol. Regions where fuel oil which is high in V is burned always show a V/Al ratio which is from 5 to 500 times the crustal value, whereas the natural aerosol appears to have V/Al ratios very close to the crustal value. The V/Al ratio of Arctic haze was right on the crustal value, which unambiguously eliminated both the northeastern United States and Europe, which have much higher V/Al ratios, as sources of the haze aerosol. Based on the very limited meteorological maps which we have been able to get so far, the air flow preceding the best haze period seemed to have come from the southwest aloft, i.e. the Asian mainland. We are therefore considering the Asian deserts as potential source areas.

(7) The concentration of the crustal aerosol in the haze layers is quite high for this region, roughly $4 \mu\text{g m}^{-3}$. By contrast, background levels over Alaska may be 25 times lower. Sahara dust plumes, monitored far from their source, on the other hand, have a concentration which is an order of magnitude higher.

B. Field sampling techniques

1. Aircraft sampling

One of the four Cessna 180's of NARL was dedicated to this work during April and early May 1976. Figure 1 shows an outside view of the sampling assembly. The right-hand door was removed and replaced by one owned by the University of Alaska, which was specially modified for this experiment, as shown in Figure 1. The window was removed and replaced by a two-part

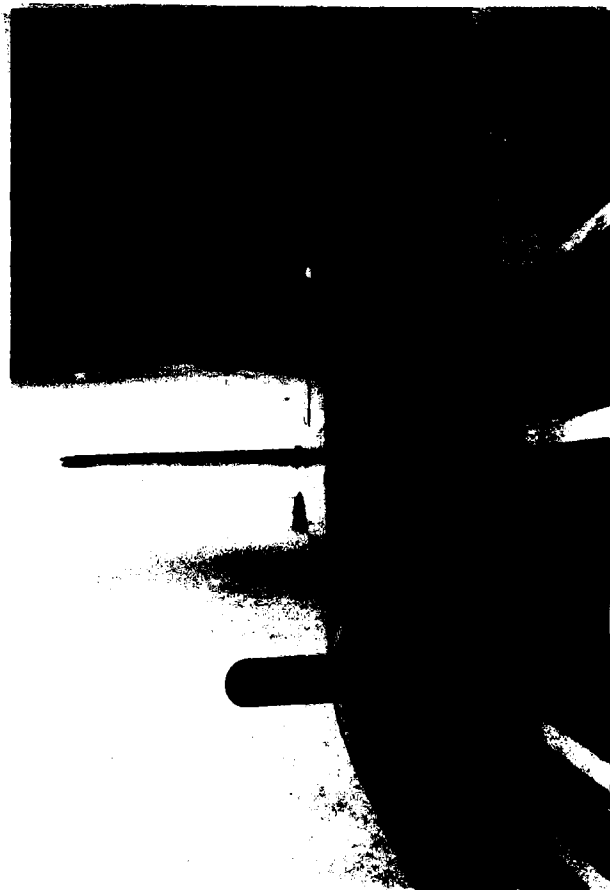


Figure 1. Exterior view of the sampling assembly.

assembly, the front half of which was a clear plastic portion of an old DC-3 window, and the rear half of which was an assembly of two PVC plates sandwiched over the window frames, which held the plastic window in place and provided exit ports for the three sampling probes. The uppermost and larger probe was for an acid-washed 11-cm diameter Whatman 41 cellulose high-volume filter; the lower, smaller probe led to 47-mm diameter Nuclepore and Millipore filters. The Whatman filter collected haze particles for chemical analysis, the Nuclepore filter collected particles for Scanning Electron Microscopy, and the Millipore filter collected particles for ice-nucleus counts. All filters were mounted inside the aircraft. Each probe was made isokinetic, so that the sampling process would not discriminate against any particular size of the haze particles. This was accomplished by adjusting the diameters of the intake orifices in the cone-shaped nozzles at the front of the probes. Sizes of the orifices depended on the linear velocity through the filters, which was different for all three filters. Holes of approximately the right diameters were drilled at the University of Rhode Island, where the apparatus was constructed, then were modified at NARL based on exact measurements of the performance of each system during a test flight there. The air velocity used to adjust the intake diameter was determined from a pitot tube inserted between the two lower air probes, as shown in Figure 1. The aircraft airspeed and altitude were adjusted to sampling conditions during these tests, so that air velocities into the probes came within 15% of the subsequent values during sampling flights.

Inside the aircraft (Figure 2) the filters were mounted in holders which could be quickly attached to or removed from the ends of the PVC probe tubes. Flexible tubing connected each filter holder to its pump. Manometers and flow meters monitored flow rates through the filters. An inverter and lead-acid batteries powered the Hurricane high-volume pump. The two smaller pumps for the Nuclepore and Millipore filters were powered directly from the aircraft's electrical and vacuum systems. Pump exhaust was fed out of the door; this also provided an extra vacuum which increased the flow rate through the Whatman filter, a very important consideration in aircraft sampling where sample volumes tend to be very small.

Contamination of the aircraft samples was considered to be a very serious potential problem, and strict measures were taken to avoid it. There were in general two possible sources of contamination: engine exhaust being entrained into the probe outside, and cabin air reaching the filters inside. To eliminate leakage from the engine to the outside, all cowlings and forward cabin joints were sealed with the blue tapes which can be seen in Figure 1. An independent test of nucleus counts at various distances along the strut confirmed that no engine exhaust was reaching the filters. Inside contamination was minimized by keeping the filters off the system and sealed until the altitude of the haze layer had been determined for that flight and sampling was ready to begin; they were then quickly opened and immediately attached to the probes. At the conclusion of sampling the process was reversed. Loading of Whatman and Nuclepore filters into and



Figure 2. Interior view of the sampling assembly.

out of their holders for sampling was always done on the ground in a laboratory. Because of the small volumes used for the Millipore filters, they had to be changed in flight.

There was no evidence of contamination in any of the samples. On the initial flights, before the haze layers intruded over Barrow, the measured elemental concentrations were extremely low - some of the lowest that have ever been measured in the Northern Hemisphere. We interpret this as confirmation of lack of contamination. There is still a more sensitive test for contamination by cabin air. A sample of cabin air showed it heavily loaded with Cu, probably from the high-volume pump. None of the filter samples showed measurable Cu - thus, there was no contamination from cabin air.

Condensation-nucleus counts, which were used to determine the height of the haze layer for each day's sampling, were taken by drawing air in through a small plastic tube which extended out through the window and terminated between the intake nozzles of the Nuclepore and Millipore filters. This final arrangement is not visible in Figure 1.

The above description applies only to the samples taken for analysis at the University of Rhode Island. The radiation measurements taken by the University of Alaska were considerably simpler and required only a hand-held sun photometer. This device was pointed directly at the sun's disk through a 2-inch hole cut into the clear plastic part of the window of the modified Cessna door. This hole is not shown in Figures 1 or 2. When the sun photometer was not in use the hole was taped over so that no cabin air could escape outside.

2. Ground-level sampling

The ground-level sampling phase of this contract will begin in September 1976. It is foreseen as follows: The station will consist of a specially-designed wooden shelter containing a standard 8 x 10-inch filter holder, a 47-mm filter holder, and two infrared heat lamps. The 8 x 10-inch filter holder will contain an acid-washed ultra-pure Whatman 41 cellulose filter through which large volumes of air will be drawn by a high-volume vacuum pump. The 47-mm filter holder will contain a glass-fiber filter through which lower air volumes will pass. The cellulose filter will be analyzed for 35-45 elements by neutron activation and atomic absorption analysis, possibly also for sulfate, nitrate, ammonium, and phosphate ions by colorimetric techniques. The large volumes of air sampled by these filters should allow very accurate analyses for large numbers of constituents of the aerosol. The glass-fiber filter will be weighed to determine total suspended particulate, a very simple quantity to measure but one which has curiously been absent from many remote-area experiments. Knowledge of the total concentration of aerosol will allow us to see what fraction of its mass we are accounting for with our various analyses, and in particular to check whether any major components are missing. The glass-fiber filter will also be analyzed for total carbon, either by one of us at U.R.I. or by Dr. Eva Hoffman of U.R.I.'s Graduate School of Oceanography. This should be a very important analysis because the sooty forms of carbon may be very important in determining the effects of the aerosol on the radiation balance of the Arctic. The combined information from the two filters should give us an excellent chemical characterization of the ground-level aerosol.

The addition of the glass-fiber filter to our ground-level sampling scheme is a modification to our original plan, which was simply to have the Whatman alone. We feel that the extra information gained in this way will be more than worth the slight extra effort involved.

The purpose of the heat lamps is to eliminate buildup of ice on the filter during sampling. This ice can seriously disturb the collection and analysis of the filters. Our idea is to shine the heat lamps continually on the filters during sampling, thus raising the surface temperatures enough to sublime any fine snow crystals which reach the filter and at the same time to lower the relative humidity enough that ice cannot form. Experiments in our laboratory at U.R.I. have shown that a single heat lamp can raise the temperature of a filter by 30-35°C, which should warm the filters enough to keep them clear of ice and snow but keep them cool enough to retain all volatile constituents of the aerosol, such as Hg, As, Se, etc., which are among the most interesting elements that can be studied in the haze layers. It must be stressed, however, that the heat lamp technique is new and has not yet been field-tested.

The two pumps will be housed in an insulated box to protect them from the weather and keep them warm. While the pumps are running they will probably give off enough heat to keep themselves adequately warm, but during the periods when the wind is out of the sampling sector they will be stopped and need some external source of heat. We will, therefore, place two heat lamps in the pump box, to operate only when the pumps are off. This should allow easy startup when the wind shifts into the clean sector.

Some sort of wind control over the sampling may be necessary to prevent local pollution aerosol from contaminating the samples. We will be using an electronic wind speed and directional control system developed at U.R.I. for this purpose. It uses an anemometer and wind vane to feed it electronic signals about wind speed and direction, respectively. The pumps will only run when the wind comes from a preset clean sector and when the wind velocity is above some preset minimum velocity. In this way we hope to keep the samples completely free of local influence, including that of our own pumps. Heat lamps will probably have to be used on the anemometer as well to keep it from freezing up in the winter.

Our original plan was to have the samples changed roughly weekly, depending on the local weather conditions and overall synoptic situation. Now that we think the haze bands are coming from Asia, we would like to install a facsimile machine at U.R.I. to keep constant track of the airflow over Alaska and the Pacific Ocean, so that changing of the filters can be controlled from U.R.I. (see Proposal Section). By starting a sample just when we think a haze layer should reach Alaska and stopping it just when we think the air should be clearing there, we should be able to maximize our chances of detecting this aerosol at ground level.

C. Analytical techniques

At the time of this writing, the only chemical analysis which we have been able to perform on the filter samples from the haze layers is neutron activation of short-lived elements. For this we have made a special modification of our previous schemes.

In the original proposal it was noted that (1) because of the expected small size of the aircraft filter samples neutron activation of short-lived elements would probably yield better data than that of longer-lived elements because of the more rapid decay of the short-lived elements; (2) fortunately, the two most interesting elements determined by neutron activation are just those with the shortest half lives, namely V (3.75 min) and Al (2.24 min); and (3) nevertheless, all elements are potentially interesting and no determinable element should be neglected. We have followed these precepts in developing an analytical scheme for the short-lived elements which (1) maximizes the accuracy of determination of V and Al by beginning the first count two minutes after irradiation instead of the more normal 3-6 minutes after irradiation, and (2) takes two counts after irradiation instead of the more normal one count, thereby better detecting those elements with somewhat longer half-lives. Our final scheme is shown in Figure 3; it has worked extremely well. Further details of the analysis will be supplied in the final report.

Because we found larger elemental concentrations in the haze layers than expected, we have decided to go ahead with the long irradiations of the samples and are anticipating good results.

We will take one-fourth of each filter for atomic absorption analysis of Pb and Cd, which we hope to complete by 30 September 1976.

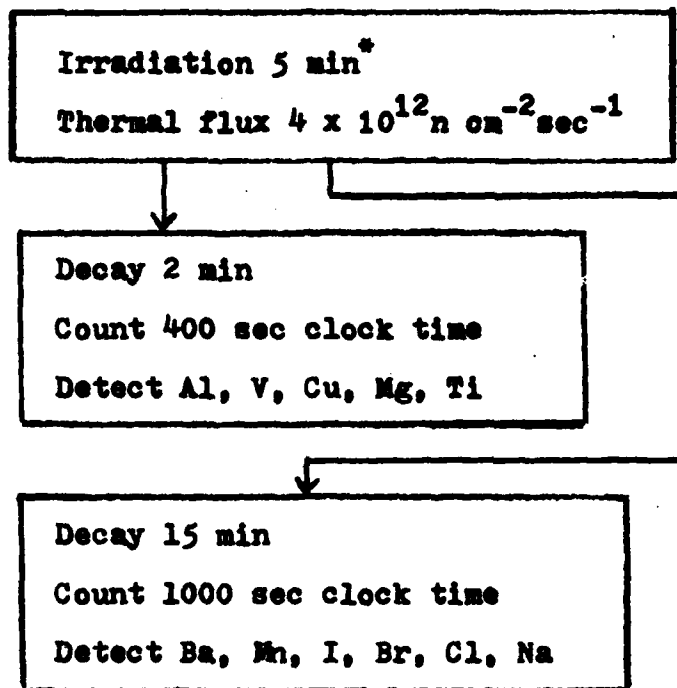


Figure 3. Irradiation and counting scheme for short-lived nuclides in haze layer samples.

*All irradiations and countings at the Rhode Island Nuclear Science Center, Narragansett, Rhode Island

D. Aircraft sampling program of April-May 1976

The aircraft-sampling phase of this project was successfully carried out in April and May of 1976 at NARL, Barrow, Alaska. This period of the year was chosen because it offers the highest probability of clear weather at Barrow; this was also the period when haze layers had been seen in 1972 and 1974. Mr. Randy Borys of U.R.I. had overall responsibility for this field program; he was joined during part of the time by Miss Sue Ann Boling and Dr. Glenn Shaw of the University of Alaska.

One of NARL's four Cessna 180's was dedicated to this project. During the period 12 April to 10 May 1976, fourteen sampling flights and one test flight were made, for a total of 65 hours in the air. Collection altitudes of the haze samples ranged from 4,000 to 11,000 feet, with an average altitude of 7,000 feet. There were nine high-volume cellulose samples collected, with volumes of 90 to 310 m³, nine SEM samples with volumes of 6 to 20 m³, and 55 ice-nucleus samples with volumes of 1 m³. The individual flights and some comments about each are listed in Table 1. On four of these flights optical measurements were also made; these flights are indicated in Table 1. (Our initial concern of very low aerosol concentrations and relatively short sampling flights prompted us to sample two consecutive flights on a single W41 high-volume filter and a single Nuclepore filter. This was only done when meteorological conditions indicated that there was no great change in the air mass over Barrow. Therefore, some samples are labelled with two consecutive flight letters, e.g. Sample AB.)

TABLE 1
The Individual Flights

<u>Flight</u>	<u>Date</u>	<u>Local Time</u>	<u>Sample Altitude (ft.)</u>	<u>Photometer</u>	<u>Remarks</u>
A	4/12/76	1317-1744	11,000	No	Low clouds, fog, light snow at surface. No visible haze. Clear conditions.
B	4/13/76	1005-1435	11,000	No	Fog at surface, 4000' overcast, 18,000' thin cirrus overcast. Good visibility at sample altitude. No visible haze.
C	4/14/76	0930-1425	6,500	No	Atmosphere appeared layered, however, good visibility with scattered clouds at 3000'.
D	4/15/76	0945-1430	4,000	No	CN counter failed. Used visual observations to choose altitude. Definite banding seen in atmosphere, chose most defined layer for sampling.
E	4/17/76	1058-1510	7,000	Yes	First flight with photometer measurements. Correlation between photometer and CN measurements appears good. A dark band was visible at sample altitude.
F	4/19/76	1035-1500	7,000	Yes	No distinct visible banding. CN and photometer gave no indication of significant changes in aerosol concentration with height.

TABLE 1 (Continued)

<u>Flight</u>	<u>Date</u>	<u>Local Time</u>	<u>Sample Altitude (ft.)</u>	<u>Photometer</u>	<u>Remarks</u>
G	4/21/76	0955-1335	9,700	No	Atmosphere warming aloft. Generally southerly flow. Banding visible.
H	4/22/76	1330-1430	-	No	Flight was terminated due to deteriorating weather one hour after take-off.
I	4/28/76	1415-1820	6,000	No	High CN concentrations and deep layer of elevated CN concentration. First time a color has appeared in haze band (light yellow).
J	4/29/76	1050-1450	7,700	No	High CN concentrations and overall hazy conditions. No definite dark banding. Some layering apparent.
K	4/30/76	1105-1600	6,800	No	A band was visible but not as distinct as J flight. CN concentrations showed a distinct layer.
L	5/1/76	1030-1300	6,600	No	Very definite visible haze layer, reddish in color, generally seen from Brooks Range to Barrow. Most distinct banding seen.
M	5/3/76	1110-1430 1520-1605	8,300- 9,300	Yes	A well-mixed atmosphere. No distinct banding. Photometer showed no measurable layering. CN concentrations indicated slight increase at 9000'.

TABLE 1 (Continued)

<u>Flight</u>	<u>Date</u>	<u>Local Time</u>	<u>Sample Altitude (ft.)</u>	<u>Photometer</u>	<u>Remarks</u>
N	5/5/76	1155-1530	6,000	Yes	Sample represents a deep layer 6000' thick. Most sampling representative of 6000'. Multi-wave-length photometer data was collected. No visible haze, very clear conditions, low CN concentrations.

During a typical flight a particle count was made every 30 seconds or so as the aircraft climbed from the ground to about 10,000 feet, its nominal ceiling. From this record it was deduced whether there was a haze layer that day and what its altitude was. If there was a layer and the particle counts agreed with visual observations as to its height, the sample was taken at this altitude for as long as the aircraft could remain aloft, usually about $3\frac{1}{2}$ to 4 hours more. If the flight had radiation measurements too, these were compared with the particle counts before the collection altitude was chosen. In general, the agreement between the two types of data was very good. When there was no detectable haze layer, the sample was taken at the altitude of greatest particle concentration.

E. Results and conclusions

Distinct Arctic haze layers were observed during April and May, with characteristics identical to those reported by previous observers. These layers could be easily seen and photographed, as documented by Figure 4, which shows solar horizons during typical non-haze and haze conditions. In the lower photo of this figure, the haze band is clearly visible, with its brownish color and diffuse outlines.

Because this report had to be prepared so soon after the fact, it was not possible to include all the data generated to date. Rather, we have chosen to present only a selection of the results, which should be sufficient to illustrate the type of data obtained and support the conclusions drawn so far. For example, consider Figure 5, which shows profiles of particle count, temperature, dew-point, and wind velocity for four consecutive flights. Temperature, dewpoint and wind velocity were obtained from soundings taken at the

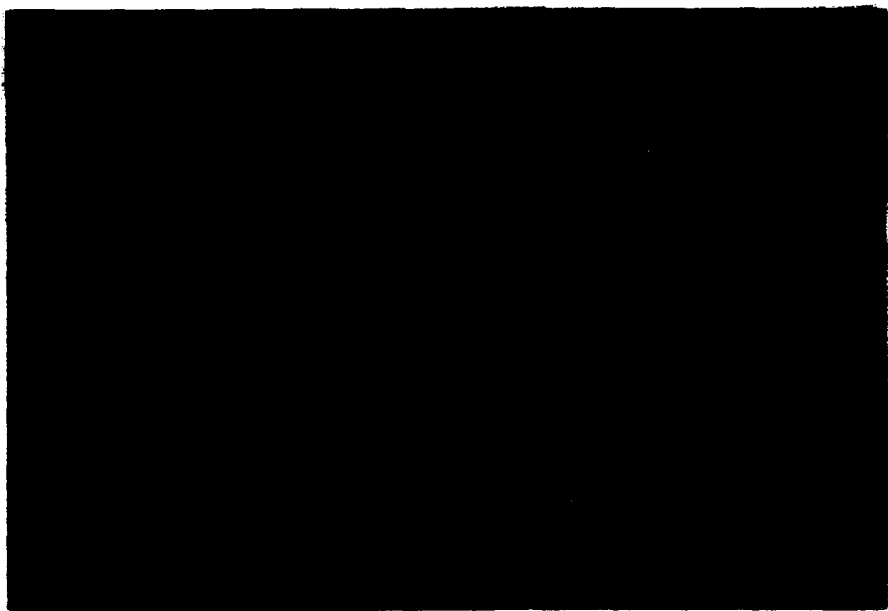


Figure 4. Solar horizons during non-haze (upper) and haze (lower) conditions.

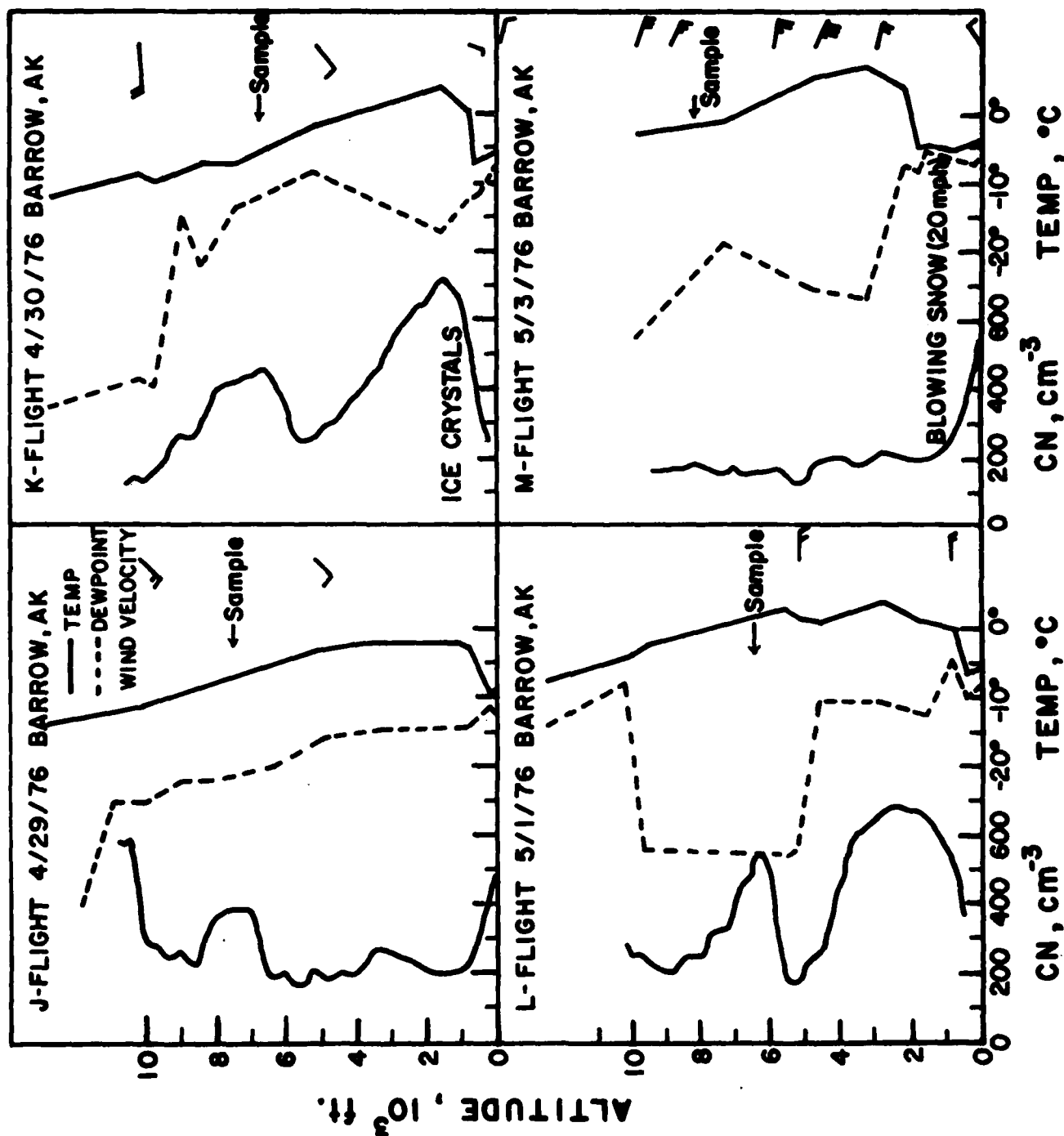


Figure 5. Vertical profiles of particle count, temperature, dewpoint, and wind velocity for selected flights.

U. S. Weather Service Office in Barrow at 1400 local time. These observations always fell within the period of each sample flight. This particular series was chosen because it illustrates the association of the haze layer with a particular type of air mass, the development of the layer with time, and ultimately its disappearance.

In flight J, 29 April 1976, a well-defined haze layer was seen between 6500 and 8500 ft elevation. There was also some evidence of another, possibly stronger layer above 10,000 feet, where the highest particle counts were observed. Unfortunately, it was not possible to follow this layer any higher because of the ceiling of the aircraft. Winds aloft were southwesterly. The following day, flight K revealed that the haze layer was somewhat lower and broader, but with approximately the same nucleus count of nearly 400 particles per cc. Note that the lower boundary of a layer of dry air aloft, which could be seen above 10,000 feet in flight J, was also descending. Winds aloft were westerly to southwesterly. By flight L the next day, both the entire dry layer and the haze layer had descended still further and intensified. The haze layer had a much sharper peak than before, between 500 and 600 particles per cc. Winds aloft were then easterly. By flight M two days later, the haze layer had completely disappeared, and the dry air mass was still lower. Winds aloft were easterly to southeasterly. Flight M was the only one of this series that was accompanied by radiation measurements, and these confirmed the absence of a haze layer.

From this series we may note that the haze layers apparently do not come and go on a day-to-day basis; rather, once they have

penetrated the Alaskan Arctic Basin they seem to be quite stable, even under shifts of wind direction. Perhaps this follows from their large horizontal dimension, commonly reported at hundreds to thousands of miles. A cloud of such dimensions can blow one way and then the next for some time and still remain overhead. After some days though, a changed circulation can remove the haze from the area and clean conditions are once again attained.

We may also note that the haze seems to be associated with winds from a broad southerly sector. Temporary easterly or westerly winds seem not to affect the haze bands greatly. Northerly winds, however, rarely or never bring haze. Light winds seem to favor the maintenance of the layer's integrity and high winds seem to break it up, as for example on flight M.

Selected elemental concentrations and aerosol-crust enrichment factors are shown in Table 2 for the nine high-volume filter samples. Several observations can be made from this table. First, note the extreme variation in Al concentrations, from a low of 10 ng m^{-3} in flight AB, one of the lowest concentrations ever measured in the Northern Hemisphere, to a high of 240 ng m^{-3} in flights IJ and M, a value which we consider to be unusually high for this region, especially aloft. All concentrations of this table are expressed for volumes of air as measured aloft; for correction to ground-level, one must divide volumes by 1.30 (for average altitude of collection of 7000 ft.) or multiply concentrations by 1.30. This makes the maximum Al concentration 310 ng m^{-3} , a typical value for ground aerosols of mid-latitude rural areas. It is definitely above the summer Al concentration of 66 ng m^{-3} measured in the remote Northwest Territories of Canada (Rahn, 1971).

TABLE 2

Elemental Concentrations and Enrichment Factors
for Aircraft Filter Samples

	Sample AB	Sample CD	Sample E	Sample F	Sample G
	Concentration, ng m ⁻³ (ambient)				
Al	10.0±0.9	17.0±1.0	35±2	34±2	91±5
V	0.035±0.006	0.148±0.010	0.126±0.012	0.094±0.010	0.22±0.02
Mn	0.146±0.012	0.36±0.02	0.59±0.04	0.58±0.03	1.55±0.08
Na	12±10	32±11	< 30	21±16	47±27
Ba	0.8±0.3	0.8±0.4	< 1.5	< 1	3.3±1.2

	Sample IJ	Sample KL	Sample M	Sample N
	Concentration, ng m ⁻³ (ambient)			
Al	240±10	203±10	240±10	14.7±1.7
V	0.40±0.03	0.37±0.02	0.40±0.04	0.0192±0.0100
Mn	3.0±0.2	3.1±0.2	3.4±0.2	0.21±0.02
Na	58±15	37±11	37±30	< 20
Ba	4.1±0.4	3.9±0.4	3.8±1.0	< 1

TABLE 2 (Continued)

	Sample AB	Sample CD	Sample E	Sample F	Sample G
Enrichment factor (Al, rock)					
Al	1.0	1.0	1.0	1.0	1.0
V	2.1	5.2	2.2	1.66	1.46
Mn	1.25	1.81	1.44	1.46	1.46
Na	3.4	5.4	< 2.5	1.77	1.48
Ba	16	9	< 8	< 6	6.9
Volume, m ³	249	341	149	176	110
Altitude (ft.)	11,000	6,500 4,000	7,000	7,000	9,700

	Sample IJ	Sample KL	Sample M	Sample N
Enrichment factor (Al, rock)				
Al	1.0	1.0	1.0	1.0
V	1.00	1.10	1.00	0.79
Mn	1.07	1.31	1.21	1.22
Na	0.69	0.52	0.44	< 4
Ba	3.3	3.7	3.0	< 13
Volume, m ³	309	365	88.7	108
Altitude (ft.)	6,000 7,700	6,800 6,600	8,300- 9,300	6,000

One may also note that the Al concentrations (and those of the other elements as well) do not vary randomly from day to day; rather, the changes are quite regular, gradual, and seem to pass through a well-defined cycle of roughly 3-4 weeks in length. In the samples reported here, which only represent one cycle and so cannot a priori be considered typical until more evidence is in, the lowest Al concentrations of 10 ng m^{-3} are found in sample AB. They then increase nearly monotonically to 17 in CD, 35 in E and F, 91 in G, and finally reaching a high of 200-240 in IJ, KL, and M. Then follows a sudden drop back down to 15 ng m^{-3} in N, which is near the values for AB. The cycle is then presumably ready to start again. From AB to N is a period of 23 days.

This relatively long period was a bit surprising to us, but is not in contradiction with previous data. Holmgren et al. (1974) and Shaw (1975) mention periods of peak turbidity of a few days in length followed by longer, less turbid periods. Rahn (1976) has measured periods of unusually high aerosol concentrations in northern Norway (latitude 70°N , about the same as Barrow) which lasted from less than one week to nearly one month. The highest Al concentrations over Barrow lasted six days.

This relatively long-lasting maximum of constant composition will allow us in the future to take fewer but larger samples of the haze layers, which will be most helpful for our particle-size sampling with a cascade impactor.

The other four elements of Table 2 varied in approximately the same fashion as did Al. In other words, the composition of the aerosol over the flights had a certain tendency toward constancy.

This can be best seen from the lower part of Table 2, where the aerosol-crust enrichment factors for the elements are listed. The aerosol-crust enrichment factor is defined by

$$EF(Al, rock) = (X/Al)_{aerosol} / (X/Al)_{rock}$$

where X/Al refers to the ratio of concentrations of element X and Al in the crust (here taken as average crustal rock) and in aerosol. The other elements had enrichment factors which were not too far from unity during these samples, but which did show some interesting and significant trends over the concentration cycle.

For example, consider V , our best indicator of pollution. In the first few, low-concentration samples, its enrichment factor is definitely above unity, reaching a maximum of 5.2 in sample CD. This means that the background aerosol over Barrow has a non-crustal, possibly pollution, source for V , at least during this season. But note how the V enrichment factor smoothly decreases to unity as the concentration of Al increases. By sample F , when Al has only increased to 34 ng m^{-3} , the V enrichment factor has started downward to 1.66 versus about 2-5 of samples $A-E$. At samples IJ it reaches 1.0 and stays there for the duration of the sampling. The other elements show similar but less pronounced trends. The enrichment factor of Mn , for example, has its high value also in CD (1.81), then decreases to about 1.2 in the high Al samples $I-M$. Na has initial enrichment factors of 3-5, then decreases to 0.4 to 0.7. Finally, Ba has enrichment factors of 9 and 16 in the first two samples which decrease to 3.0 to 3.7 in the high Al samples.

Taken together, the trends of these enrichment factors clearly indicate that the Alaskan haze aerosol is crustal in composi-

tion, not pollution. The gamma-ray spectra from the short irradiations of the best haze samples looked identical to those of the Sahara aerosol with which one of us (K. Rahn) just finished working with for eight months in Mainz, West Germany. This is a very important result, which we will try to confirm by analyzing for Pb in these samples by atomic absorption. To be sure, this conclusion is not ironclad, for there are indeed areas, such as Los Angeles, where the V enrichment factor is unity because only small amounts of fuel oil (which is also low in vanadium) are burned, but what is certain from these results is that neither the northeastern United States nor Europe, areas of high atmospheric V (from combustion of V-rich fuel oil) could have been the source of this haze aerosol. They might have been the source of the background aerosol observed in the first samples, but they could not have been the source of the haze aerosol. The northeastern United States and Europe have year-round V enrichment factors between 5 and 500, not the values of unity observed here.

What about the Los Angeles area with its lower enrichment factors for V? Could this have been the source of the haze aerosol? The Pb analyses will settle this question, but we doubt that the haze aerosol could have come from this area. Meteorological maps for the end of April, the period immediately preceding the haze episode at Barrow, show the Los Angeles aerosol passing to the west over the continental U. S. In order to reach Barrow, Los Angeles aerosol would have to be carried by the Northeast Tradewind system out into the middle of the Pacific Ocean, then curve to the north to make the long trajectory to northern Alaska, which we consider to be unlikely.

What seems much more logical, however, is that the Asian deserts may be the source of this crustal aerosol. There are many factors which lend credence to this idea. First, springtime (when these haze layers were observed) is just the period most favored for large-scale dust storms in deserts, because of the ideal combination of deep convection caused by intense solar heating at the surface and strong winds both at the surface and aloft caused by intense latitudinal temperature gradients. In the summer the surface heating is stronger, but the latitudinal temperature gradients are weaker, so that dust storms are less frequent and their dust clouds do not travel as far as in the spring. Second, the composition of this aerosol is virtually identical to the Sahara aerosol (Rahn et al., 1976). Third, the haze aerosol seems to be associated with very dry layers aloft, which at least during this episode gradually descended. A dry air mass like this is compatible with a desert source. Jackson et al. (1973) discuss possible long-range transport of air masses from Japan to Europe. They cite the case of a storm developing off the coast of Japan, which creates a strong jet stream oriented toward the Gulf of Alaska. Air entering this circulation ascends and flows northward to Alaska, where it is deflected southward and begins to descend. This then would be the perfect mechanism for transporting Asian desert dust to Alaska; the high-level momentum is present because of the spring season and the storm, the direction of transport and altitude is right, and the descending pattern over Alaska is right. Indeed, just before the dust haze layers reached Barrow, the flow aloft was strongly southerly-southwesterly. The fourth factor in favor of an Asian origin of the haze is distance.

The Asian deserts (Takla Makan and Gobi) are quite far north, lying mostly between 40° and 50° north latitude. The great-circle distance from the midpoint of these deserts to Barrow (6000 km) is actually shorter than from southern Algeria (the source of most major Sahara dust storms) to Barbados (7200 km), a well-documented transport path for desert dust.

In summary, then, the time of year, composition, altitude, air flow, and distance are right for the Alaskan haze aerosol to have had an Asian desert source. This is thus our working hypothesis. Unfortunately, little information is immediately available about the intensity or frequency of dust storms in these deserts; we are actively seeking such information. (see inserted pages 31a, b)

The following is a description of typical information obtained from the radiation measurements conducted by the University of Alaska on these flights. The data in this case is for flight M, May 3, 1976, from 11:15 ADT to 16:22 ADT. In the vicinity of Barrow skies were clear, winds easterly at 20 knots or so with gusts. No cirrus were seen, but there was a thin, whitish haze, possibly a thin haze layer at about 8,300 feet.

The aerosol optical depth was determined at ground level with a Mark III sun photometer and in the aircraft with the specially designed airborne sun photometer. The optical depth is expressed as

$$\tau_A = \beta \lambda^{-\alpha}$$

where λ is in μm , and α and β are the Angstrom turbidity and turbidity wavelength coefficients, respectively, with values of $\beta = 0.102 \pm 0.005$ and $\alpha = 0.21 \pm 0.15$ at the 90% confidence level. Note that τ is to the base e, i.e. $\tau(\text{slant aerosol}) = \exp(-m \tau_A)$, where $m \approx \sec Z$,

Trajectory Analysis
(Note added in proof)

In the hope of being able to include some form of trajectory analysis in the Progress Report-Renewal Proposal, a request was made to the National Climatic Center to rush us the pertinent upper air charts for the month of April 1976. We were very fortunate to receive the charts in time to include here a rough preliminary analysis of the air mass history for the single most interesting period of the aircraft sampling work, flights K and L.

The following assumptions were made for the analysis:

(1) The 700-mb level was chosen for this initial look at the air mass history since it is found at about the 3 km, or 10,000 ft. level. This is about the level at which the sample was collected and should be representative of a rather deep layer centered at 700 mb. (2) Since wind speeds were not reported at the 700 mb level, a mean wind speed of 30 knots was assumed. This is reasonable because typical contour spacing required for this wind speed at 700 mb and at latitudes around 40°N were encountered during most of the trajectory. (3) A 12-hr. time step was used during the construction of the trajectory because charts were available for 0Z and 12Z only. Given this time interval and the assumed wind speed, a linear step of 6° latitude was used between each point plotted. This distance was taken directly from the chart because the length of one degree of latitude varies with latitude on a polar stereographic projection. (4) Wind direction was assumed to parallel the contour lines.

The results of this preliminary trajectory were quite interesting and supportive of our initial belief of an Asian origin for the air mass. The trajectory starting 9 days prior to its passing over Barrow is essentially as follows: At day -9 (nine days before reaching Barrow) the position was 41°N 86°E , or located within the arid regions around the Takla Makan Desert. At this time it was associated with a high pressure center and under the influence of flow from the north. The surface chart for this period shows two surface stations approximately 2000 km upwind of the trajectory location reporting blowing sand and/or dust. The airmass moved south and then east until by day -5 it was located at 32°N 140°E , or approximately 350 km south of Tokyo, Japan. From there it proceeded in a NE direction to Barrow by April 30.

All of the upper level charts support this trajectory, including the 300 mb level. Just prior to the haze event of flights K and L, there was meridional transport from approximately 50°N to Barrow at all levels. It should be emphasized that this is a very simple first look at transport to the Arctic. We plan to look at the history of each sample collected at various levels to determine how varied the source regions were during our sampling in April and May.

and z = solar zenith angle. Figure 6 is a plot of $\ln \tau_\lambda$ versus $\ln \lambda$, and shows individual measurements and their error bars.

The total precipitable water in a vertical column has been derived from optical transmission measurements in the $\rho\tau$ band at $\lambda = 0.95 \mu\text{m}$. The value for flight M was $9.3 \pm 0.4 \text{ mm}$.

The total vertical optical depth above height h has been derived from the airborne sun photometer for three different elevations, according to the formula

$$\tau_A(\lambda, h) = \int_h^\infty \beta_A(\lambda, h) dh$$

where $\beta(\lambda, h)$ is the aerosol volume extinction (absorption plus scattering) coefficient. The results are shown in Table 3. From the plot of this data (Figure 7), an average tropospheric scale height of 10.1 km may be derived (i.e. $\beta = \beta_0 e^{-h(\text{km})/10.1}$).

This value is large; surface-generated aerosol usually falls off with a scale height of about 1.5 km.

By taking a tropopause height of 11.0 km and extrapolating through the troposphere, we deduce that 66% of the aerosol mass is in the troposphere, leaving about 34% which must be stratospheric aerosol, i.e. $0.34 \tau_0 = 0.34 \times 0.103 = 0.035 = \tau_{\text{strat}}$ at $\lambda = 677 \text{ nm}$.

All these values found are high - these numbers could be easily obtained at a moderately polluted low latitude location. Remember that the vertical profile of turbidity has been smoothed - it does not show the low haze layer of thickness about 500 ft., nor does it show the elevated layer at 8,300 ft. which was barely detectable by both the sun photometer and the nucleus counter.

It is possible to derive some physical characteristics for the Barrow aerosol of 3 May 1976 based on the measurements on that

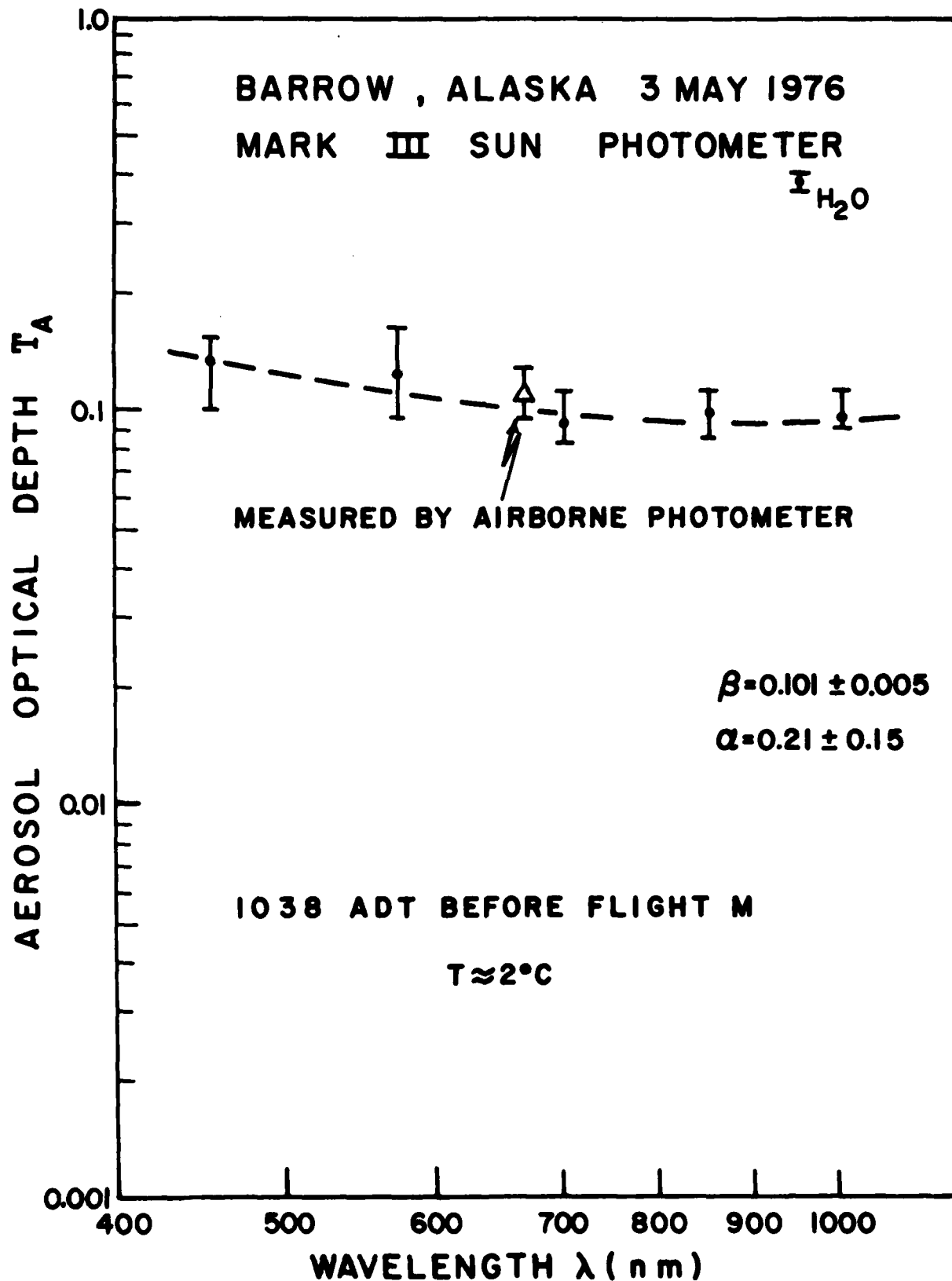


Figure 6. Atmospheric turbidity versus wavelength.

TABLE 3
Aerosol Optical Depth (τ_A) as a Function of Elevation
Barrow, 3 May 1976

<u>Elevation, km</u>	<u>τ_A (677 nm)</u>	
0.15	0.104	11.16 to 11.50 ADT $Z_0 \approx 90^\circ - 32^\circ = 58^\circ$
0.30	0.090	
2.88	0.075	
0.15	0.103	15.25 to 15.40 ADT $Z_0 \approx 90^\circ - 31^\circ = 59^\circ$
0.45	0.097	
2.12	0.084	

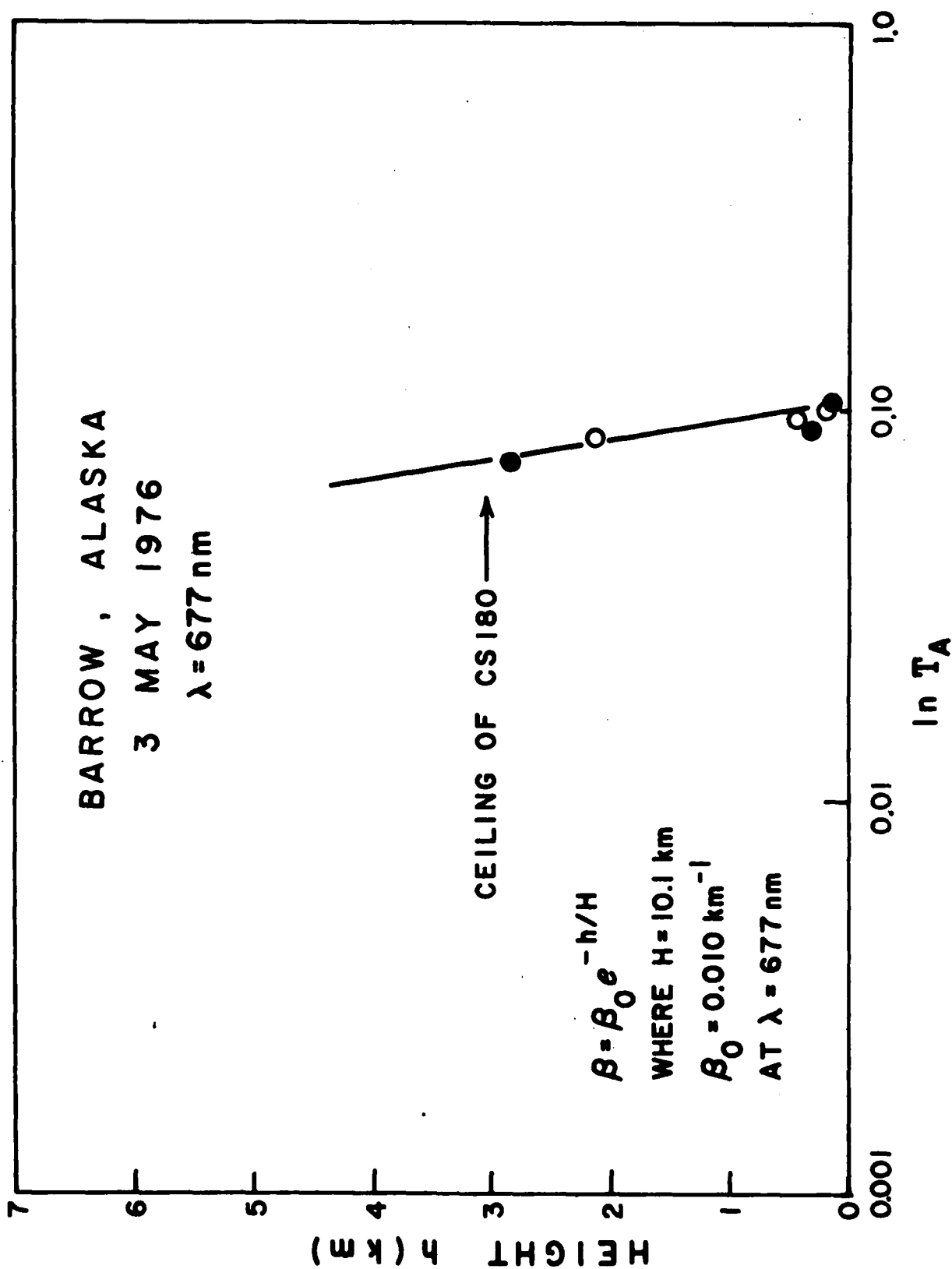


Figure 7. Vertical profile of atmospheric turbidity.

day. Assuming an index of refraction of $n = 1.54 + 10.00$ (representative of silicates and sulfates), and using

$$dN/dr = \text{Const. } r^2 e^{-kr}$$

as a size distribution function we may derive:

$$r_{\max} = 0.12 \pm 0.014 \mu\text{m}$$

$$\Gamma = \text{total columnar mass loading} = 17.4 \pm 2.0 \text{ mg m}^{-2} \\ (\text{for } \rho = 1 \text{ g cm}^{-3})$$

$$N_0 = \text{columnar number density} = 3.4 \pm 1.3 \times 10^7 \text{ particles cm}^{-2}$$

$$r(\Gamma/2) = 0.34 \mu\text{m} = \text{the radius above and below which half the total aerosol mass is found.}$$

For comparison, for the South Pole in December 1974

$$r_{\max} = 0.04 \pm 0.014 \mu\text{m}$$

$$\Gamma = 2.3 \pm 0.9 \text{ mg m}^{-2}$$

$$N_0 = 11.4 \pm 4.7 \times 10^7 \text{ particles cm}^{-2}$$

Notice that $\Gamma_{\text{Barrow}} / \Gamma_{\text{South Pole}} = 7.5$, i.e. the columnar aerosol loading at Barrow is about eight times larger than at the South Pole and that the particles are much larger at Barrow.

Finally, the aerosol mass concentration near the surface can be estimated by

$$\gamma = \frac{\Gamma}{H} = \frac{17.4 \text{ mg m}^{-2}}{10.1 \times 10^3 \text{ m}} = 1.7 \mu\text{g m}^{-3}$$

A very strange phenomenon may be noted from Figure 5 and Table 2. For flight M, after the haze layer had all but disappeared as measured by both the sun photometer and the condensation-nucleus counter, the elemental concentrations of Al, V, Mn, etc. remained very high, in fact, even increased over their values in flight KL. This was a great surprise to us, for up to that time we had automatically assumed that the elements were intimately coupled with the haze layers. But it is clearly not necessarily so, at least for the elements we measured here. What can the explanation be for this strange occurrence? First of all, it reminds us that we are really measuring three different size ranges of the aerosol in this experiment. The condensation-nucleus counter counts total number of particles, which are essentially all in the Aitken particle range (radius $< 0.1 \mu\text{m}$). The sun photometer measures the aerosols which interact with visible light, which are found in the large particle range (radius 0.1 to $1 \mu\text{m}$). Finally, the crustal particles which apparently make up the bulk of the mass in the haze layer should be found in the giant particle range (radius $> 1 \mu\text{m}$). These giant particles have significantly greater fall speeds than do the large or Aitken particles, and so have the possibility of being more evenly distributed through the troposphere than the smaller particles, which tend much more to remain with their original layer. And this is apparently just what happens here - the large and Aitken particles follow each other approximately in their vertical profiles, as evidenced by the similarity of the optical and CNC profiles, but at least on some occasions the giant particles are quite differently distributed. Therefore, the implicit assumption

which we held that our filter measurements are representative only of the haze layers is not so. We do not know (1) anything about the vertical distribution of the crustal component of the Barrow atmosphere, or (2) whether the large particle component of the crustal particles is really the haze-producing agent. The way is left open for some entirely different source to be creating the large particles which are for some reason found together with the giant crustal particles and produce the haze. We do not consider this very probable, but it is possible. For all we know, the concentration of the crustal particles outside the haze layers is every bit as large as it is inside them - their numbers are so small that they are completely masked by the Aitken counts. Furthermore, we now see that our filter measurements to date may have told us very little about the actual haze-producing agent, and that future measurements must segregate out this large-particle component which actually produces the haze and carefully determine whether it has the same source as the rest of the haze mass.

It is now very clear that (a) the Alaskan aerosol is very complicated, and (b) that two types of new measurements are necessary in the second stage of our airborne measurements: (1) vertical profiles of the crustal elements, and (2) particle-size information from within and possibly also from outside the haze layers. In short, the crustal aerosol may be the dominant one by mass in the haze layers, but it may not cause the associated optical effects.

We close this section with a word about volcanoes as a possible source for the haze aerosol. This was considered in the

original proposal and has assumed new relevance here with the eruption of Mt. Augustine in southern Alaska in January 1976. Fortunately, one of us (R. Borys) was on the NCAR Electra as it sampled this plume about a week after the eruption. Elemental concentrations and enrichment factors determined from a single filter sample in the middle of the plume are listed in Table 4, where it can be seen that five out of the six elements listed (except Cu) were present in nearly crustal proportions. Vanadium seems a bit enriched, but this may not be significant, and surely could not be used to claim that the Arctic haze could not be volcanic. The important feature of this table is the relatively low concentration of Al compared to Arctic haze, the volcano-plume concentrations being only about four times higher than the haze concentrations. We feel quite strongly that if the volcano plume were advected to Barrow, it would be diluted by much more than a factor of 4, probably more like a factor of 100-1000 or more. Furthermore, the haze episode at Barrow came two months after this volcano sample was taken, and no major eruptions occurred during our period of sampling in Barrow. Also, it is very hard to imagine a single point-source volcano producing the broad haze bands as seen over Alaska, which may extend horizontally over 1000 miles or more. And lastly, the volcano source height was about 3,900 feet, much lower than the 10,000 feet or more often observed for the Alaskan haze layers. These arguments, put together, suggest to use that Mt. Augustine could not have been much of a contributor to the haze layers during April and May of 1976.

TABLE 4

Elemental Concentrations and Enrichment Factors
in the Mt. Augustine Plume
(R. Borys, 1976)

<u>Element</u>	<u>Concentration ng m⁻³</u>	<u>Enrichment Factor (Al, rock)</u>
Al	925 ± 50	1.00
V	2.5 ± 0.3	1.63
Na	360 ± 30	1.13
Mn	11.6 ± 0.4	1.08
Ti	38 ± 8	0.75
Cu	19 ± 8	30

F. Work plan through September 1976

1. Analysis of samples

Between now and 30 September 1976 we will analyze the haze samples by neutron activation for the long-lived elements and by atomic absorption for Pb and probably also Cd. The samples will also be examined under the Scanning Electron Microscope for morphological characteristics, which should help to decide whether Asian deserts were the actual source. The ice-nucleus samples taken on Millipore filters will also be analyzed. The finding that the greatest mass in the haze layers was crustal makes these analyses especially important because crustal fragments are particularly good ice nuclei.

2. Trajectory analysis

Accurate trajectory analysis of the haze-laden air masses should be most helpful in revealing the source of the haze aerosol. We have unfortunately had some difficulty obtaining the maps for April and May of 1976 because there is normally a six-month delay before the maps are available on microfilm. The National Climatic Records Center in Asheville, North Carolina, is expediting our request to the maximum degree and has just delivered the maps for April. We hope to get the maps for May sometime during August or September. Dr. Paul Twitchell of ONR Boston, a meteorologist with much experience in making Arctic trajectories and who has a special interest in this project, has offered to come to U.R.I. and work with us on the trajectories. We anticipate positive results.

3. Setup of ground stations in Alaska

The second part of the original proposal was to perform a one-year ground-level study of the aerosol at some location in Alaska, probably either Barrow or in the interior, in an effort to get some idea about the seasonal frequency of the occurrence of the haze layers there, if indeed the haze layers could be detected at ground level. As one surprising result after another has been produced in the past weeks from this study, leading to the major hypothesis of substantial flows of Asian desert dust into the Arctic Basin, we have been forced to rethink our whole approach to the next year's work. If the Asian deserts do routinely contribute major amounts of dust to the Arctic aerosol, this phenomenon should be studied in much greater detail, both in the Arctic and nearer to the Asian source. Clearly the way to do this best would be further aircraft measurements, now that we have demonstrated that it can be quite satisfactorily done. But we are only a small project and dare not expand too far too fast. We literally have neither the manpower nor the general capacity to make a long series of flights during the next contract year. Recognizing the great value of more and better aircraft measurements though, we have worked out a compromise scheme which we feel is a realistic next step. This scheme involves proceeding as planned for a ground sampling program for next year, for the following reasons:

- (1) The machinery is already in motion - pumps are ordered, shelters designed and built, arrangements made, etc. etc.
- (2) Such a ground study involves negligible cost and manpower for sampling and only moderate manpower for analysis.

(3) A similar study performed some years ago by one of us (K. Rahn) in northern Norway was highly successful. Pollution aerosol carried northward from Europe in the airflow aloft was quite strongly detected at ground level and led to rather positive identification of the source and transport mechanism. During periods of high pollution, the background aerosol for that region was completely masked by the pollution component.

(4) The Sahara plume, which travels across the Atlantic Ocean from West Africa to Barbados at altitudes of 2-6 km, is easily detected at sea level at all points along the trajectory. In fact, the whole phenomenon was discovered by a sea-level site in Barbados.

(5) A ground-level study in Alaska should yield much valuable general information about the nature and sources of the Alaska aerosol, over and above what it shows about the haze component. One never knows what may emerge from such information - the Alaska aerosol is very understudied up to now.

(6) The anomalous behavior of sample M, where a high crustal concentration was found with no evidence of a concurrent haze layer, has cast doubt on our original assumption that all the elements of the aerosol would have their maximum concentrations in the haze layer. It has also provided indirect evidence that the large mass of the haze layer is indeed associated with giant aerosol particles, as it should be. These particles are very subject to fallout, and thus would tend to be detected more at ground level than would the smaller particles of the haze layers.

(7) Finally, the alternative to a continuous ground-level study, a continuous aircraft study, is simply unreasonable at this

point, both in terms of finances and manpower. Furthermore, such a study would probably have a large percentage of inactive time because of poor flying conditions at Barrow during much of the year.

During his trip to Alaska in April-May 1976 for the major purpose of aircraft sampling of the haze layers at Barrow, Mr. Randy Borys of U.R.I. inspected a number of possible ground-level sampling sites in and around both Barrow and Fairbanks. The best of these was NOAA's Global Monitoring for Climatic Change (GMCC) site just outside of Barrow, where extensive air samples are taken and radiation measurements are made throughout the year. Conversations with NOAA personnel at the site and subsequent exchanges of letters with Dr. Kirby Hanson of NOAA in Boulder, Colorado have established NOAA's generous offer to aid us by having their personnel at Barrow change filters routinely over the year and mail them back to U.R.I. for analysis. This cooperation, which is free of charge to this project and which is not necessarily afforded by NOAA to all experimenters (because of NOAA's full program for its own personnel at the Barrow site), will allow us to obtain a valuable suite of filter samples, with a minimal expense and effort, and at the same time have access to a great deal of supporting atmospheric measurements made by NOAA on other atmospheric parameters during these same periods. This year in particular will be a very good one for cooperation with NOAA at the Barrow site because Mr. Emerson Wood of NOAA, the person most likely to change our samples, will be making a special series of measurements on aerosols (with a 4-wavelength nephelometer, a Pollack counter, and a sun photometer) during the winter to collect data for a Master's thesis

under the direction of Dr. Shaw. We will therefore set up our Barrow ground-level station at NOAA's GMCC site during the week of 13 September 1976.

We have decided also to make a change from our original proposal and run a two-point ground-sampling program in Alaska, with the second site just outside Fairbanks. The impetus for this addition came from Dr. Glenn Shaw of the University of Alaska and his boundless enthusiasm for studying the background aerosol of interior Alaska. A Fairbanks site would be very useful to us for the following reasons:

(1) There is mounting evidence that Arctic haze aerosol may indeed pass over Fairbanks on its way from the south to Barrow and northern Alaska. First is the general association we have seen between the haze periods at Barrow and southerly winds. On one occasion the haze layers were tracked from Barrow to the Brooks Range, and since the air flow at the time was northward over the Brooks Range, the haze must have come from the Alaskan interior. A second piece of evidence comes from observations by Dr. Glenn Shaw of very high turbidities over Fairbanks in late February and early March 1976. These turbidities were associated with southwesterly winds, and the trajectories for these periods showed that the air masses involved could not have recently passed over polluted Europe or the northeastern United States. These turbidities and air flows are not incompatible, however, with a source for the aerosol in the Asian deserts according to the picture which we are independently developing from data of northern Alaska. The discovery of a common cause for high turbidities over Barrow and Fairbanks would be

exciting indeed.

(2) University of Alaska personnel make as many radiation measurements as possible at Fairbanks during the year. Such turbidity measurements could be compared with aerosol trends from a Fairbanks station in exactly the same way as we have already done for the aircraft flights this spring at Barrow.

(3) The aerosol of interior Alaska may be quite different from that around Barrow. In fact, little or nothing is known about the composition or sources of this aerosol, and Dr. Shaw has been particularly eager to get whatever information he can about it, to help him interpret a series of turbidity measurements which he has been accumulating for the past several years and which may eventually turn out to have great relevance to our understanding of the aerosol of northern Alaska.

Because of Dr. Shaw's interest in a series of measurements from Fairbanks essentially identical to what we were independently planning for Barrow, we thought it would be most opportune to operate a completely parallel program at Fairbanks for this year. The station will be set up during the week of 6 September 1976 and will operate for about one year. Samples will be collected by Dr. Shaw or an assistant at very little cost to this project. Equipping the site will cost less than \$1,000, and for the time being we will use the spare pumps foreseen originally for Barrow, so that there would be virtually no initial cost. The setup will have no wind controls so that no anemometer or associated electronics will be needed. We have chosen the site of Ester Dome, approximately ten miles west of Fairbanks. This is a research site operated by the University of

Alaska, which has a number of buildings with electrical current which could be used for the pumps. Local contamination is very small, especially in the winter when Ester Dome is well above the mixed layer of Fairbanks (elevation of Fairbanks is 600 feet; that of Ester Dome 2,364 feet). There are only a few houses nearby, which appear to be heated with electric heat and so emit minimal pollution. We feel that even if local effects were to ruin half the samples taken here during a year, the other half will make the project worthwhile.

Our experience with field sampling has shown us that if two sets of samples are to be taken in regions where a certain effect is to be studied, such as the transport of aerosol into Alaska, simultaneous programs are vastly preferred over separate programs. So when the chance came to add Fairbanks to the program, we decided to do it.

In summary, the overall work plan for August and September 1976 is:

August 1976

Continue with analysis of haze samples; make trajectory analyses for sampling dates at Barrow during April 1976; construct and test ground stations at U.R.I.; ship ground stations to Barrow and Fairbanks.

September 1976

Complete analysis of haze samples; make trajectory analyses for sampling dates at Barrow during May 1976; install ground stations at Barrow and Fairbanks; receive first ground-level filters at U.R.I.

G. Publications in preparation

For obvious reasons of time, this project has as yet produced no publications. However, certain communications of our results are foreseen. We plan to submit a short publication to Nature as soon as the chemical analyses and trajectories are finished. One of us (K. Rahn) will be attending a conference in Gothenburg, Sweden, 18-20 October 1976, sponsored by the Secretariat for International Ecology, Sweden (SIES), on the topic of measurement and effects of Sahara dust. We will present a short summary of our results there. We have just received an invitation from Dr. Troy Péwé of Arizona State University to attend a symposium on desert dust which he is organizing for the annual meeting of the AAAS in February 1977 in Denver. If time permits we may give a talk, but in any event we have been encouraged to prepare a paper for the proceedings volume of the conference.

II. Renewal Proposal: "Arctic Haze: A Chemical, Physical, Optical and Meteorological Study"

A. Introduction and rationale

The original Arctic haze proposal of 20 August 1975 anticipated a two-part program consisting of a month-long aircraft field-sampling program in Barrow followed by setup of a ground-based sampling program in Barrow or vicinity. The aircraft program would yield information about the composition of the Arctic haze layers, while the ground program would hopefully provide some data on the seasonal frequency of occurrence of haze layers at Barrow, plus more detailed chemical analysis of the Barrow aerosol in general. The ground-level sampling program was to extend for one year, or through the latter part of the original granting period and most of the one-year renewal, which was anticipated to begin 1 October 1976.

As noted above in the Progress Report section of this report, the aircraft sampling part of the original contract has been carried out (in April and May 1976). It seems to have been very successful, and analysis of the samples is now being completed. Concerning the ground-station program, we have decided to set up two stations instead of the originally-planned one, for reasons which are also discussed above. Briefly, these are: (1) the second station just outside of Fairbanks will be maintained by University of Alaska personnel at little cost to this project; (2) it should yield confirmatory data for the more northerly Barrow site, because Fairbanks is to the south, the direction from which the haze layers appear to come into Barrow. (In fact, Dr. Glenn Shaw of the University of Alaska observed anomalously high turbidities over Fairbanks this past spring during periods of southwesterly flow aloft);

and (3) turbidity measurements are made regularly in Fairbanks and can be compared with our aerosol measurements there.

The first part of our renewal proposal for the period 1 October 1976 through 30 September 1977 is therefore the maintenance of these two ground stations and the analysis of filters collected from them.

The second part of our renewal proposal is a follow-up series of aircraft samples of the Arctic haze layers over Barrow, using aircraft from NARL in about the same way as the first pilot study there did. This again represents something of a departure from our original idea for the renewal, which was to only run the ground program. The reasons for adding a second aircraft phase are several: (1) Our chemical analyses of the first set of haze layer samples showed that aircraft sampling within the layers was much easier than we had anticipated, because the concentrations of aerosol mass were generally much higher than expected; (2) Condensation nucleus counts as a function of height during the flights occasionally revealed apparent layers of aerosol well above the 10,000-foot sampling ceiling of the Cessna 180's used during the pilot study; radiation measurements during some of the flights confirmed this idea by showing that much of the turbidity of the Barrow atmosphere was above the levels sampled. This agrees with the totality of radiation measurements from Barrow, which suggest that 60-80% of the haze-producing aerosol is above the typical flight levels of 7,000-10,000 feet. A level of 10,000 feet may only be the base of a substantial haze layer, the origins and properties of which are unknown. The stratosphere apparently cannot account for very much of this "excess" turbidity; (3) We learned that NARL will have one of its Super DC-3's

set aside for research purposes which can be used; these aircraft can fly enough higher and longer (ceiling about 20,000 feet, flight time about 10 hours) than the Cessna 180's that sampling from them would be a significant improvement over our pilot study; (4) We need to know the chemical composition of the haze particles as a function of particle size in order to confirm that the particles of crustal composition indeed are present in the giant size range (radius $> 1 \mu\text{m}$), where they should be if they are indeed produced from the crust by natural dispersion processes, as we suspect. Such measurements can be made with a high-volume cascade impactor; (5) We need to know the vertical profiles of this crustal aerosol and of its components during haze and non-haze conditions, because flight M has shown us that the concentrations of crustal material may have little or no relation to the presence or absence of haze. In particular, we need to know whether the crustal aerosol has a maximum concentration at the same point where the haze layer does (as measured by particle counts of Aitken nuclei). If the concentrations of crustal aerosol are generally high at all levels of the lower troposphere when a haze band is present, then the crustal aerosol can no longer be considered as an indicator of the location of the haze layers, and something else will have to be sought.

For both the ground-level and aircraft studies, detailed trajectory analyses for all samples will be made, which will provide important corroborative information about the locations of sources of the aerosols sampled.

In summary, then, our Renewal Proposal contains the following goals:

(1) Seek to establish the seasonal frequencies of occurrence of the haze layers over Alaska by a year-long ground-station study at Barrow and Fairbanks;

(2) If the haze aerosol is detected in the ground-level aerosol at either or both of these sites, a very careful trajectory analysis will be performed for the haze periods to see whether they all have the same source and what this source or sources might be;

(3) Determine the composition of the ground-level aerosol as a function of particle size during the haze periods and compare the results with a similar study to be done by aircraft in the layers aloft;

(4) A major aircraft study of the haze layers over Barrow next spring to see whether their composition is the same as this year (i.e. is the haze aerosol always crustal?), study their composition as a function of particle size, make better size distribution measurements of the haze and non-haze layers (perhaps with an airborne Royco particle counter), measure the vertical profiles of the various components of the Barrow atmosphere during haze and non-haze conditions, and to see which components are the best indicators of the location and intensity of the haze layers;

(5) A much broader goal, to be discussed in detail below: To begin a comprehensive study of the composition of the 1-10 μ m fraction of erodible soils, i.e. that size fraction of the soil which actually makes up the crust-derived aerosol. Such information will be most helpful now and in the future in confirming whether Arctic haze actually comes from the earth's crust via a wind-generation mechanism.

Future research which might develop if an Asian desert source is confirmed this year but which is not proposed for this renewal, might be oriented toward (1) examining the transport paths of Asian aerosol between Asia and Alaska in more detail, with an eye toward levels of transport, modification of the particle population during transport by fallout, precipitation, etc.; (2) distinctive chemical features of Asian desert dust which can aid in its identification; (3) fate of this crustal material after it is injected into the Arctic vortex (this could possibly develop into a cooperative international program if other northern countries were interested enough); and (4) a more detailed theoretical and experimental study of the effect of dust particles on the radiation balance of the Arctic.

It can easily be seen from the above discussion that our program for the next year is at a higher overall level than had been originally anticipated; this is also reflected in the budget. Part of the reason for this increase in size is due to the nature of the analytical results which we have obtained for the haze samples - if the haze indeed has its source in the Asian deserts, then this is a major discovery which merits an expanded program. But a second reason why we have felt confident to propose a larger program is because of the following purely coincidental set of circumstances of which we have chosen to take fullest advantage.

From September 1975 to May 1976, Dr. Kenneth A. Rahn of this project was an invited guest scientist at the Max-Planck-Institut für Chemie (Otto-Hahn-Institut), Mainz, West Germany, directed by Prof. Christian Junge. This institute has perhaps the foremost comprehensive program of research into atmospheric chemistry in the world. Dr. Rahn's principal activity during these eight months was

the analysis and interpretation of a suite of Sahara soil samples and a suite of Sahara aerosol samples taken over the North Atlantic Ocean. The analyses performed on these samples by neutron activation were the most detailed of any Sahara samples to date. They yielded a great deal of information about the composition of the aerosol itself and also revealed an intimate relation between the composition of the parent soil and its derived aerosol, which appears to be much more complex than generally realized. At the conclusion of Dr. Rahn's visit to Mainz, Prof. Junge suggested that one of his graduating Ph.D. students, Mr. Lothar Schütz, pay a return research visit to the University of Rhode Island and work for six months to one year with Dr. Rahn on analysis of aerosols by and soils by neutron activation, then return to Mainz and establish a similar program there. Mr. Schütz has been working on the physical and meteorological aspects of the generation and transport of Sahara dust for several years and has written a Master's thesis and is finishing his Ph.D. thesis in this area. He is undoubtedly one of the world's experts on the topic of generation of crustal aerosol and its long-range transport. He also has a great deal of experience in electron microscopy of desert and marine aerosols. It was agreed that Mr. Schütz's research at U.R.I. would be most profitable if it were divided roughly equally between analysis of aerosols and analysis of size-fractionated soil samples. The latter is a completely new field, which was decided upon because it would hopefully explain why the crustal component of the world background aerosol does not more closely match bulk soils in its composition, a recent finding for which there is mounting evidence (Rahn, 1975a, b; Rahn, 1976a, b).

When we decided to add the Fairbanks site to the ground-level sampling program, Mr. Schütz agreed to be the analyst for these samples, whether or not ONR supported him financially. The analysis of the soil samples was seen as a project of interest to the atmospheric chemistry community as a whole but one which could not be supported by ONR.

Then came the finding that the haze aerosol might well be from Asian deserts. Mr. Schütz's visit to U.R.I. suddenly took on a much more interesting dimension, for his expertise in desert aerosols could be used to great advantage in this project. Nearly simultaneously, it was also being arranged that he should stay at U.R.I. for more than six months, hopefully 9-12 months, so that he could make a genuine contribution to whatever project he worked on. It is now very clear to all of us that a happier marriage between visiting scientist and needy project could hardly be arranged. We of U.R.I. have offered Mr. Schütz a flat six months' salary from whatever grant we needed to take it; Prof. Junge has added a pledge of 3-6 months' additional support plus travel expenses, and so it is now definite that Mr. Schütz will begin his visit here 1 January 1977 for some period longer than six months.

We propose to make Mr. Schütz an intimate part of this Alaska project while he is here and that he essentially devote his full effort to it. We are requesting six months' salary for him under this project, which together with the contribution from Prof. Junge will allow his full-time participation. We ask ONR to take the long view and recognize that Mr. Schütz's analysis of size-fractionated soil samples (all of which he will fractionate

in Mainz at no cost to ONR before coming to U.R.I.) may ultimately be as valuable a contribution to delineating a source for the Arctic haze aerosol as his analysis of the ground-station samples will be, and, in fact, will open up a whole new branch of research into soils versus the aerosol. Mr. Schütz will, of course, assist with many other aspects of our Alaskan haze research, and we expect that his contribution to the overall project will be invaluable.

Furthermore, the analysis of the size-fractionated soils shows every prospect of being enthusiastically received by the atmospheric chemistry community as a whole. For example, Dr. Jarvis Moyers, Director of the Atmospheric Analysis Laboratory of the University of Arizona, Tucson, has already collected a desert soil sample for us and has offered, free of charge to this contract, to analyze the size fractions of all the soil samples by atomic absorption for about 20 elements, including the most interesting Pb, Cd, Si, Bi, and Tl, which would normally not be determinable by neutron activation at U.R.I. We expect this project to (1) provide a much better estimate of the global crustal precursor to the aerosol than is presently available; and (2) to give some much-needed information about the multi-elemental composition of various soils, including various deserts. It may be that some element or combination of elements will turn out to be an indicator of each desert. (An obvious first step to take would seem to be analysis of soil from the Asian deserts. We are presently trying to obtain a soil sample from either the Gobi or Takla Makan Desert.)

B. General plan of the work

1. The ground stations

The two ground stations in Barrow and Fairbanks will both run from September 1976 to at least September 1977. As described earlier, each will have two pump-filter setups, one for trace metals and the other for total aerosol and organic carbon. The station at Fairbanks will run continuously, one at Barrow will have wind control. Filters will be changed at each site on command from U.R.I., where the hemispheric flow situation will be followed from real-time meteorological maps printed several times daily by a standard facsimile machine. Changing of filters will take place every few days when the air mass or wind system changes. Special attention will be paid to flow patterns from the Asian deserts to Alaska - we will start a new filter each time that such air should reach Alaska and keep the filter running as long as the situation persists. In this way we hope to get the best possible samples of desert air over Alaska.

Filters will be mailed back to U.R.I. and analyzed in groups of 5-10, or in smaller groups as the situation demands.

Two or three times during the course of this year we will take high-volume cascade impactor samples at each ground site. These will give information about the haze and non-haze aerosol as a function of particle size, which should allow us to quite accurately discriminate between crustal material (large particles) and material from other sources (smaller particles). These impactors will be made for us in U.R.I.'s machine shop at only nominal charge.

2. Improved aircraft sampling

We originally shied away from including aircraft sampling in this Renewal Proposal because we felt that in order to improve our sampling significantly over the Cessna 180 flights already made we would have to step up as far as the NCAR Electra, the use of which is much too big an undertaking for this project. We then were reminded of the two Super DC-3's at NARL, one of which is reserved for scientific work. Mr. Richard Delafield, aircraft operations manager of NARL, confirmed that he would indeed be delighted to use one of these aircraft for our purposes and that they would be ideally suited for our type of work.

At present we are therefore planning a second, follow-up series of aircraft samples of the haze layers over Barrow, to be taken under the direction of Mr. Randy Borys, who directed the first successful pilot study there. This study would take place next spring, probably in April again, and would be approximately one month in duration. As before, the flight would incorporate particle counts, radiation measurements, and aerosol sampling, and possibly particle-size distribution determinations during the flight by a Royco counter to be supplied by the University of Alaska. Particle-size distributions may also be determined more accurately for mineral and non-mineral fractions of the aerosol by sampling on Delbag Microsorban filters, dissolving in toluene, and counting under light and/or scanning electron microscopes. Mr. Schutz has had much experience with this technique. Each flight would be up to ten hours long and up to 20,000 feet in elevation depending on where the haze layer was found. Six aerosol samples would be taken

simultaneously: two high-volume cascade impactors (one with Whatman cellulose filters for trace-metal determinations, the other with glass-fiber filters for total aerosol and total organic carbon determinations), two high-volume total filters (Whatman and glass-fiber), as well as the low-volume SEM and ice-nucleus filters. Radiation instruments would include the sun photometer and possibly also the multi-spectral hemispheric flux detector, a new instrument of Dr. Shaw which seems to be working well and which could be mounted in a hatch of the Super DC-3.

3. Meteorological analyses

Meteorological analyses, particularly trajectory analysis, will form an ever more important part of our program. As mentioned above, we will use a facsimile machine to control the changing of filters for the ground-sampling program. In addition, we will make trajectory analyses for the flight periods of April-May 1976 and those anticipated for April-May 1977, as well as for all periods of interest during the ground sampling. To do this we will place a standing order with the National Climatic Records Center in Asheville, North Carolina, for microfilms of hemispheric weather maps for five levels (surface, 850 mb, 700 mb, 500 mb and 300 mb) twice daily for the year. Using these, together with the Arctic trajectory techniques learned from Dr. Paul Twitchell of ONR Boston, we should be able to fairly well document the source(s) of aerosol over Alaska at all times of the year. We will also look into the possibility of using NASA satellite photographs to follow dust clouds from the Asian deserts northward and eastward, as has been done successfully for Sahara dust moving westward across the Atlantic Ocean to the Caribbean.

4. Outline of work plan

The overall plan of the work for this one-year project is then as follows:

October-December 1976

Begin analyses of Barrow and Fairbanks ground-level samples; install facsimile machine at U.R.I. and begin control of sample changing at these two sites from U.R.I.; improve trajectory analysis for aircraft samples of April-May 1976; fractionate soil samples (Mainz); plan and order sampling equipment for spring aircraft sampling in Alaska.

January-March 1977

Continue analysis of Barrow and Fairbanks samples; begin analysis of fractionated soil samples (including AA work at University of Arizona); assemble and test equipment for spring aircraft sampling in Alaska; trajectory analysis for ground samples of October-December 1976.

April-June 1977

Continue analysis of aerosol and soil samples; aircraft sampling in Barrow using Super DC-3; trajectory analysis for January-March 1977.

July-September 1977

Begin analysis of aircraft samples and radiation data of April-May 1977; continue analysis of aerosol and soil samples; trajectory analysis for April-June 1977; close down ground sampling sites at Barrow and Fairbanks.

C. Facilities available

University of Rhode Island

Two well-equipped chemistry laboratories, one in the Horn Building at the Graduate School of Oceanography and the other in the Rhode Island Nuclear Science Center (RINSC) adjacent to the School of Oceanography, will be used in this work. A new \$30,000 Class 100 clean laboratory is being constructed for our group in the RINSC and should be available by September 1976. Also available for this project are three laminar-flow clean benches. A machine shop is located on the main campus.

All neutron activation analysis will be performed at the RINSC. The RINSC swimming pool reactor operates at two megawatts and delivers a thermal neutron flux of approximately $4 \times 10^{12} \text{ n cm}^{-2}\text{sec}^{-1}$ at the irradiation sites. Counting equipment available for this work includes several large Ge(Li) solid-state detectors and associated electronics, which may be used with either a Nuclear Data Model 2200 4096-channel analyzer or a Digital Equipment Corporation PHA-11 pulse-height analysis system. Data and spectrum reduction on these systems can either be done via magnetic tape output with subsequent use of the IBM 360-60 computer on the main campus or directly on the PDP-1140 computer which is part of the PHA-11 system.

Also located at the RINSC is a complete atomic absorption analysis laboratory, including three Perkin-Elmer instruments (Models 303, 360 and 503), HGA-2000 and HGA-2100 heated graphite atomizer attachments and other accessories.

An ice-nucleus counter, utilizing Millipore filters and the forced-air cooling technique, is also located at the RINSC.

The Graduate School of Oceanography has a Stereoscan S4 scanning electron microscope (Cambridge Scientific Instruments, Ltd.) which is available for general use. It features two CRT displays, a magnification range of 10-200,000X, and a resolution in the secondary electron imaging mode of 150Å at 30 kV. In addition, the GSO has recently acquired a JEOL 50-JXA electron microprobe with 3-wavelength spectrometers and the KRISSEL automation package, including a PDP-11/05 16K computer. This unit will have 70-Å resolution and a 1 µm beam.

University of Alaska

The Geophysical Institute of the University of Alaska is housed in the eight-story C. T. Elvey Building on the West Ridge of the College campus. Available facilities here include machine shops, welding, carpentry, painting, staging and assembly, electronics shop, instrument repair, electron microscope laboratory, optics dark tunnel, photographic services, drafting, reports production, programming and computing, data processing, optics laboratory, meteorology laboratory and optics test laboratory.

The Geophysical Institute library offers a comprehensive coverage of solar-terrestrial physics, meteorology and climatology, glaciology, oceanography, the solid-earth sciences, and environmental studies. The archives, adjacent to the library, include a world-wide collection of auroral and magnetic records, together with a more selective sampling of other records in the various geophysical disciplines.

D. Current support and pending applications

Dr. K. A. Rahn

At the time of this writing, Dr. K. A. Rahn is supported as a Research Associate by NSF Grant ATM75-23725, "Atmospheric Chemistry of the Halogens: Natural and Anthropogenic", for the two-year period 1 January 1976 to 31 December 1977. He is Co-Principal Investigator on the grant, the total budget for which is \$90,364. Fifty percent of his salary comes from this grant. The other 50% of Dr. Rahn's salary comes from the ONR Arctic haze contract for which renewal is being sought here. Its budget for the eight-month period 1 February 1976 to 30 September 1976 is \$28,222. Dr. G. E. Shaw of the University of Alaska is the other Co-Principal Investigator.

Dr. G. E. Shaw

<u>Title</u>	<u>Agency</u>	<u>Period</u>	<u>Amount</u>	<u>P.I. Time</u>
<u>Current Support</u>				
OPP73-05829-A01 Studies of the Size Distribution of the Background Aerosols as Determined from Multispectral Measurements of Atmospheric Transparency	NSF	09-01-73 04-30-77	\$63,800	7 mos.
P.O. 43434 Arctic Haze: Natural or Pollution?	ONR	02-24-76 06-30-76	\$ 3,947	3/4 mo.
DAAD 07-76-M-5382 Atmospheric Aerosol Collection in Interior Alaska	Army	02-01-76 01-31-77	\$ 7,054	3/4 mo.
03-6-022-35154 Radiation Studies at Mauna Loa Observatory	NOAA	02-01-76 01-31-77	\$18,485	3 mos.

<u>Title</u>	<u>Agency</u>	<u>Period</u>	<u>Amount</u>	<u>P.I. Time</u>
<u>Pending Applications</u>				
Radiation Studies at Mauna Loa Observatory	NOAA	1 year	\$21,069	
Study of Non-Resonant Scattered Sunlight at Alaska	NSF	1 year	\$41,599	
Studies of the Atmospheric Radiation Field in Antarctica	NSF	1 year	\$32,446	
Tropospheric Investigations in Sub-Polar Regions, Part II	NSF	1 year	\$31,482	
Studies of Atmospheric Particulates and Atmospheric NO ₂	NSF	1 year	\$39,885	

E. Comments on the budget

The proposed budget for the one-year period beginning 1 October 1976 is presented in Section F. Its total cost is \$72,674, which is 72% higher than the annual equivalent of last year's eight-month budget. This increase comes about for several reasons: increased participation by Dr. Rahn and Mr. Borys in the project, the timely addition of Dr. Schütz to the program, the operation of a ground program and aircraft program in the same year, as well as a larger program of meteorological interpretation of the data. We feel strongly, however, that these increases are reasonable ones and quite justified in light of the progress that this project has made in the past six months. In February 1976, we knew only what the literature could tell us about Arctic haze layers; now in August 1976, we have a proven method of sampling them, know what their composition was in April-May 1976, and have strong suspicions about their source. If our ideas about Asian deserts are correct, the

transport of large masses of crustal aerosol from Asia into the Arctic represents a major hitherto-unknown phenomenon of some significance.

Specific comments on the budget follow.

1. Salaries

We are requesting six months' salary each for Co-Principal Investigator Dr. Kenneth A. Rahn, Research Associate Dr. Lothar Schutz, and Research Assistant Mr. Randolph D. Borys. For Dr. Rahn and Mr. Borys this will accurately reflect the actual time spent on the project during the year-long granting period. For Dr. Schütz one-third to one-half of his salary will be provided by the Max Planck Society of West Germany, even though he will work on the project full-time. The remainder of both Dr. Rahn's and Mr. Borys' salaries will be paid by NSF Grant ATM75-23725, "Atmospheric Chemistry of the Halogens: Natural and Anthropogenic", a two-year grant from 1 January 1976 through 31 December 1977.

Dr. Rahn, who has been at the University of Rhode Island since November 1973, will be responsible for U.R.I.'s portion of this project. Mr. Borys, who is a meteorologist with extensive air-sampling experience in remote areas and who designed and conducted the successful aircraft-sampling phase of the first Arctic haze project, will also be responsible for the aircraft-sampling phase of this project. He will also manage all equipment for the ground-sampling program, perform trajectory analyses, take a major role in guiding the changing of samples at the ground sites in Alaska based on the developing hemispheric air-flow patterns, and will perform many of the chemical and physical analyses of the samples. We are

particularly pleased to have Dr. Lothar Schütz of the Max-Planck-Institut für Chemie, Mainz, West Germany, join us on the project. Dr. Schütz will analyze the size-fractionated soil samples, possibly including some from the Asian deserts, and the aerosol samples from the Fairbanks ground stations. In addition, he will offer important assistance in many matters having to do with long-range transport of desert dust, in which field he is an expert.

University of Alaska

We are requesting one month's salary for Co-Principal Investigator Dr. Glenn E. Shaw. The remainder of his salary will be paid from various grants (see Current Support under Biographical Information) and from state funds. Dr. Shaw will have full responsibility for the University of Alaska's part in this program, including the maintenance of the ground-sampling station near Fairbanks and the radiation measurements during the field program in Barrow next spring.

3. Permanent equipment

University of Rhode Island

Two high-volume cascade impactors will be needed to perform the critical determinations of mass versus particle size for the elements in the aerosol both at the ground stations and aloft. At U.R.I. we have successfully used the Sierra-type impactors, but as a modified version built in our own shop at very little cost compared to the commercial model, which presently costs about \$750 including base. We assume that our shop can make the two more that we need for this project, but in case something happens we have budgeted \$1,500 for two commercial versions.

The high-volume air sampling during the aircraft flights will be provided by Gelman Hurricane pumps. Four will be needed simultaneously, which with four spares, gives eight total needed. We have three from the previous project so we are requesting funds for five more.

The single Rotron high-volume pump we have requested is for a spare for the ground-level sampling, needed because we diverted the original spare foreseen for Barrow to be the active pump at Fairbanks. This brand of pump is rugged and highly reliable, and we do not anticipate any difficulty with its operation in the field. Nevertheless, we should have at least one spare.

The four inverters of 1000 watts capacity apiece are foreseen for use in the aircraft sampling to provide power to one Hurricane pump apiece. This is the system used in the original flights in spring 1976, which worked successfully. The four Hurricane pumps which will run simultaneously will, therefore, require four inverters. As spares we will use the two left from the original project.

At this point a word of explanation should be injected about the final aircraft sampling system. There seem to be two options in powering the pumps: a generator or batteries. The generator is bulky, very noisy, and produces much dirty exhaust, but does not need recharging and should be very reliable. Batteries are neat and clean, but are heavy (we may need as many as 30), give off acid fumes during the flight, and need to be recharged after each flight. Furthermore, the inverter used with batteries cannot accommodate the Gast-type high-vacuum, low-volume pumps that we would

like to use with the Scanning Electron Microscope and ice-nucleus filters. At the moment we have not decided between these two systems. Their costs are about the same, however, and for the purposes of this proposal we describe the battery system. Perhaps the deciding factor will be whether the Super DC-3 will have a good vacuum system of its own which we can tap into; if this happens, then the Gast pumps for the low-volume samples can be eliminated and we will almost certainly choose the battery system.

We hope that NARL can provide four 50-amp battery chargers, which, of course, would only be necessary with the battery system. We have, however, budgeted for the worst case.

The last item of permanent equipment, a shaker-sieve system for soil fractionation, is part of our long view toward the Asian deserts and/or arid regions in general as sources of crustal aerosol which may move into the Arctic atmosphere. The soil samples which Mr. Schütz will analyze as part of this project will all be fractionated at his laboratory in Mainz because we have no equipment for it here. We are, therefore, requesting this relatively modest sieve system which will allow us to perform whatever additional fractionations should prove necessary during and after his stay here.

4. Expendable equipment and supplies

We have budgeted \$2,000 for equipping the Super DC-3 sampling system; that is, intake nozzles, air tubes into the aircraft, etc. This amount seems reasonable because last year's equivalent for the Cessna 180, a much smaller system, cost \$700. It was, however, fabricated by an outside contractor because the machine shop of U.R.I. had too great a backlog of projects, and our project had

to move fast. This year we are hoping to have enough lead time to have all construction done at our own shop, in which case we only pay for material. To be safe though, we have included the \$2,000 worst-case estimate.

We are requesting 30 lead-acid batteries for the aircraft sampling, even though we have ten in storage at NARL. These ten must go through a winter there, and if anything happens and they freeze they will be ruined. To be safe, therefore, we are assuming that we will have to start all over next spring with new batteries.

Of the five Gast Model 0522 high-vacuum, low-volume pumps we are requesting for aircraft and ground-level sampling, three are for the aircraft and two for the ground as spares. If the Super DC-3 has a good vacuum system that we can use for the low-volume SEM and ice-nucleus filters, the three Gasts will not be needed in the aircraft. If only one spare is taken for the ground stations, this request could conceivably be cut to \$200.

5. Travel

The total of \$3,000 requested for the spring 1977 field work in Barrow is based on Mr. Borys there full-time and Dr. Rahn for a shorter period (he was unable to participate in last spring's air sampling because of being in Germany), and three round-trips from Fairbanks to Barrow for Dr. Shaw and/or others of the University of Alaska.

The request of \$400 to attend a SIES (Secretariat for International Ecology, Sweden) conference (Gothenburg, Sweden, 18-20 October 1976) on Sahara dust and its effects is for Dr. Rahn, who will independently be attending the WMO Technical Conference on

Atmospheric Pollution Measurement Techniques to be held the week before in Gothenburg. Dr. Rahn was invited to attend the SIES conference by Prof. C. E. Junge of Mainz to present his work on Sahara aerosol and soils, done at Prof. Junge's institute in Mainz. At the same time, however, Dr. Rahn has offered to present the initial results of the Alaska study to this conference, in particular as they relate to Asian deserts as a possible source of Arctic aerosol. This conference will assemble the world's experts on desert dust and its transport and should be an excellent opportunity to discuss the significance of our Alaska work and perhaps to interest others in the chemistry of the Arctic aerosol. On this same trip Dr. Rahn is planning stops in Denmark and Norway to discuss this work with researchers there who are also concerned with the Arctic aerosol, particularly the group of Dr. B. Ottar of the Norwegian Institute for Air Research, Kjeller, with whom Dr. Rahn has worked in the past. The basic transportation costs to and from Gothenburg will be paid by NSF; we are requesting that ONR supplement this for the extra days at the SIES meeting and for the visits to Denmark and Norway.

Finally, we are requesting \$1,000 for a single trip to Alaska from Rhode Island for Dr. Rahn to close down the ground-level sampling program there next September.

7. Other costs

Telephone costs between Rhode Island and Alaska will be a major expense during this granting period, especially because we will control the ground-level filter-changing from Rhode Island. At present we can use the AUTOVON system to call Dr. Shaw in Fairbanks

and NARL; we only need pay for the time to Washington, D. C. But the calls to the Barrow GMCC site must presently be made completely commercially. The cost of two 10-minute calls to the GMCC site weekly for one year works out to \$1,125; we are, therefore, requesting \$1,500 for telephone for the year. We are looking into the possibility of getting an FTS identification number to reduce these costs to the GMCC site, but we do not yet know if this will be possible.

We are requesting \$2,500 for the rental of a facsimile machine to provide us with daily meteorological maps with which to control the ground-level sampling. It is possible that the Navy would have this item in its stock somewhere else so that much of this cost could be saved.

Our trajectory analyses will require daily meteorological maps from five levels in the atmosphere in a more permanent and comprehensive form than comes from the facsimile machine. We are, therefore, requesting \$1,000 for these maps to be supplied on microfilm from the National Climate Records Center, Asheville, North Carolina. The basic charge is \$66 per month (\$792 per year). The extra \$208 requested will allow us to obtain extra maps for special situations.

Cost sharing

Both the University of Alaska and the University of Rhode Island will participate in the financial support of this research. U.R.I. will underwrite all reactor fees, which may amount to several thousand dollars, and will also underwrite the use of the atomic absorption laboratory. Although the University of Alaska does not cost-share per se with ONR, at least 4% of Dr. Shaw's salary comes from state funds. The equipment used by the University of Alaska

for the research proposed here will be drawn from its general inventory, at no cost to ONR. Lastly, the salary of Dr. Schütz will come approximately one-half from the Max Planck Society of West Germany.

F. Budget

	<u>University of Rhode Island</u> FY 77	<u>University of Alaska</u> FY 77
(1) Salaries:		
Co-Principal Investigator Dr. Kenneth A. Rahn, Research Associate 6 months (50%)	\$10,000	
Co-Principal Investigator Dr. Glenn E. Shaw, Associate Professor 1 month (8%) Reserve for annual leave (12%) Holiday and sick leave (9.5%)		\$ 3,205 385 304
Research Associate Dr. Lothar Schütz 6 months (50%)	6,000	
Research Assistant Mr. Randolph Borys 6 months (50%)	6,000	
Secretary 2 months (16%)	1,500	
TOTAL SALARIES	\$23,500	\$ 3,894
(2) Fringe benefits @ 12% of salaries	-	\$ 467

University of
Rhode Island

University of
Alaska

(3) Permanent equipment:

Sierra high-volume cascade impactors with bases (2)	\$ 1,700
Hurricane high-volume vacuum pumps for aircraft sampling (5)	625
Rotron high-volume vacuum pumps for ground-level air sampling (1 spare)	375
Inverters, 1000 watts (4)	2,000
Battery chargers, 50 amp (4)	2,000
Shaker, 6 sieves, for soil fractionations	550
TOTAL PERMANENT EQUIPMENT	\$ 7,250

-

(4) Expendable equipment and
supplies:

Chemicals, glassware, field supplies, etc.	\$ 1,500
Miscellaneous	
Miscellaneous aircraft- sampling equipment and supplies	2,000
Lead-acid batteries (30) for aircraft sampling	2,000
Gast 0522 high-vacuum pumps (5) for aircraft and ground sampling	1,000
TOTAL EXPENDABLE EQUIPMENT	\$ 6,500

\$ 300

\$ 300

	<u>University of Rhode Island</u>	<u>University of Alaska</u>
(5) Travel:		
Field work in Barrow (April-May 1977)	\$ 2,500	\$ 500
SIES Gothenburg conference on Sahara dust, associated visits to Denmark and Norway (October 1976)	400	-
Attend 2 conferences in U.S., 2 people each conference	1,600	
Trips to Ester Dome near Fairbanks to change ground-level samples		125
Close down ground-sampling in Alaska (September 1977)	1,000	
TOTAL TRAVEL	\$ 5,500	\$ 625
(6) Publications	\$ 500	\$ 250
(7) Other costs:		
Computer 5 hrs. CPU	\$ 750	
Maintenance of sampling and analytical equipment	1,000	
Postage (Barrow-R.I.)	200	
Freight (Alaska-R.I.)	1,500	
Telephone (Alaska-R.I.)	1,500	
Scanning electron microscope	250	
Electron microprobe	250	
Rental of facsimile machine (1 year)	2,500	
Meteorological maps on micro- film-----	1,000	
TOTAL OTHER COSTS	\$ 8,950	-
TOTAL DIRECT COSTS	\$52,200	\$ 5,536

	<u>University of Rhode Island</u>	<u>University of Alaska</u>
(8) Indirect costs:		
Overhead and fringe ● 55% of salaries	\$12,925	
Overhead ● 51.7% of salaries		\$ 2,013
TOTAL COSTS	\$65,125	\$ 7,549
<u>GRAND TOTAL</u>		<u>\$72,674</u>

G. Biographical information

Co-Principal Investigator

NAME: Kenneth A. Rahn

EDUCATION: B.S. Massachusetts Institute of Technology, 1962
(Chemistry)
Ph.D. University of Michigan, 1971 (Meteorology)

PROFESSIONAL
EXPERIENCE:

1976 - Present Research Associate, Graduate School of Oceanography
University of Rhode Island
1975 - 1976 Invited Visiting Scientist
Max-Planck-Institut für Chemie, Mainz, West Germany
1973 - 1975 Research Associate, Graduate School of Oceanography
University of Rhode Island
1971 - 1973 Research Associate, Institute for Nuclear Science
University of Ghent, Belgium
1968 - 1971 Graduate Assistant, University of Michigan
Ann Arbor, Michigan
1970 - summer Lawrence Radiation Laboratory, Livermore, California
1963 - 1968 Science and Mathematics Teacher
Classical High School and Barrington College
Providence, Rhode Island

PROFESSIONAL
SOCIETY

MEMBERSHIPS: American Chemical Society

RECENT
PUBLICATIONS:

Dams, R., J.A. Robbins, K.A. Rahn, and J.W. Winchester, "Non-destructive neutron activation analysis of air pollution particulates", Anal. Chem., 42, 861 (1970).

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Co-Principal Investigator

NAME: Glenn E. Shaw

EDUCATION: B.S. Montana State University, 1963
M.S. University of Southern California, 1965
Ph.D. University of Arizona, 1971

PROFESSIONAL
EXPERIENCE:

July 1974 - Present	Associate Professor of Geophysics Geophysical Institute, University of Alaska
May 1971 - July 1974	Assistant Professor of Geophysics Geophysical Institute, University of Alaska
1968 -1971	Research Associate, University of Arizona Studies involving radiative transfer through the atmosphere
1965 - 1968	Research Assistant, University of Arizona Physics of lightning and atmospheric electricity research
1965 - 1967	Hughes Fellow, Hughes Aircraft Company, Electron Dynamics Division, Inglewood, California Electron dynamics in microwave devices
Summer 1962	Research Associate, Argonne Laboratories, EBR II, Idaho Falls, Idaho Nuclear reactor technology
1962 - 1963	Engineering Associate, Engineering Research Laboratory, Bozeman, Montana Development of electronics
1957 - 1959	Electronics Technician, U. S. Navy

PROFESSIONAL
ORGANIZATIONS: American Association for the Advancement of Science
American Geophysical Union
American Meteorological Society
Royal Meteorological Society

RECENT
PUBLICATIONS:

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Research Associate

NAME: Lothar Willibald Schütz

EDUCATION: M.S. University of Mainz (West Germany), 1971
(Meteorology)
Ph.D. University of Mainz (West Germany), anticipated
late 1976 (Meteorology)

PROFESSIONAL
EXPERIENCE:

Max-Planck-Institut für Chemie (Otto-Hahn-Institut)
Department of Air Chemistry, Saarstr. 23, D-6500 MAINZ

1974 - Present Research Assistant
1968 - 1974 Graduate student under Professor Dr. C. Junge

PROFESSIONAL
SOCIETY

MEMBERSHIPS: Deutsche Meteorologische Gesellschaft
Deutsche Gesellschaft für Elektronen-Mikroskopie

PUBLICATIONS:

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dem subtropischen Nord-Atlantik. Ph.D. Thesis, 1976, (in
preparation).

Research Assistant

NAME: Randolph D. Borys

EDUCATION: B.S. University of Michigan, 1971 (Meteorology and Oceanography)
M.S. University of Michigan, 1971 (Meteorology)

PROFESSIONAL
EXPERIENCE:

1975 - Present Research Assistant, Graduate School of Oceanography,
University of Rhode Island
1972 - 1975 Research Technician, Graduate School of Oceanography,
University of Rhode Island
1971 - 1972 Oceanographic Technician, Woods Hole Oceanographic
Institution, Woods Hole, Massachusetts
1969 - 1971 Oceanographic and Meteorological Technician,
Department of Meteorology, University of Michigan,
Ann Arbor, Michigan
1968 - 1969 Chemical Technician, Department of Meteorology and
Oceanography, University of Michigan,
Ann Arbor, Michigan

PROFESSIONAL
SOCIETY

MEMBERSHIPS: American Meteorological Society

RECENT
PUBLICATIONS:

Borys, R.D. "The general atmospheric circulation of the Cretaceous:
paleo-winds of the northern hemisphere", Oceanography Field
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and organic components of gaseous chlorine, bromine, and iodine
in the atmosphere", to be presented at the WMO Technical
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Gothenburg, Sweden, October 11-15, 1976.

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