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NITROGEN OXIDES REACTIONS WITHIN URBAN PLUMES TRANSPORTED OVER THE OCEAN

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ABSTRACT

The report describes an airborne measurements program in the downwind urban plume of Boston. The variables measured included ozone, nitric oxide, oxides of nitrogen, nitric acid, peroxyacetylnitrate, carbon monoxide, nonmethane hydrocarbon, freon-11, C_1-C_5 hydrocarbons, condensation nuclei, nitrate, sulfate, temperature, and dew point temperature. The rate of removal or conversion of nitrogen oxides was observed to follow psuedo-first order kinetics. The average pseudo-first order rate constant was determined to be 0.18 per hour, with a range of 0.14 to 0.24 per hour. The removal process is dominated by chemical conversion to nitric acid and organic nitrates. The removal rate suggests an atmospheric lifetime for nitrogen oxides of about 5 to 6 hours in urban air.

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SECTION I

INTRODUCTION

Since the early 1970's interest in the atmospheric reactions of sulfur and nitrogen pollutants has continually increased. To date, sulfur compounds have been more thoroughly studied, especially in terms of the rate of ambient air transformations. This is because the health data on sulfates became available before nitrate studies were completed and because the nitrogen reaction path is somewhat more complicated than the sulfur path. Also, sensitive analytical methods for studying many important nitrogen spicies have only recently been developed. As a consequence of these factors, knowledge of the ambient air reactions of nitrogen oxides has lagged.

The area in which our understanding of atmospheric NO_x chemistry is most deficient is the rate of NO_x transformation to products. Few atmospheric studies have approached this problem due to the technical difficulties involved. Breeding and co-workers[1] investigated the transformations of a number of pollutants around St. Louis. Their results suggest a 2-4 hour half-life for NO in the St. Louis plume, but their data for NO_2 are inconclusive. Thus little was learned about the important conversion of NO_x* to products.

Our group investigated the fate of nitrogen oxides in the St. Louis and Los Angeles urban areas in 1973[2]. The object of our studies was to identify the major NO_x reaction products and, to the extent possible, to define the nitrogen mass balance. The experiment was not designed to obtain data on conversion rates, but if certain assumptions are accepted, a transformation rate** of $0.10 \pm 0.05\ hr^{-1}$ is consistent with the Los Angeles data.

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*NO_x is defined throughout this report as $NO + NO_2$

**The quoted value is actually in the form of a rate constant. Since it is calculated from an <u>average</u> percent conversion divided by a time interval, it should not be taken as a true rate constant and does not imply first order kinetics.

Calvert has estimated the rate of NO_x removal from Los Angeles air using LARPP data[3]. He calculates $a(3.0 \pm 2.4) \times 10^{-4}$ ppm min^{-1} conversion to products which were not detected by the LARPP chemiluminescence monitors. This rate, which may include deposition losses, is somewhat higher than our measurements[2] suggested for conversion to all products under moderate Los Angeles smog conditions.

In more recent experiments downwind of Los Angeles in 1976, we have observed[4] lower limit NO_x conversion rates from 0.02-0.16 hr^{-1} in ground level and aircraft sampling. Typical rates were 0.05-0.10 hr^{-1}. Transformation to PAN ranged from <0.01 to 0.08 hr^{-1}.

The Los Angeles conversion rates are generally higher than those we observed in Phoenix, Arizona in 1977[5]. Phoenix was selected for study because it is an isolated source. As such, the NO_x reactions could be followed downwind of the city over the desert, where complications due to fresh NO_x and tracer emissions were minimal. The Phoenix study was the first experiment designed principally for the determination of NO_x conversion rates. Based on the NO_x and tracer concentrations and instrument sensitivities, NO_x conversion rates of 0.05 hr^{-1} should have been detectable around Phoenix. Only rarely was this detection limit exceeded. This result is puzzling, since it is contrary to the earlier field results in Los Angeles and is inconsistent with the expectations derived from modeling and smog chamber studies.

From this brief review, it should be clear that, while much has now been learned of the distribution, balance and fate of oxidized nitrogen in urban atmospheres, there is still much uncertainty regarding the rates of NO_x transformations in ambient air. The few available measurements of this conversion rate cover a broad range and seem to be city-specific. In order to better understand (and model) atmospheric NO_x reactions to assess their impact on health, visibility, and precipitation chemistry, we need to determine the NO_x conversion rates much more exactly, and we need to identify the factors which affect these rates. The study described in this report focuses on these objectives.

PROJECT DESCRIPTION

The program described in this report was aimed at better defining the rates of NO_x transformations within urban plumes. To do this in the least ambiguous way, it was desirable for the urban source to be isolated so that downwind emissions into the urban plume are minimal. The city must also be a strong source of NO_x and the downwind terrain should be relatively smooth. In view of these considerations, Boston was selected as the most appropriate city for this study. The predominant summer winds from the west and southwest take the city's polluted air eastward over the ocean, where smooth terrain and minimal fresh emissions are the rule. Boston, being a northeastern coastal city, also presents a sharp contrast with the hot, dry Phoenix site mentioned earlier. Thus the Phoenix results will be tested, and the scope of our investigations expanded, in a rather different environment.

The field experiment was conducted from July 27 to August 30, 1978. An instrumented twin-engine research aircraft was employed for continuous monitoring and sample collection in the Boston urban plume. Both gas and aerosol samples were collected. The integrated gas samples were analyzed after each flight at Battelle's mobile air quality laboratory. The aerosol samples were returned to our main laboratory in Columbus for analysis.

The mobile laboratory served both as ground support for the aircraft program and as a continuous air quality and meteorology monitoring station. The mobile lab and aircraft were based at Beverly Airport in Beverly, Mass., approximately 25 kilometers northeast of Boston. In a typical day's experiment hourly meteorological data from several eastern Massachusetts stations were obtained by telephone several times each day and were used to construct working trajectories for Boston's polluted morning air mass. Using these trajectories, the morning air mass was followed throughout the day by three or more monitoring flights. Data were collected during multiple traverses of the urban plume on each of the flights in order to bracket the morning air parcel. In this way, data on pollutant concentrations within the air parcel were obtained from early morning through late afternoon. Transport out to ∿150 km was investigated. Information on background pollutant concentrations was also obtained. The variables measured during aircraft operations

included O_3, NO_x, $HONO_2$, PAN, CO, NMHC, F-11, C_1-C_5 hydrocarbons, condensation nuclei, NO_3^-, $SO_4^=$, temperature and dew point. The ground station measured these and a number of other variables.

Subsequent sections of this report will describe the study area, the experimental methods, the results, and the interpretations of the Boston plume experiments.

SECTION 2

SUMMARY AND CONCLUSIONS

This report presents the results of a field investigation of nitrogen oxides reactions conducted in the Boston, Mass. urban plume from July 27 to August 30, 1978. The program was conducted by Battelle's Columbus Laboratories under the sponsorship of the Environmental Protection Agency's Environmental Science Research Laboratory. The aim of the study was a better understanding of NO_x reactions and especially the NO_x reaction rate, in polluted urban air.

The field measurements made use of an instrumented twin-engine aircraft to obtain data in the Boston plume as it was transported eastward over the ocean. A mobile laboratory located at the Beverly, Mass. airport served as ground support for the flight program and obtained ground level data on pollutant behavior and meteorological conditions.

This report describes the experimental aspects of the field program and presents an analysis and interpretation of the data as they relate to the program objectives. Important findings of the study are summarized below.

- During the Boston plume study the weather was generally rainy and overcast with a few sunny clear days interspersed. Pollutant levels at the ground station in Beverly were normally low. On a few days southwesterly winds transported Boston's polluted air to Beverly. One very clear case of pollutant transport occurred on 16 August, when O_3, PAN and light scattering aerosol reached very high valves just before dawn.
- Based on a subset of 14 days during which all the pertinent species were measured, the 24-hour distribution of oxidized nitrogen was

	Concentration (ppm)	Fraction of Total Oxidized Nitrogen (%)
NO_x ($NO + NO_2$)	.018	86
PAN	.0018	9
$HONO_2$	.0010	5
NO_3^-	.00004	<1

The average oxidized nitrogen burden at Beverly Airport was low due to its location (emissions density to the west, north and east is quite low). On the average about 14% of the oxidized nitrogen was present in the form of reaction products. The ratio of the average PAN and $HONO_2$ concentrations was 1.8.

- The concentration of nitrate in the aerosol phase was extremely low at Beverly Airport, with gaseous nitrates accounting for 98% of the total atmospheric nitrate. The gaseous/total nitrate ratios for several geographical locations are listed below for comparison.

Location	Gaseous Nitrate / Total Nitrate
St. Louis, Mo. (1973	.95
West Covina, Ca. (1973)	.98
Phoenix, Az. (1977)	.50
Temple City, Ca. (1976)	.75
Upland, Ca. (1976)	.96
Rubidoux, Ca. (1976)	.45
Beverly, Mass. (1978)	.98

For many of the locations, gaseous nitrate dominates the total nitrate burden, as observed at Beverly.

- Based on four days of flights for which detailed analysis is presented, the removal of NO_x from the transported Boston plume followed first order kinetics reasonably well. The pseudo-first order rate constant for NO_x removal ranged from 0.14 hr^{-1} to 0.24 hr^{-1} with an average of 0.18 hr^{-1}. Maximum ozone concentrations in the plume on these four days ranged from .095 to .160 ppm.

- On the days when all the necessary data are available, the nitrogen balance in the plume was quite good, with PAN and nitric acid accounting for nearly all the reacted NO_x. For example, during three transects of the urban plume on August 30, 1978, the nitrogen mass balance averaged 88 percent.

The pseudo-first order rate constants obtained in these experiments provide a basis for estimating the lifetime of NO_x (as $NO + NO_2$) in transported urban air under photochemically active conditions. The lifetime, τ, can be defined as the time required for chemical and physical removal processes to reduce the NO_x concentration to 1/e of its initial value (i.e. when $\frac{(NO_x)_o}{(NO_x)_t} = e$). Substituting into the integrated form of the rate equation:

$$\ln \frac{(NO_x)_o}{(NO_x)_t} = kt$$

$$\ln e = k\tau$$

$$\tau = 1/k$$

For the four available experiments τ ranges from 7.1 hours to 4.2 hours. The average of the four rate constants yields a lifetime of 5.5 hours. The NO_x half-life defined as

$t_{1/2} = \frac{.69}{k}$ averages 4.1 hours.

To the best of our knowledge this is the first accurate determination of NO_x lifetime in polluted urban air. The reported values are applicable only to daylight hours under sunny, photochemically active conditions. Further research will be required to extend these conclusions to other areas which have different meteorological conditions or emissions factors.

SECTION 3

SITING

The most suitable location for a study of urban plume reactions is downwind of a city that is a strong emissions source. Ideally, the downwind area should be smooth and there should be no complicating downwind emissions to the urban plume. As an additional constraint, we wished to carry out the experiments around a city having a different environment than Phoenix, in order to compare the results with an earlier study there[5]. After careful consideration of these requirements and the geography and meteorology of a number of urban areas, Boston was selected as the plume source for this project.

The area selected for investigation in this program is pictured in Figure 1. The Battelle mobile laboratory and aircraft were based at Beverly Airport in Beverly, Mass., approximately 25 km northeast of Boston. The site is shown in Figure 1. The mobile laboratory experienced a variety of conditions during the study, including polluted Boston air, clean air from northern New England, very clean marine air and, occasionally, the plume from the Salem power plant located ∿5 km SSE.

All aircraft monitoring flights were initiated from Beverly Airport. Prior to each flight, the air traffic control center at Logan Tower was informed of our intended flight pattern by telephone. At this time, preliminary premission was gained to fly within Logan's TCA (terminal control area) if the sampling plan for the flight required close-in monitoring of Boston's polluted air. Altitudes were also assigned for the overwater flights. This was necessary to avoid the large number of low altitude fish-spotting aircraft which operate throughout Massachusetts Bay. The cooperation of the air traffic controllers was excellent, enabling all monitoring flights to proceed on schedule and as planned.

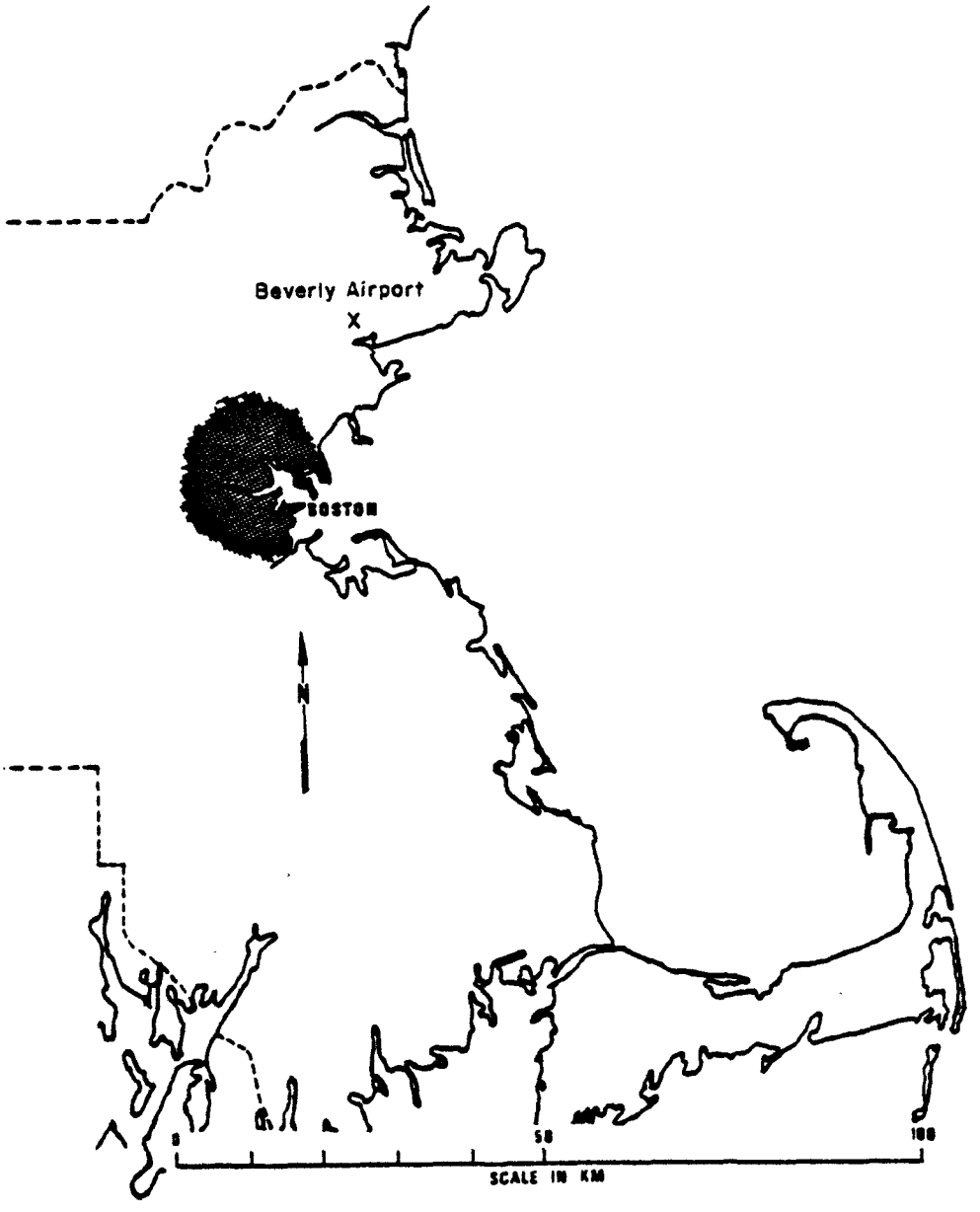

FIGURE 1. STUDY REGION - BEVERLY AIRPORT GROUND STATION IS MARKED

SECTION 4

EXPERIMENTAL METHODS

Two interacting facilities were employed for data collection during the Boston plume study. One was a Cessna 411 twin-engine research aircraft which was used for continuous airborne measurements and also for collection of filter and bag samples for later analysis. The second facility was the Battelle Mobile Air Quality Laboratory, which served as a continuous ground monitoring station and as the support laboratory for aircraft operations.

AIRCRAFT DESCRIPTION AND METHODS

The airborne sampling platform utilized during this study was the Battelle Cessna 411 research aircraft pictured in Figure 2. This twin-engine all-weather aircraft was equipped at the start of the study for the measurements described in Table 1. Most flights were conducted at or below 1000 feet AGL (above ground level). Power was supplied to the instruments listed in Table 1, as well as to recorders and a data acquisition system, from a nominally 1 KVA power inverter supplied from two 100 amp, 28 volt alternators. The instruments were operated 24 hours a day on ground power and instantaneously switched to aircraft power just prior to takeoff.

The gas monitoring instruments drew their sample from excess ram air which entered the plane through a stainless-steel sampling probe. Each instrument sampled from the manifold through Teflon tubing. Tedlar sampling bags were filled through Teflon tubing containing a variable stainless steel orifice. Ram pressure was used to fill the bags. Each bag was evacuated, tested for leaks, backfilled with zero nitrogen and evacuated twice more in the mobile lab prior to loading aboard the aircraft. Each bag was evacuated once again on board the plane just prior to its use for sampling. This procedure assured negligible contamination or carry over in the sample bags.

TABLE 1. AIRCRAFT MEASUREMENTS

Specie	Instrument	Technique
O_3	Dasibi Model	U.V. Photometry
NO_x	Monitor Labs 8440HP	Chemiluminescence
$HONO_2$	Monitor Labs 8440HP	Chemiluminescence after conversion to NO
NO_3^-, $SO_4^=$	High Volume Sampler	High Volume collection on quartz filters
C_2-C_5 Hydrocarbons	Varian 3700 FID G.C. (cryogenic pre-concentration)	Collection in Tedlar bags and analysis at the Mobile Laboratory*
Fluorocarbon-11	Varian EC-GC	
PAN		
CH_4, NMHC, CO	Beckman Model 6800 G.C.	
Temperature	Metrodata M8	Shielded thermistor
Dew Point	Cambridge System 137-C3	Condensation
Condensation Nuclei	Environment One	Cloud Condensation

*See Mobile Laboratory measurements section for description

FIGURE 2. AIRCRAFT SAMPLING PLATFORM

High volume filter collections aboard the aircraft are described in a later section of this report. The aircraft filters were analyzed and the gas monitoring instruments were calibrated in the same manner as described in the next section. The modifications to and performance of the chemiluminescence nitric acid monitor have been described elsewhere[6].

Signals from the O_3, NO_x, $HONO_2$, and CNC monitors were continuously recorded by two dual pen strip chart recorders. These signals, as well as time, temperature, and dew point, were also digitized by a Digitec data logger and recorded every six seconds on a magnetic tape cassette. The tape was returned to the mobile lab after the flights and the data reduced and tabulated by an LSI-11 microprocessor.

MOBILE LABORATORY MEASUREMENTS

The mobile laboratory was equipped to serve both as a continuous ground monitoring station and as a support lab for aircraft operations. The instruments used to determine PAN, fluorocarbon-11, NMHC, CH_4, CO, and C_2-C_5 hydrocarbons were needed for both purposes. In order for these instruments to be available to analyze aircraft bag samples and also assess ground level air quality, two-hour integrated Tedlar bag samples of outside air were collected at the mobile lab site and analyzed for F-11, NMHC, CH_4, CO and C_2-C_5 hydrocarbon between aircraft bag analyses. Thus, these data are reported as two hour averages. PAN measurements were made directly on outside air every 15 minutes.

The mobile laboratory was used to monitor meteorological conditions, solar irradiation intensity, and gas-phase composition while simultaneously collecting aerosol samples for subsequent chemical analysis. Data from all instruments were fed to a Digitem data acquisition system where the analog input is converted to digital form, serialized by bit, and presented in ASC II code on magnetic tape. Each instrumental channel was interrogated every 10 minutes for 24 hours on most sampling days. The information on tape was read into Battelle's CDC 6500 computer, conditioned, and permanently stored on magnetic tape.

Instrumentation and experimental methods employed in the mobile laboratory are discussed in the following paragraphs.

Meteorological Measurements

The mobile laboratory makes use of an automated MRI, Inc., Model 1071 weather station. The instruments listed in Table 2 provide a continuous readout of temperature, relative humidity, wind speed, and wind direction. The laboratory also employs an Eppley Laboratory, Inc., 180° pyrheliometer to determine global radiation (total sun and sky).

Laboratory records were kept of general weather conditions such as cloud cover and intervals during which rain occurred.

TABLE 2. METEOROLOGICAL MEASUREMENTS

Wind Speed and Direction	MRI, Model 1074-2 Sensor
Temperature	MRI, Model 802 Sensor
Relative Humidity	MRI, Model 907 Sensor
Global Radiation Intensity	Eppley Lab, 180° pyrheliometer

Air Quality Measurements

The instruments used for air quality monitoring are listed in Table 3. Air samples were pulled into the mobile laboratory through an aluminum stack used for high-volume aerosol sampling. The top of the stack was about 15 feet above the trailer roof or roughly 25 feet above the ground. Flow rate through the stack was at least 30 cubic feet per minute, so that the residence time was no more than about 6 seconds in the stack. From the stack the samples were transported through short lengths of 1/4-inch Teflon tubing to the appropriate instrument. A brief description of the instrumental methods employed in this study follows.

Ozone. Ozone determination in the mobile lab was based on the detection of the chemiluminescence from the reaction of O_3 with excess ethylene. Peak intensity from this reaction is in the 4000-4500Å region. The technique is thought to be free from major interferences. The sensitivity of the instrument used for this study is about 0.001 ppm. The instrument was zeroed daily and was calibrated during the field study using a KI calibrated McMillan

TABLE 3. AIR MONITORING INSTRUMENTATION

Determination	Instrument/Method	Calibration
O_3	Bendix Chemiluminescence Monitor	Photolytic O_3 generator calibrated by neutral buffered KI
NO_x	TECO 14D Chemiluminescence Monitor	NBS Cyl. "NO in N_2" and NO_2 permeation tube
$HONO_2$	TECO 14D Chemiluminescence monitor	Actual samples of $HONO_2$
PAN	Electron Capture Gas Chromatograph	Actual samples referenced to to IR
Fluorocarbon-11	Electron Capture GC	Dilute samples of actual gas
C_2-C_5 Hydrocarbons	Varian 3700 Cryogenic FID Gas Chromatograph	Actual samples referenced to NBS "Propane in Air" primary standard
THC	Beckman Model 6800 Chromatograph	NBS Cyl. "Propane in Air"
CH_4	Beckman Model 6800 Chromatograph	Actual sample referenced to to NBS standard
CO	Beckman Model 6800 Chromatograph	NBS Cyl. "CO in N_2"
SO_2	Meloy SA285 Flame Photometric	Permeation tube
Nitric Acid (Integrated)	Dual filter collection and ion chromatograph analysis	Actual samples
Mass Loading	High Volume Sampling (Quartz Filters)	Calibrated Venturi
Light Scattering Aerosol	MRI Integrating Nephelometer	Freon-12
NH_4^+	Gas Sensing Electrode	Actual Samples
NO_3^-, $SO_4^=$	Dionex Ion Chromatograph	Actual samples

Electronics Corporation ozone generator. A heated Hopcalite catalyst bed was used to destroy the ethylene effluent from this instrument. Ozone was monitored aboard the aircraft with a Dasibi 1003-AAS U.V. photometer. This instrument is specially designed for airborne monitoring. It was calibrated in the same manner as the chemiluminescence unit.

NO_x/$HONO_2$. The instrument used for continuous nitrogen oxide and nitric acid determination employs the reaction of nitric oxide with excess ozone for the generation of infrared (1.2 μ peak) chemiluminescence. The infrared radiation passes through a filter and is detected by a sensitive photomultiplier tube. Noise from the photomultiplier tube is reduced by cooling the tube to subambient temperatures. The instrument used here has a minimum detectible concentration of 0.002 ppm and is linear over a range of 0.002-5 ppm. Activated carbon is used to remove ozone from the instrument's exhaust gas. The basic instrument was modified by the addition of a second catalytic converter and a filter holder with nylon filter. These modifications enable the instrument to detect gas phase nitric acid, as described in detail by Joseph and Spicer[6].

Integrated collections for nitric acid were also made on selected study days using a dual Teflon/nylon filtration procedure[7]. Following collection, the filters were returned to Columbus for nitrate determination by ion chromatography.

Peroxyacetyl Nitrate (PAN). Determination of PAN was carried out with a Varian Series 1200 gas chromatograph equipped with an ATC wide range high sensitivity electron capture detector. A 19-inch column of 1/8-inch Teflon packed with 10 percent Carbowax 400 on Anakrome ABS was operated at 30 C with oxygen-free nitrogen at 30 cc/minute as the carrier gas. The gas chromatograph was calibrated with authentic samples of PAN which had been analyzed prior to dilution using the infrared absorption coefficients reported by Stephens[8].

Fluorocarbon-11 (CCl_3F). Fluorocarbon 11 was determined in all aircraft and mobile laboratory Tedlar bag samples with a varian 3700 gas

chromatograph equipped with a ^{63}Ni electron capture detector. F-11 was separated from other constituents with a 6' x 1/8" stainless-steel column packed with Porapak Q operated at 125°C at a flow rate of 25 cc/min O_2-free nitrogen. The detector was maintained at 150°C. Sample volume was 1 cc. Static dilution (smog chamber) and dynamic dilution (permeation tube) of pure F-11 was used for calibration. These calibrations were referenced to an absolute mass spectrometric calibration performed at Washington State University.

C_2-C_5 Hydrocarbons. Because of the low levels of hydrocarbons expected in the dilute Boston plume and the need for very precise concentration values, a special cryogenic concentrating and backflush procedure was developed for this study after consultation with W. Lonneman of EPA. A Varian 3700 flame ionization gas chromatograph with a 16' x 1/8" aluminum column packed with Durapak (phenylisocyanate) at 30°C was employed for separation of C_2-C_5 hydrocarbons in air.

A 500 cc sample of air from the aircraft or mobile lab bag samples was trapped at liquid O_2 temperature in a small stainless steel loop packed with Carbowax 1500 on Chromosorb WHP. After trapping, the liquid O_2 was removed and the sample valve opened to allow carrier gas to flow through the trap for 90 seconds. As the trap warmed, the low molecular weight hydrocarbons (C_1-C_5) were vaporized into the carrier gas stream but the heavier hydrocarbons remained in the trap. After 90 seconds the sample valve was closed and the trap was backflushed for several minutes at room temperature with zero-N_2 to purge the higher molecular weight hydrocarbons from the trap. An example of chromatographic output for a field sample is included as Figure 3. An example of a typical reprodicibility check on a field sample (Bag 12-14, 8-7-78) is provided in Table 4. In general the reproducibility was quite good.

Non-Methane Hydrocarbons, CH_4 and CO. Total hydrocarbons, carbon monoxide, and methane were measured in the integrated Tedlar bag samples with a Beckman Model 6800 Air Quality Chromatograph. The hydrocarbons are determined by flame ionization detection after chromatographic separation. Carbon monoxide is first separated from the hydrocarbons, then reduced to CH_4 via a heated Ni/H_2 catalyst, and finally detected by flame ionization.

FIGURE 3. OUTPUT FROM FIELD G. C. WITH RETENTION TIMES AND PEAK IDENTITIES

Retention Time, Min.	Identity
1.42	ethane
1.85	ethylene
2.42	propane
3.71	acetylene
4.57	isobutane
5.24	n-butane
5.77	propylene
11.05	isopentane
12.66	n-pentane

TABLE 4. CHROMATOGRAPHIC REPRODUCIBILITY CHECK ON BOSTON FIELD SAMPLE (Bag 12-14, 8-7-79)

	Values in ppbC	
	Sample No. 1	Sample No. 2
ethane	10.1	8.9
ethylene	3.8	3.9
propane	4.1	4.1
acetylene	5.4	5.4
iso-butane	3.6	3.7
n-butane	10.6	11.2
propylene	1.2	1.6
iso-pentane	16.8	16.5
n-pentane	5.9	6.2

The instrument is calibrated for carbon monoxide using a National Bureau of Standards "CO in N_2" primary standard cylinder. Hydrocarbon calibrations make use of ppm concentrations (in air) of CH_4 and hydrocarbons referenced to a National Bureau of Standards "propane in air" primary standard cylinder. Methane yields a greater response in the THC channel of the chromatograph than higher molecular weight hydrocarbons. The CH_4 response factor has been well characterized and the NMHC data have been corrected.

Gaseous Sulfur. Gas-phase sulfur was monitored with a Meloy SA285 flame photometer. The instrument was shipped directly from the factory to our mobile lab in Beverly, where it was used with its factory calibration. A complete calibration in Columbus after the field experiment verified that the factory settings were correct. Since the instrument arrived late, sulfur monitoring was delayed until the sixth sampling day.

Light Scattering Aerosol. Determination of b_{scat} made use of an MRI integrating nephelometer. The nephelometer was zeroed and electronically spanned each day. The instrument is calibrated periodically with Freon 12.

Aerosol Collections

Aerosol samples for inorganic analysis were collected over periods coinciding with the gaseous measurement times. Samples were collected from 25 feet above ground through a 6-inch-diameter aluminum stack. High-volume blowers were used to maintain an average flow rate of 1.2 m^3/min. Pressure-drop measurements were made at the beginning and end of each day's sampling in order to correct for day-to-day fluctuations in flow rate. Initial calibration of the blowers was done with a calibrated venturi.

Aerosol samples were collected on 6-inch-diameter high-purity quartz mat filters (Pallflex Product Corporation) backed by a stainless steel fritted disk. Each filter was cut and preweighed in the laboratory at 40 percent relative humidity and then stored in an individual glassine envelope enclosed in a sealed polyethylene bag. After sampling, the filter was returned to its glassine envelope in its plastic bag. On return to the Columbus Laboratories the filters were equilibrated at 40 percent relative humidity and reweighed. The filters were then partitioned for analysis.

Quartz filters (61 mm diameter) were also used for aerosol sampling aboard the aircraft. The high volume sampler on the plane made use of a separate stainless steel probe extending out the roof of the cockpit with a gentle bend. This probe can be seen in Figure 2. The aircraft samples were collected at a flow rate of 0.3 m^3/minute. Several filters were preloaded in individual filter holders specially designed for this application. These preloaded filters could be readily changed during a flight, permitting separate aerosol collections over different portions of the flight path. After each flight, these filters were stored in individual glassine envelopes and sealed in separate plastic bags.

Aerosol Analysis

The high volume filters from the field study were analyzed at Battelle's Columbus Laboratories for NH_4^+, NO_3^-, $SO_4^=$, and total carbon, hydrogen. The aircraft filters were analyzed for NO_3^- and $SO_4^=$ only.

- Ammonium was determined by dissolving soluble ammonium salts in water, adding NaOH, and measuring the resulting NH_3 with an ammonia gas sensing electrode.
- Nitrate and sulfate analysis was carried out by ion chromatography using the D-ION-X Model 10 ion chromatograph.
- Total C, H, N were determined with a Perkin Elmer Model 240 Elemental Analyzer which employs pyrolysis and thermal conductivity detection for elemental analysis.

SECTION 5

RESULTS

Summaries of Beverly Airport ground station data and the aircraft results are presented in this section. The ground monitoring data will be presented first.

GROUND MONITORING RESULTS

The weather during the Boston plume study was rainy and overcast during much of the first half of the field experiment, clear and sunny in the middle of the program and cloudy or rainy at the end. Intensity of photochemical smog in the Beverly Airport area could be best characterized as light. An ozone concentration of 0.08 ppm was equalled or exceeded on 9 of the 24 days; however, the 0.12 Federal standard was never reached.

A detailed summary of the air quality data at Beverly Airport for the 24 days of field monitoring between July 27 and August 30, 1978 is given in Tables 5 and 6. A one hour averaging period was employed for all continuously monitored variables. These results are presented in Table 5 along with a general weather summary and daily TSP and light scattering results. Data on a number of species, including total hydrocarbons (THC), methane, carbon monoxide, fluorocarbon 11 (F-11) and C_2-C_5 hydrocarbons were obtained from samples integrated over 2-hour periods in Tedlar gas-sampling bags. Summaries of these 2-hour data are included in Table 6. The 2-hour samples were analyzed for C_2-C_5 hydrocarbons only when the gas chromatograph was not busy with aircraft samples. The results of all the 2-hour average C_2-C_5 analyses are presented in Table 7.

TABLE 5. SUMMARY OF AIR QUALITY DATA - BEVERLY, MASS., 1978

Date	Weather Conditions: General[a]	Weather Conditions: Temp, C[b]	Weather Conditions: RH %[c]	Aerosol Mass Loading, $\mu g/m^3$	b_{scat}, $\times 10^{-4} m^{-1}$	Pollutants, Daily Average: O_3, ppm	Daily Average: NO_x, ppm	Daily Average: PAN, ppm	Daily Average: $HONO_2$[d], ppb	Daily Average: $HONO_2$[e], ppm	Daily Average: SO_2 ppm	1-Hour Max: O_3, ppm	1-Hour Max: NO_x, ppm	1-Hour Max: PAN, ppm	1-Hour Max: b_{scat}, $10^{-4} m^{-1}$
7/27/78	PC	--	77	51.5	2.4	.049	.015	.007*	--	≤ .002	--	.087	.032	.008	4.5
7/28/78	H	26.5	72	16.6	0.8	.014	.013	.001	.57	≤ .002	--	.067	.016	.001	1.2
8/2/78	R,C	20.3	93	28.2	1.7	.025	.011	≤ .001	--	≤ .002	--	.052	.030	< .001	3.0
8/3/78	R	28.7	82	29.6	1.4	.020	.020	≤ .001	--	≤ .002	--	.060	.044	< .001	1.4
8/4/78	R	24.5	92	21.6	1.9	.010	.052	≤ .001	.27	≤ .002	--	.038	.135	< .001	4.3
8/5/78	R,C	20.9	86	28.6	2.2	.030	.027	≤ .001	1.26	≤ .002	.061	.070	.072	< .001	3.9
8/7/78	R	23.3	94	25.5	1.6	.015	.010	≤ .001	--	≤ .002	.043	.061	.026	.003	2.5
8/8/78	R	28.6	87	41.3	1.6	.047	.020	≤ .001	--	≤ .002	.116	.076	.051	.001	2.7
8/9/78	H	28.9	65	78.9	3.6	.082	.014	.004	1.29	≤ .002	.016	.110	.026	.008	6.1
8/10/78	H,S	27.8	59	25.0	0.6	.031	.012	≤ .001	.50	≤ .002	.002	.063	.023	.003	2.8
8/11/78*	S	26.5	41	25.4	0.4	.056	.018	.002	.88	.002	.015	.068	.010	.002	0.6
8/15/78*	S,H	24.6	82	50.1	1.2	.048	.026	.005	1.14	≤ .002	.008	.086	.071	.019	6.4
8/16/78	H	28.6	83	55.6	2.8	.063	.014	.006	2.19	≤ .002	.005	.118	.029	.022	4.5
8/17/78	H	31.2	69	49.8	1.9	.060	.015	.003*	1.73	≤ .002	.005	.118	.026	.007	3.6
8/18/78*	S	27.1	56	22.2	0.5	.062	.007	.002	.84	≤ .002	.009	.089	.011	.005	0.6
8/19/78*	S	23.8	43	17.2	0.3	.068	.005	≤ .001	--	≤ .002	.007	.080	.010	< .001	0.5
8/21/78	S	20.9	70	18.6	0.3	.018	.032	≤ .001	.24	≤ .002	.005	.045	.099	.001	0.8
8/22/78	S	23.0	64	28.4	0.5	.024	.015	≤ .001	--	≤ .002	.006	.068	.115	< .001	1.5
8/23/78	S	26.9	53	35.0	1.0	.052	.014	≤ .001	.70	≤ .002	.006	.106	.035	< .001	2.2
8/24/78*	C,R	15.8	71	19.2	≤ 0.2	.014	.002	--	--	≤ .002	≤ .002	.036	.004	--	0.4
8/27/78	S	19.3	68	17.8	0.5	.024	.015	.001	--	≤ .002	.007	.055	.102	.004	0.8
8/28/78	C,R	21.3	93	37.2	2.3	.012	.021	≤ .001*	--	≤ .002	.007	.054	.034	< .001	5.7
8/29/78	C,H	30.6	70	38.2	1.6	.055	.013	≤ .001	1.08	≤ .002	.006	.092	.029	.001	4.2
8/30/78	S	22.1	69	28.5	0.7	.030	.029	.002	.64	≤ .002	.004	.076	.086	.005	1.3

(a) S = Sunny; PC = Partly cloudy; C = Cloudy; R = Rain; H = Haze.
(b) Maximum 1-hour.
(c) Daily average.
(d) Integrated filter collection.
(e) Continuous chemiluminescence average.

* Abbreviated sampling day.

TABLE 6. TWO-HOUR INTEGRATED BAG SAMPLE RESULTS FROM BEVERLY AIRPORT FOR NMHC, CH_4, CO AND FLUOROCARBON-11

Date, 1978	Time: 0800-1000 EDT				1000-1200 EDT				1200-1400 EDT				1400-1600 EDT			
	NMHC, ppmC	CH_4, ppm	CO, ppm	F-11, ppt	NMHC, ppmC	CH_4, ppm	CO, ppm	F-11, ppt	NMHC, ppmC	CH_4, ppm	CO, ppm	F-11, ppt	NMHC, ppmC	CH_4, ppm	CO, ppm	F-11, ppt
7/28	--	--	--	251.3	--	--	--	264.0	--	--	--	344.4	--	--	--	210.8
8/2	--	--	--	172.0	--	--	--	119.3	--	--	--	115.0	--	--	--	86.3
8/3	≤0.2	1.8	0.62	--	≤0.2	1.8	0.52	--	≤0.2	1.8	0.29	--	≤0.2	1.8	0.20	--
8/4	≤0.2	1.7	0.26	--	≤0.2	1.8	0.18	--	≤0.2	1.8	0.37	--	≤0.2	1.9	0.80	--
8/5	0.5	1.8	0.55	--	≤0.2	1.8	0.33	--	≤0.2	1.9	0.48	--	≤0.2	1.8	0.51	--
8/7	0.4	1.9	0.67	204.8	≤0.2	1.9	0.61	176.0	≤0.2	1.9	0.56	124.2	≤0.2	1.9	0.71	154.7
8/8	≤0.2	1.9	0.62	195.8	≤0.2	1.9	0.52	253.6	≤0.2	1.8	0.66	355.9	≤0.2	1.9	0.60	254.2
8/9	≤0.2	1.8	0.56	224.0	≤0.2	1.9	0.43	191.0	0.4	1.8	0.26	-1	≤0.2	1.8	0.34	176.4
8/10	≤0.2	1.8	0.67	174.1	≤0.2	1.8	0.42	168.4	≤0.2	1.7	0.22	232.3	≤0.2	1.7	0.18	141.3
8/11	≤0.2	1.7	0.47	151.3	≤0.2	1.7	0.21	152.9	≤0.2	1.7	0.24	312.0	≤0.2	1.7	0.31	322.9
8/14	≤0.2	1.8	0.77	185.3	≤0.2	1.8	0.56	202.7	≤0.2	1.8	0.42	149.8	≤0.2	1.8	0.36	153.5
8/15	≤0.2	1.8	0.34	235.4	0.3	1.7	0.25	209.6	≤0.2	1.7	0.31	143.8	≤0.2	1.8	0.27	397.5
8/16	--	--	--	277.9	--	--	--	236.0	--	--	--	231.4	--	--	--	366.0
8/17	--	--	--	376.6	--	--	--	237.4	--	--	--	358.8	--	--	--	300.4
8/18	≤0.2	1.8	0.40	184.1	0.3	1.8	0.41	163.9	≤0.2	1.8	0.28	194.2	≤0.2	1.8	0.35	169.1
8/19	≤0.2	1.9	0.35	162.8	≤0.2	1.8	0.34	176.5	≤0.2	1.8	0.36	132.1	≤0.2	1.8	0.37	131.3
8/21	≤0.2	2.0	0.31	153.9	--	--	--	149.5	≤0.2	1.9	0.39	129.3	≤0.2	1.8	0.39	143.4
8/22	≤0.2	2.0	0.56	203.5	≤0.2	1.9	0.31	146.8	≤0.2	1.9	0.35	152.8	≤0.2	1.8	0.44	215.0
8/23	≤0.2	2.0	0.80	252.1	≤0.2	2.0	0.56	--	≤0.2	2.0	0.48	176.5	≤0.2	1.9	0.48	211.9
8/24	≤0.2	1.9	0.50	142.4	≤0.2	2.0	0.37	173.2	≤0.2	2.0	0.33	152.8	≤0.2	2.0	0.36	162.9
8/27	≤0.2	2.1	0.51	152.1	≤0.2	2.1	0.42	182.8	≤0.2	2.1	0.34	144.6	≤0.2	2.0	0.71	185.4
8/28	≤0.2	2.3	1.03	240.2	0.4	2.1	0.64	223.1	0.3	2.1	0.56	268.3	≤0.2	2.1	0.50	247.8
8/29	≤0.2	2.4	1.17	553.4	≤0.2	2.3	0.71	165.8	≤0.2	2.3	0.64	149.5	≤0.2	2.2	0.50	163.4
8/30	≤0.2	2.2	0.57	231.9	≤0.2	2.2	0.44	132.6	≤0.2	2.2	0.45	167.1	≤0.2	2.2	0.47	170.6

TABLE 7. C_2-C_5 HYDROCARBON RESULTS FROM TWO-HOUR INTEGRATED BAG SAMPLES AT BEVERLY AIRPORT (ppbC)

Date	Time Span	Ethane	Ethylene	Propane	Acetylene	Isobutane	n-Butane	Propylene	Isopen-tane	n-Pentane
28 July 78	9 - 11	-1	11.0	2.8	3.7	2.0	4.5	-1	4.2	-1
	11 - 13	-1	8.5	7.4	4.1	3.1	8.8	-1	8.3	4.2
	13 - 15	-1	4.7	3.6	2.8	2.5	5.5	-1	-1	-1
	15 - 17	-1	7.4	4.8	2.9	3.1	9.6	-1	10.0	-1
2 August 78	8 - 10	3.5	4.1	6.5	5.3	3.8	11.3	2.0	17.2	4.9
	10 - 12	6.7	4.2	3.8	3.1	2.1	5.8	3.2	13.6	-1
	12 - 14	18.9	2.7	2.9	4.3	1.4	3.4	1.0	8.2	-1
	14 - 16	16.4	3.3	2.9	2.9	1.7	4.6	1.8	8.8	-1
7 August 78	8 - 10	14.3	20.4	7.8	11.0	19.6	59.1	11.4	134.7	28.4
	10 - 12	17.7	5.3	5.2	7.2	4.1	10.2	4.3	11.4	-1
	12 - 14	14.8	5.5	6.0	7.9	5.2	15.6	1.7	24.5	8.7
	14 - 16	9.9	4.9	4.8	11.4	4.3	10.5	3.2	16.5	5.1
8 August 78	8 - 10	-1	7.2	8.0	9.7	11.8	39.4	2.9	63.7	22.0
	10 - 12	-1	7.6	5.9	17.0	5.3	16.5	2.7	28.0	10.0
	12 - 14	-1	8.2	5.7	10.2	5.3	13.7	1.4	16.0	8.1
	14 - 16	-1	6.1	5.5	9.5	5.2	12.4	3.3	14.1	7.6
10 August 78	8 - 10	6.7	7.4	7.0	6.9	4.7	10.0	1.3	11.6	5.6
	10 - 12	8.1	6.0	3.8	12.5	3.9	10.7	2.9	28.8	4.5
16 August 78	8 - 10	6.1	9.0	7.2	12.0	8.3	16.3	2.8	16.2	-1
	10 - 12	4.2	6.0	6.2	8.0	6.0	13.2	2.6	13.1	2.9
	12 - 14	3.7	5.0	4.6	6.6	5.7	11.2	-1	12.0	-1
	14 - 16	3.4	2.9	3.6	5.7	4.6	10.0	1.5	10.0	-1
17 August 78	8 - 10	5.7	8.0	6.0	8.3	6.4	13.0	1.6	13.6	5.8
	10 - 12	6.1	4.0	5.7	6.5	5.0	9.8	1.5	9.7	-1
	12 - 14	6.0	2.9	6.0	5.1	5.3	9.3	0.7	8.7	4.3
	14 - 16	9.4	5.3	5.0	4.4	4.4	8.1	1.4	7.1	3.4
24 August 78	8 - 10	1.9	1.5	0.8	1.7	1.1	2.1	-1	5.5	-1
	10 - 12	2.2	1.6	0.8	2.5	1.1	3.0	1.6	8.6	-1
	12 - 14	2.1	1.6	0.9	2.5	1.4	3.8	1.1	12.8	2.1
	14 - 16	2.0	2.2	0.8	1.8	1.7	5.7	2.0	17.3	2.7
27 August 78	8 - 10	2.3	3.1	1.5	2.3	4.5	14.3	0.8	25.3	6.2
28 August 78	8 - 10	4.0	8.5	6.5	11.4	7.0	23.1	3.7	49.1	4.8
	10 - 12	3.6	9.0	4.0	9.8	3.6	8.7	3.2	15.2	5.4
	12 - 14	2.5	4.5	1.9	6.7	2.7	7.3	1.3	7.8	4.1
	14 - 16	2.5	4.5	1.4	4.3	1.8	5.7	1.0	6.0	2.8

Individual daily data tables which include the hourly and daily averages for all continuously monitored variables are included in Appendix A of this report. The symbol -1.0 in these tables indicates no data for that interval.

The results of daily (8 or 24 hour) high volume sampling on high purity quartz fiber filters (QAST, Pallflex Corp.) are listed in Table 8. After equilibration at 40 percent relative humidity the filters were weighed and then partitioned and analyzed for nitrate, sulfate, ammonium, and C, H, N as described in the Experimental Methods section.

Additional ground level wind speed and direction data were obtained from the National Climatic Center for 9 locations throughout eastern Massachusetts. Data are available from our mobile lab at Beverly and from Logan Airport, Race Point on Cape Cod, Merrimac River Coast Guard Station, Buzzards Bay Coast Guard Station, Boston Lighthouse, Bedford, Norwood, Provincetown, and Eastern Point Light Station on Cape Ann. The frequency of wind observations at each site is listed in Table 9. The geographical distribution of the stations is shown in Figure 4.

The wind speed and direction data have been used to construct surface level wind field grids from which trajectories have been computed. These trajectories will be used later in the report to assist in interpreting the aircraft sampling results.

AIRCRAFT SAMPLING RESULTS

Altogether, 39 aircraft sampling missions of varying duration were undertaken during the 24 days of the field program. Due to the extensive periods of rain, nearly all the 39 flights were actually concentrated in 15 study days. Maps showing each flight pattern and the geogaphical location of each integrated bag sample and filter sample are included in Appendix B. A legend which lists salient features of the flights is incorporated with each map.

TABLE 8. BOSTON PLUME STUDY GROUND LEVEL AEROSOL RESULTS ($\mu g/m^3$)

Date	TSP	NO_3^-	$SO_4^=$	NH_4^+	C	H	N
7-27-78	51.5	.07	15.4	1.1	4.3	1.3	1.7
7-28-78	16.6	.10	9.4	.4	3.6	1.2	0.5
8-02-78	28.2	2.70	13.6	.5	2.9	0.5	1.4
8-03-78	29.6	.11	8.1	.2	3.4	0.6	0.7
8-04-78	21.6	.04	6.8	.5	5.2	0.9	1.1
8-05-78	28.6	.15	19.5	1.1	6.2	1.2	1.8
8-07-78	25.5	.83	10.1	.4	4.4	1.1	1.2
8-08-78	41.3	.10	24.1	1.9	7.0	1.8	2.6
8-09-78	78.9	<.03	68.7	4.5	8.0	3.4	4.9
8-10-78	25.0	.08	13.5	.7	5.6	-	1.5
8-11-78*	25.4	.28	3.0	.30	5.3	2.5	1.0
8-15-78	50.3	.12	.7	2.9	7.8	2.1	3.6
8-16-78	55.6	.03	1.3	3.0	6.1	2.2	3.4
8-17-78	49.8	.08	2.1	2.6	7.2	1.8	2.7
8-18-78*	22.2	.16	22.0	.68	4.1	-	1.4
8-19-78*	17.2	.30	8.8	.08	3.3	-	1.2
8-21-78	18.6	.11	1.2	<.03	4.2	-	.5
8-22-78	28.4	.13	4.9	.09	6.6	.8	.6
8-23-78	35.0	.05	37.6	1.3	5.6	.7	1.7
8-24-78*	19.2	.68	1.0	.03	2.5	-	.3
8-27-78	17.8	.13	4.8	.10	3.9	-	.1
8-28-78	37.2	.03	24.8	1.6	5.3	1.5	2.0
8-29-78	38.2	.03	29.8	1.8	6.5	2.3	2.6
8-30-78	28.5	.06	7.4	.3	6.6	1.3	.6
Average	32.9	.27	14.1	1.1	5.2	1.6	1.6
Estimated Minimum Detection	-	.03	.3	.03	.8	.4	.1

* 8-hr sampling period.

TABLE 9. FREQUENCY OF WIND SPEED AND DIRECTION OBSERVATIONS AT TEN EASTERN MASSACHUSETTS SITES

Station	Observation Frequency		
	Hourly		Every 3 Hours
Beverly	X		
Logan Airport	X		
Race Point			X
Merrimac River			X
Buzzards Bay			X
Boston Light Station			X
Bedford	X		
Norwood	X		
Provincetown		Variable	
Eastern Point Light Station			X

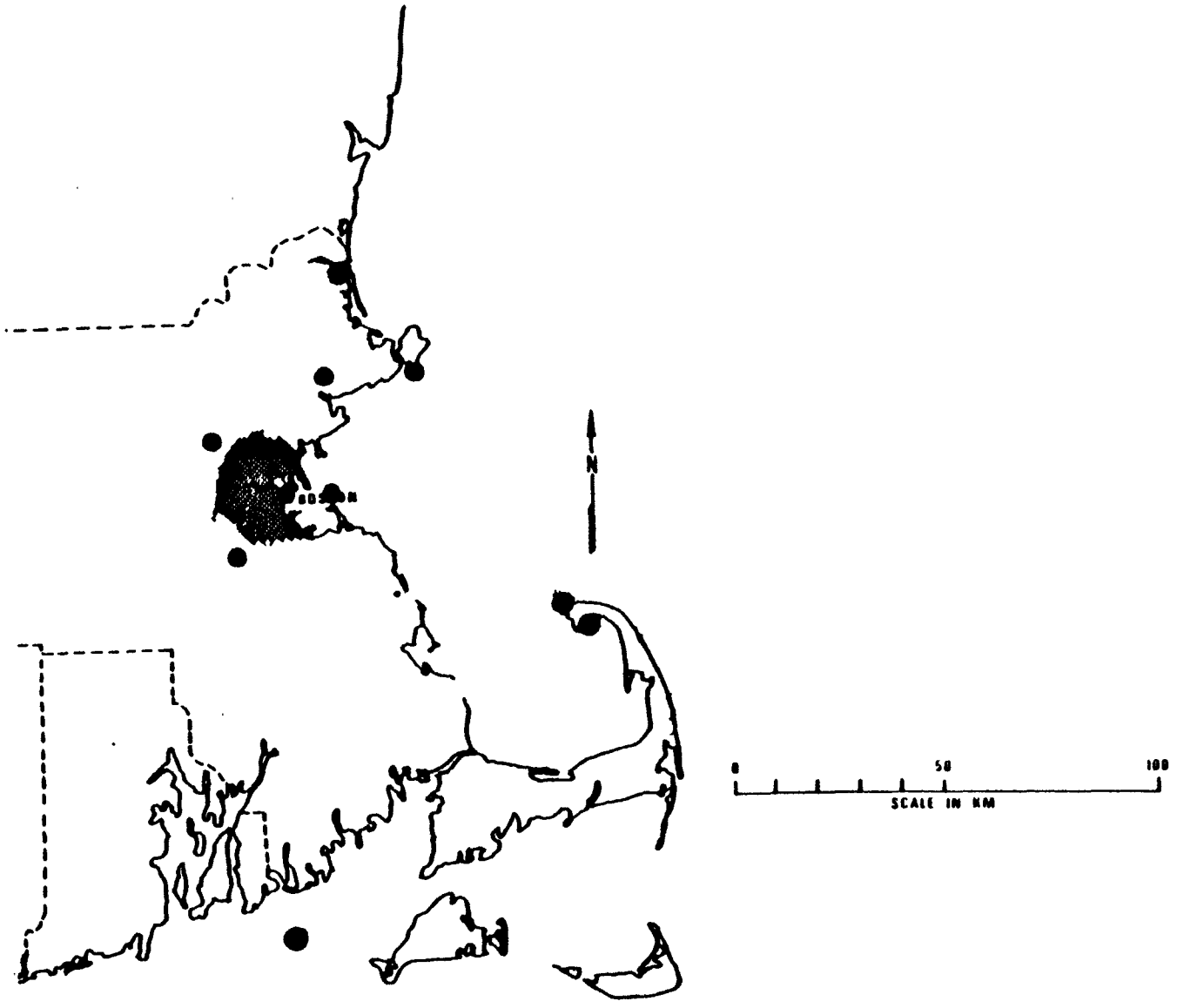

FIGURE 4. DISTRIBUTION OF WIND MONITORING STATIONS FOR BOSTON PLUME STUDY.

For purposes of data analysis, the continuous aircraft data must be averaged over the same times as the bag collections to place all the results on a comparable basis. During the flights, records were kept of the bag collection times using the data system clock. After the continuous data were transferred from magnetic tape to disc and converted to concentration units, averages were computed for each compound over the bag collection times.

The results of the aircraft flights, including bag sample analyses and continuous data averaged over the bag collection times, are listed in Table 10. The symbol "NO_x+" refers to the sum of the NO_x and HNO_3 values. The tabulated flight and bag numbers are keyed to the flight maps in Appendix B. Missing data are listed in the table as -1.0. Nearly all of the bag samples were analyzed within one hour of collection. Storage of PAN in the darkened bags was found to be excellent, in agreement with the results of Lonneman et al.[9].

The results of the aircraft filter sample analyses are shown in Table 11. The filter data are keyed to the flight maps in Appendix B by a flight and filter number. In order to collect enough material for accurate analyses, aircraft filters were collected during multiple passes through the plume. All filters samples were collected over at least 25 minutes, and many for much longer, at a nominal flow rate of 0.3 m^3/min (11 cfm).

TABLE 10. AIRCRAFT SAMPLING RESULTS (KEYED TO DATE, FLIGHT NO. AND BAG SAMPLE NO.)

80978

F0381

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
-.100E-02	.770E-01	.850E-02	.950E-02	.100E-02	.800E+04	.500E+03
PAN	F.11	NMHC	CH4	CO		
.004	432.4	≤0.2	1.8	.41		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
-1.00	2.06	5.31	3.54	2.43	5.54	-1.00	3.47	-1.00

F0382

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
-.100E-02	.590E-01	.280E-01	.320E-01	.400E-02	.160E+04	-.100E-02
PAN	F.11	NMHC	CH4	CO		
.002	197.2	≤0.2	1.8	.42		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
-1.00	3.79	6.92	5.56	3.55	7.36	-1.00	6.26	-1.00

F0383

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
-.100E-02	.800E-01	.500E-02	.600E-02	.100E-02	.600E+04	-.100E-02
PAN	F.11	NMHC	CH4	CO		
.003	196.2	≤0.2	1.8	.36		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
-1.00	3.99	6.67	3.74	3.29	5.63	-1.00	3.93	-1.00

80978

F0481

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.254E+02	.111E+00	.629E-02	.819E-02	.190E-02	.611E+05	.126E+04
PAN	F.11	NMHC	CH4	CO		
.002	182.1	.5	1.8	.32		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
-1.00	1.90	4.96	4.24	4.37	9.87	-1.00	8.81	-1.00

F0482

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.260E+02	.105E+00	.500E-02	.673E-02	.173E-02	.482E+05	.129E+04
PAN	F.11	NMHC	CH4	CO		
.005	170.4	≤0.2	1.8	.29		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
-1.00	1.54	4.13	3.41	2.62	5.09	-1.00	-1.00	-1.00

F0483

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.267E+02	.956E-01	.319E-02	.428E-02	.109E-02	.622E+05	.111E+04
PAN	F.11	NMHC	CH4	CO		
.005	228.7	≤0.2	1.8	.27		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
-1.00	1.92	3.66	3.01	2.68	3.86	-1.00	-1.00	-1.00

80978

F0581

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.269E+02	.123E+00	.652E-02	.820E-02	.168E-02	.978E+04	.112E+04
PAN	F.11	NMHC	CH4	CO		
.005	170.2	≤0.2	-.1	-.01		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
-1.00	1.70	4.23	4.41	2.98	5.62	-1.00	4.22	-1.00

F0582

(Table 10. Continued)

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   TEMP       OZONE       NOX       NOX+       HNO3        AN         ALT
 .265E+02  .121E+00  .979E-02  .112E-01  .137E-02  .826E+04  .137E+04
      PAN       F.11       NMHC       CH4        CO
    .003      171.1       ≤0.2       1.8       .39
 ETHANE    ETHYLENE   PROPANE   ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
   -1.00       1.71       4.06       4.74       3.05       6.63      -1.00       5.13     -1.00

 81078
F06B1
   TEMP       OZONE       NOX       NOX+       HNO3        AN         ALT
-.100E-02  .660E-01  .175E-01  .185E-01  .100E-02  .150E+05 -.100E-02
      PAN       F.11       NMHC       CH4        CO
   ≤0.001      218.8        .9       1.8       .38
 ETHANE    ETHYLENE   PROPANE   ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
   -1.00       3.31       4.60       6.16       3.98       9.22      -1.00      10.02     -1.00
F06B2
   TEMP       OZONE       NOX       NOX+       HNO3        AN         ALT
-.100E+01  .760E-01  .550E-02  .750E-02  .200E-02  .700E+04 -.100E+01
      PAN       F.11       NMHC       CH4        CO
   ≤0.001      502.1       ≤0.2       1.8       .28
 ETHANE    ETHYLENE   PROPANE   ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
   -1.00       1.94       4.53       3.70       4.15       7.47      -1.00       6.42     -1.00
F06B3
   TEMP       OZONE       NOX       NOX+       HNO3        AN         ALT
-.100E+01  .430E-01  .250E-02  .350E-02  .100E-02  .350E+04 -.100E+01
      PAN       F.11       NMHC       CH4        CO
   ≤0.001      170.6       ≤0.2       1.8       .13
 ETHANE    ETHYLENE   PROPANE   ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
   -1.00       2.27       2.35       1.14       1.48       1.17      -1.00      -1.00     -1.00

 81078
F07B1
   TEMP       OZONE       NOX       NOX+       HNO3        AN         ALT
 .309E+02  .521E-01  .393E-02  .373E-02  0.          .753E+05  .120E+04
      PAN       F.11       NMHC       CH4        CO
   ≤0.001      173.2       ≤0.2       1.8       .15
 ETHANE    ETHYLENE   PROPANE   ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
   -1.00        .73       2.21       1.51       1.63       2.20      -1.00      -1.00     -1.00
F07B2
   TEMP       OZONE       NOX       NOX+       HNO3        AN         ALT
 .307E+02  .666E-01  .413E-02  .396E-02  0.          .601E+05  .829E+03
      PAN       F.11       NMHC       CH4        CO
   ≤0.001      191.6       ≤0.2       1.8       .23
 ETHANE    ETHYLENE   PROPANE   ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
   -1.00        .97       3.06       2.96       2.23       3.27      -1.00      -1.00     -1.00
F07B3
   TEMP       OZONE       NOX       NOX+       HNO3        AN         ALT
 .310E+02  .905E-01  .461E-02  .544E-02  .828E-03  .719E+05  .863E+03
      PAN       F.11       NMHC       CH4        CO
   ≤0.001      172.6        .3       1.8       .24
 ETHANE    ETHYLENE   PROPANE   ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
   -1.00       1.30       3.44       3.35       2.46       4.23      -1.00      -1.00     -1.00

 81178
F08B1
   TEMP       OZONE       NOX       NOX+       HNO3        AN         ALT
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(Table 10. Continued)

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 .196E+02  .497E-01  .287E-02  .362E-02  .754E-03  .931E+04  .134E+04
      PAN      F.11      NMHC       CH4        CO
     .002     146.8      ≤0.2       1.7       .20
 ETHANE   ETHYLENE   PROPANE  ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
   2.43       1.74      1.75       1.93      1.95      1.69     -1.00     -1.00     -1.00
F0882
  TEMP       OZONE       NOX       NOX+      HNO3        AN       ALT
 .195E+02  .319E-01  .374E-01  .411E-01  .366E-02  .569E+04  .112E+04
      PAN      F.11      NMHC       CH4        CO
     .002     316.8      ≤0.2       1.9       .75
 ETHANE   ETHYLENE   PROPANE  ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
   5.15       9.81      5.41      13.49      7.54     18.42      2.77     21.03     11.16
F0883
  TEMP       OZONE       NOX       NOX+      HNO3        AN       ALT
 .210E+02  .694E-01  .245E-02  .327E-02  .811E-03  .546E+04  .990E+03
      PAN      F.11      NMHC       CH4        CO
   ≤0.001     182.7      ≤0.2       1.7       .33
 ETHANE   ETHYLENE   PROPANE  ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
   2.14       1.03      2.33       1.99      2.63      2.53     -1.00     -1.00     -1.00

5 81178
F0981
  TEMP       OZONE       NOX       NOX+      HNO3        AN       ALT
 .204E+02  .705E-01  .300E-02  .497E-02  .197E-02  .466E+05  .133E+04
      PAN      F.11      NMHC       CH4        CO
     .003     152.6      ≤0.2       1.8       .19
 ETHANE   ETHYLENE   PROPANE  ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
   2.24       1.30      2.36       2.31      2.29      2.88     -1.00     -1.00     -1.00
F0982
  TEMP       OZONE       NOX       NOX+      HNO3        AN       ALT
 .223E+02  .344E-01  .248E-01  .266E-01  .201E-02  .811E+05  .122E+04
      PAN      F.11      NMHC       CH4        CO
   ≤0.001     225.9      ≤0.2       1.8       .40
 ETHANE   ETHYLENE   PROPANE  ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
   3.94       5.27      3.18       7.60      5.31     12.22       .99     13.05      4.21
F0983
  TEMP       OZONE       NOX       NOX+      HNO3        AN       ALT
 .225E+02  .726E-01  .355E-01  .398E-01  .432E-02  .872E+05  .119E+04
      PAN      F.11      NMHC       CH4        CO
     .003     338.3        .5       2.0       .80
 ETHANE   ETHYLENE   PROPANE  ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
   6.04      10.66      7.05      17.25     12.66     29.35      2.00     30.91     16.26
F0984
  TEMP       OZONE       NOX       NOX+      HNO3        AN       ALT
 .221E+02  .851E-01  .227E-01  .268E-01  .405E-02  .101E+06  .135E+04
      PAN      F.11      NMHC       CH4        CO
   ≤0.001     224.3      ≤0.2       1.9       .67
 ETHANE   ETHYLENE   PROPANE  ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
   4.98       7.04      4.54      11.23      6.35     16.73     -1.00     17.67      8.94
F0985
  TEMP       OZONE       NOX       NOX+      HNO3        AN       ALT
 .206E+02  .591E-01  .150E-01  .168E-01  .174E-02  .940E+05  .106E+04
      PAN      F.11      NMHC       CH4        CO
     .004     220.7      ≤0.2       1.8       .33
 ETHANE   ETHYLENE   PROPANE  ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
  11.57       3.90      4.87       5.20      8.48     16.85     -1.00     16.31      7.23
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(Table 10. Continued)

81178

F1081

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.236E+02	.901E-01	.575E-02	.725E-02	.150E-02	.468E+05	.136E+04
PAN	F.11	NMHC	CH4	CO		
≤0.001	240.9	≤0.2	1.8	.26		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
3.01	1.24	2.36	4.03	2.35	4.77	-1.00	5.01	-1.00

F1082

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.233E+02	.806E-01	.531E-02	.741E-02	.211E-02	.504E+05	.163E+04
PAN	F.11	NMHC	CH4	CO		
≤0.001	197.1	≤0.2	1.7	.22		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
2.42	1.57	2.02	3.13	2.08	3.97	-1.00	-1.00	-1.00

F1083

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.174E+02	.960E-01	.120E-01	.140E-01	.204E-02	.892E+05	.298E+04
PAN	F.11	NMHC	CH4	CO		
≤0.001	249.7	.3	1.8	.39		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
3.45	3.29	3.70	6.53	4.94	10.04	-1.00	9.24	-1.00

81478

F1181

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.270E+02	.637E-01	.312E-02	.402E-02	.900E-03	.533E+05	.109E+04
PAN	F.11	NMHC	CH4	CO		
≤0.001	138.8	≤0.2	1.7	.26		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
-1.00	.57	1.86	1.22	1.14	1.41	-1.00	-1.00	-1.00

F1182

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.267E+02	.688E-01	.276E-02	.399E-02	.123E-02	.656E+05	.111E+04
PAN	F.11	NMHC	CH4	CO		
≤0.001	160.2	≤0.2	1.7	.29		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
15.43	.44	2.06	1.33	1.20	1.33	-1.00	-1.00	-1.00

F1183

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.252E+02	.616E-01	.372E-02	.625E-02	.253E-02	.715E+05	.128E+04
PAN	F.11	NMHC	CH4	CO		
.002	164.8	≤0.2	1.8	.35		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
-1.00	1.42	3.22	3.02	2.22	3.29	-1.00	-1.00	-1.00

81478

F1281

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.278E+02	.145E+00	.131E-01	.162E-01	.312E-02	.964E+05	.114E+04
PAN	F.11	NMHC	CH4	CO		
≤0.001	210.1	.3	1.8	.75		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
6.33	5.11	5.64	11.92	7.89	19.35	-1.00	19.49	9.40

F1282

(Table 10. Continued)

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.276E+02	.160E+00	.170E-01	.210E-01	.400E-02	.942E+05	.118E+04
PAN	F.11	NMHC	CH4	CO		
≤0.001	246.2	≤0.2	1.8	.67		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
6.21	5.09	6.12	11.78	8.81	20.59	-1.00	19.35	10.18

81478

F1381

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.287E+02	.189E+00	.694E-02	.960E-02	.266E-02	.816E+05	.114E+04
PAN	F.11	NMHC	CH4	CO		
≤0.001	238.4	≤0.2	1.8	.58		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
5.39	2.26	3.77	7.58	5.00	11.04	-1.00	10.22	-1.00

F1382

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.281E+02	.153E+00	.600E-02	.700E-02	.100E-02	.453E+05	.122E+04
PAN	F.11	NMHC	CH4	CO		
≤0.001	183.2	≤0.2	1.8	.57		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
4.82	1.44	3.86	5.81	4.22	8.95	-1.00	7.17	-1.00

81578

F1481

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.238E+02	.467E-01	.155E-02	.264E-02	.109E-02	.616E+05	.111E+04
PAN	F.11	NMHC	CH4	CO		
≤0.001	143.7	.4	1.3	.17		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
2.04	.46	1.36	.92	-1.00	1.20	-1.00	-1.00	-1.00

F1482

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.242E+02	.354E-01	.176E-01	.191E-01	.158E-02	.830E+05	.988E+03
PAN	F.11	NMHC	CH4	CO		
.003	238.0	.2	1.9	.55		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
4.85	7.60	7.77	9.77	15.31	36.03	2.95	32.29	16.86

81578

F1581

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.241E+02	.352E-01	.366E-01	.403E-01	.367E-02	.949E+05	.135E+04
PAN	F.11	NMHC	CH4	CO		
.003	304.3	.2	1.9	.73		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
4.48	9.33	6.63	11.66	7.96	16.48	2.73	19.05	9.83

F1582

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.247E+02	.592E-01	.152E-01	.284E-01	.132E-01	.733E+05	.125E+04
PAN	F.11	NMHC	CH4	CO		
.005	214.1	.5	1.8	.57		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
4.61	7.72	5.62	9.74	5.69	13.09	1.48	13.96	-1.00

F1583

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT

(Table 10. Continued)

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  .251E+02  .594E-01  .314E-01  .424E-01  .110E-01  .679E+05  .137E+04
       PAN       F.11      NMHC       CH4        CO
      .005      283.5        .3       1.8       .81
  ETHANE   ETHYLENE   PROPANE  ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
      7.10      10.95      7.83      14.09      8.12     19.55      2.52     22.60     11.54
F1584
   TEMP      OZONE       NOX      NOX+      HNO3        AN       ALT
  .262E+02  .727E-01  .632E-01  .787E-01  .155E-01  .728E+05  .114E+04
       PAN       F.11      NMHC       CH4        CO
      .004      542.9        .6       2.0      1.90
  ETHANE   ETHYLENE   PROPANE  ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
     13.03      23.96     14.06      33.77     21.51     53.77      6.39     56.45     31.86

  81578
F1681
   TEMP      OZONE       NOX      NOX+      HNO3        AN       ALT
 -.100E+01  .169E+00  .260E-01  .290E-01  .300E-02  .180E+05 -.100E+01
       PAN       F.11      NMHC       CH4        CO
      .001      335.5      ≤0.2       1.9       .88
  ETHANE   ETHYLENE   PROPANE  ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
      6.34      6.18      7.00      14.17      9.83     22.85     -1.00     23.19     11.00
F1682
   TEMP      OZONE       NOX      NOX+      HNO3        AN       ALT
 -.100E+01  .116E+00  .140E-01  .160E-01  .200E-02  .150E+05 -.100E+01
       PAN       F.11      NMHC       CH4        CO
    ≤0.001      182.4      ≤0.2       1.8       .43
  ETHANE   ETHYLENE   PROPANE  ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
      4.13      1.48      5.43      4.28      3.04      6.14     -1.00      5.80     -1.00
F1683
   TEMP      OZONE       NOX      NOX+      HNO3        AN       ALT
 -.100E+01  .117E+00  .140E-01  .160E-01  .200E-02  .140E+05 -.100E+01
       PAN       F.11      NMHC       CH4        CO
      .005      155.2        .3       1.8       .38
  ETHANE   ETHYLENE   PROPANE  ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
      3.76      1.16      3.58      3.88      2.63      4.74     -1.00      4.22     -1.00

  81578
F1781
   TEMP      OZONE       NOX      NOX+      HNO3        AN       ALT
  .279E+02  .115E+00  .528E-02  .795E-02  .268E-02  .891E+05  .140E+04
       PAN       F.11      NMHC       CH4        CO
      .003      208.7        .6       1.8       .40
  ETHANE   ETHYLENE   PROPANE  ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
      3.93      1.31      4.42      4.19      2.70      5.27     -1.00     -1.00     -1.00
F1782
   TEMP      OZONE       NOX      NOX+      HNO3        AN       ALT
  .258E+02  .970E-01  .974E-02  .132E-01  .350E-02  .915E+05  .132E+04
       PAN       F.11      NMHC       CH4        CO
      .003      173.2        .3       1.8       .32
  ETHANE   ETHYLENE   PROPANE  ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
      2.98      1.88      3.21      3.77      3.21      6.09     -1.00      4.67      -.00
F1783
   TEMP      OZONE       NOX      NOX+      HNO3        AN       ALT
  .266E+02  .123E+00  .420E-02  .731E-02  .311E-02  .568E+05  .177E+04
       PAN       F.11      NMHC       CH4        CO
      .005      148.7        .6       1.8       .38
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(Table 10. Continued)

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
3.76	1.16	3.58	3.88	2.69	4.74	-1.00	4.22	-1.00

81678
F1881

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
-.100E+01	.110E+00	.700E-02	.800E-02	.100E-02	.140E+05	-.100E+01
PAN	F.11	NMHC	CH4	CO		
.013	331.6	.4	-1.0	-1.00		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
3.38	2.22	3.03	4.64	3.71	7.14	-1.00	6.45	-1.00

F1882

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
-.100E+01	.105E+00	.600E-02	.750E-02	.150E-02	.140E+05	-.100E+01
PAN	F.11	NMHC	CH4	CO		
.017	191.4	.4	-1.0	-1.00		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
2.61	1.37	2.58	3.33	3.14	5.09	-1.00	4.63	-1.00

81778
F1981

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
-.100E+01	.115E+00	.450E-02	.650E-02	.200E-02	.130E+05	-.100E+01
PAN	F.11	NMHC	CH4	CO		
50.001	207.7	.4	-1.0	-1.00		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
4.72	1.85	4.79	4.66	4.08	7.67	-1.00	7.05	3.15

81878
F2081

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.207E+02	.163E-01	.270E-01	.300E-01	.300E-02	.474E+05	.119E+04
PAN	F.11	NMHC	CH4	CO		
.002	251.4	.7	1.6	.54		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
6.96	7.30	4.11	8.67	5.45	11.64	2.12	14.44	6.69

F2082

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.209E+02	.266E-01	.212E-01	.229E-01	.168E-02	.765E+05	.130E+04
PAN	F.11	NMHC	CH4	CO		
.008	215.2	.7	1.6	.45		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
4.94	5.32	3.06	6.83	3.63	7.25	1.36	9.30	4.17

F2083

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.202E+02	.124E-01	.367E-01	.279E-01	0.	.866E+05	.153E+04
PAN	F.11	NMHC	CH4	CO		
50.001	234.7	.5	1.7	.43		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00

F2084

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.214E+02	.263E-01	.136E-02	.287E-02	.151E-02	.355E+05	.134E+04
PAN	F.11	NMHC	CH4	CO		
.003	277.4	.6	1.5	.24		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE

(Table 10. Continued)

2.66	.73	2.10	1.58	1.34	1.77	-1.00	1.64	-1.00

81878
F2181

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.221E+02	.562E-01	.972E-02	.121E-01	.242E-02	.876E+05	.111E+04
PAN	F.11	NMHC	CH4	CO		
.002	187.5	.7	1.5	.42		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
33.99	8.88	2.71	5.34	3.29	6.24	-1.00	7.76	3.61

F2182

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.228E+02	.683E-01	.747E-02	.106E-01	.311E-02	.857E+05	.947E+03
PAN	F.11	NMHC	CH4	CO		
.002	234.7	.9	1.5	.71		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
3.62	3.11	3.94	6.06	5.57	10.10	-1.00	10.34	5.01

F2183

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.221E+02	.764E-01	.847E-02	.207E-01	.122E-01	.886E+05	.135E+04
PAN	F.11	NMHC	CH4	CO		
.002	139.6	.6	1.5	.45		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
4.25	3.10	2.86	5.33	3.02	6.48	-1.00	7.43	2.98

81878
F2281

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.240E+02	.125E+00	.494E-02	.830E-02	.336E-02	.639E+05	.107E+04
PAN	F.11	NMHC	CH4	CO		
.009	194.9	1.1	1.1	.39		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
3.82	1.27	2.45	5.00	3.03	5.87	-1.00	5.23	2.35

F2282

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.238E+02	.129E+00	.597E-02	.841E-02	.244E-02	.731E+05	.110E+04
PAN	F.11	NMHC	CH4	CO		
.013	235.7	1.0	1.1	.40		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
3.90	1.35	2.60	5.25	3.40	5.97	-1.00	4.89	2.28

F2283

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
-.100E+01	.950E-01	.500E-02	.700E-02	.200E-02	.100E+05	-.100E+01
PAN	F.11	NMHC	CH4	CO		
.005	296.8	1.3	1.0	.36		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
3.14	1.05	2.39	3.67	2.81	5.08	-1.00	4.50	2.04

81978
F2381

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.198E+02	.393E-01	.561E-02	.675E-02	.115E-02	.488E+05	.121E+04
PAN	F.11	NMHC	CH4	CO		
≤0.001	159.1	≤0.2	1.9	.32		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
2.54	2.08	1.84	3.05	2.27	3.70	-1.00	4.46	1.97

(Table 10. Continued)

F23B2

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.220E+02	.298E-01	.252E-01	.238E-01	0.	.909E+05	.117E+04
PAN	F.11	NMHC	CH4	CO		
≤0.001	404.8	≤0.2	1.9	.49		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
4.06	4.51	4.70	6.68	7.58	14.81	1.55	15.34	8.02

F23B3

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.214E+02	.448E-01	.186E-02	.273E-02	.869E-03	.358E+05	.107E+04
PAN	F.11	NMHC	CH4	CO		
≤0.001	136.9	≤0.2	1.9	.25		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
3.09	.93	1.43	1.50	1.29	1.45	-1.00	-1.00	-1.00

81978

F2481

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.246E+02	.680E-01	.242E-02	.537E-02	.294E-02	.369E+05	.118E+04
PAN	F.11	NMHC	CH4	CO		
≤0.001	220.5	≤0.2	1.9	.31		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
3.92	1.91	1.80	2.97	2.63	.37	-1.00	4.39	2.09

F2482

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.245E+02	.927E-01	.463E-02	.661E-02	.198E-02	.379E+05	.129E+04
PAN	F.11	NMHC	CH4	CO		
≤0.001	192.7	≤0.2	1.9	.38		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
3.90	2.80	2.40	4.33	3.19	5.58	-1.00	5.96	3.21

82178

F2581

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.171E+02	.104E-01	.519E-02	.593E-02	.744E-03	.134E+06	.948E+03
PAN	F.11	NMHC	CH4	CO		
≤0.001	128.7	≤0.2	2.0	.29		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
2.50	1.56	3.83	1.49	2.74	4.91	-1.00	3.94	1.65

F2582

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.176E+02	.919E-02	.198E-01	.153E-01	0.	.134E+06	.967E+03
PAN	F.11	NMHC	CH4	CO		
≤0.001	194.1	≤0.2	2.1	.50		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
2.42	3.04	1.76	3.69	2.94	5.66	.90	6.33	2.61

F2583

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.175E+02	.847E-02	.281E-01	.206E-01	0.	.130E+06	.109E+04
PAN	F.11	NMHC	CH4	CO		
≤0.001	206.8	≤0.2	2.1	.51		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
3.73	5.60	3.19	6.39	4.03	8.15	1.76	8.62	5.14

82178

F2681

(Table 10. Continued)

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.219E+02	.735E-01	.656E-02	.927E-02	.271E-02	.127E+06	.110E+04
PAN	F.11	NMHC	CH4	CO		
≤0.001	169.4	≤0.2	-.1	-.01		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00

F26B2

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
-.100E+01	.700E-01	.110E-01	.135E-01	.250E-02	.190E+05	-.100E+01
PAN	F.11	NMHC	CH4	CO		
≤0.001	235.0	≤0.2	2.0	.48		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
3.82	3.76	2.94	4.54	3.94	7.56	.37	7.91	3.89

F26B3

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
-.100E+01	.480E-01	.215E-01	.245E-01	.300E-02	.220E+05	-.100E+01
PAN	F.11	NMHC	CH4	CO		
≤0.001	173.9	≤0.2	-.1	-.01		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00

F26B4

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
-.100E+01	.450E-01	.240E-01	.260E-01	.200E-02	.310E+05	-.100E+01
PAN	F.11	NMHC	CH4	CO		
≤0.001	208.1	≤0.2	2.0	.64		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
4.15	5.98	4.21	7.53	9.18	19.46	1.85	21.95	11.43

82278

F27B1

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
-.100E+01	.940E-01	.650E-02	.900E-02	.250E-02	.110E+05	-.100E+01
PAN	F.11	NMHC	CH4	CO		
≤0.001	195.5	≤0.2	1.9	.53		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
2.71	1.97	2.77	4.31	3.90	7.53	-1.00	6.88	2.94

F27B2

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
-.100E+01	.960E-01	.120E-01	.135E-01	.150E-02	.600E+04	-.100E+01
PAN	F.11	NMHC	CH4	CO		
≤0.001	218.7	≤0.2	1.9	.58		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
3.15	2.96	3.47	6.19	3.70	7.39	-1.00	7.97	1.51

F27B3

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
-.100E+01	.920E-01	.650E-02	.850E-02	.200E-02	.120E+05	-.100E+01
PAN	F.11	NMHC	CH4	CO		
≤0.001	170.6	≤0.2	1.9	.40		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
1.97	1.46	1.64	2.95	2.51	3.59	-1.00	3.44	1.47

82278

F26B1

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
-.100E+01	.120E-01	-.100E+01	-.100E+01	-.100E+01	.650E+05	-.100E+01
PAN	F.11	NMHC	CH4	CO		

(Table 10. Continued)

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    ≤0.001       -1.0       ≤0.2        1.8        .36
  ETHANE   ETHYLENE   PROPANE  ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
    -1.00      -1.00     -1.00      -1.00     -1.00     -1.00      -1.00      -1.00     -1.00

  82378
F2981
   TEMP       OZONE       NOX       NOX+       HNO3        AN         ALT
 -.100E+01  .250E-01  .100E-02  .100E-02  0.          .500E+04 -.100E+01
      PAN       F.11       NMHC        CH4        CO
    ≤0.001     377.5       ≤0.2        1.9       .31
  ETHANE   ETHYLENE   PROPANE  ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
     4.55       9.88      5.28        .66       .49       .74      -1.00      -1.00     -1.00
F2984
   TEMP       OZONE       NOX       NOX+       HNO3        AN         ALT
 -.100E+01  .400E-01  .520E-01  .520E-01  0.          .800E+04  .150E+03
      PAN       F.11       NMHC        CH4        CO
      .004     425.2       ≤0.2        2.2      1.36
  ETHANE   ETHYLENE   PROPANE  ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
    11.00      17.23     12.13      23.65     18.49     41.16       5.06      45.28     25.12
F2985
   TEMP       OZONE       NOX       NOX+       HNO3        AN         ALT
 -.100E+01  .280E-01  .700E-01  .700E-01  0.          .160E+05  .100E+03
      PAN       F.11       NMHC        CH4        CO
      .001     614.5       ≤0.2        2.2      1.60
  ETHANE   ETHYLENE   PROPANE  ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
    10.17      20.54      7.48       27.2     15.29     29.71       6.08      38.76     23.51

  82378
F3081
   TEMP       OZONE       NOX       NOX+       HNO3        AN         ALT
 -.100E+01  .630E-01  .570E-01  .590E-01  .200E-02  .200E+05  .150E+03
      PAN       F.11       NMHC        CH4        CO
    ≤0.001     399.5       ≤0.2        2.1      1.29
  ETHANE   ETHYLENE   PROPANE  ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
     7.92      15.24      8.02      23.46     17.32     32.62       5.48      37.34     18.97
F3082
   TEMP       OZONE       NOX       NOX+       HNO3        AN         ALT
 -.100E+01  .950E-01  .420E-01  .420E-01  0.          .600E+04  .500E+02
      PAN       F.11       NMHC        CH4        CO
    ≤0.001     321.4       ≤0.2        2.2      1.24
  ETHANE   ETHYLENE   PROPANE  ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
     7.56      12.87      7.14      21.00     13.35     29.06       2.91      33.46     19.22

  82378
F3181
   TEMP       OZONE       NOX       NOX+       HNO3        AN         ALT
  .286E+02  .134E+00  .177E-01  .214E-01  .362E-02  .770E+05  .500E+03
      PAN       F.11       NMHC        CH4        CO
    ≤0.001     224.0         .2        2.0       .84
  ETHANE   ETHYLENE   PROPANE  ACETYLENE ISOBUTANE N-BUTANE  PROPYLENE ISOPENTANE N-PENTANE
     4.26       5.57      5.06      11.61      6.65     14.46      -1.00      16.21      7.72
F3182
   TEMP       OZONE       NOX       NOX+       HNO3        AN         ALT
  .300E+02  .144E+00  .189E-01  .230E-01  .411E-02  .781E+05  .500E+03
      PAN       F.11       NMHC        CH4        CO
    ≤0.001     215.3       ≤0.2        2.0       .87
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(Table 10. Continued)

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
4.79	5.56	5.12	12.73	7.43	16.05	-1.00	-1.00	0.60

F3183

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.304E+02	.137E+00	.100E-01	.136E-01	.362E-02	.820E+05	.500E+03

PAN	F.11	NMHC	CH4	CO
≤0.001	-1.0	≤0.2	2.0	.62

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
3.64	2.69	3.79	7.96	5.69	11.77	-1.00	11.74	5.30

F3184

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.330E+02	.117E+00	.194E-01	.251E-01	.567E-02	.724E+05	.500E+03

PAN	F.11	NMHC	CH4	CO
.002	242.3	≤0.2	1.9	.61

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
3.86	4.91	3.82	7.85	4.96	10.96	.39	14.62	5.82

82378

F3281

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.240E+02	.108E+00	.590E-02	.780E-02	.191E-02	.810E+05	.116E+04

PAN	F.11	NMHC	CH4	CO
≤0.001	233.2	≤0.2	1.9	.44

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
2.65	1.03	3.28	4.01	2.51	5.47	-1.00	4.51	-1.00

F3282

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.269E+02	.104E+00	.346E-02	.659E-02	.313E-02	.726E+05	.661E+03

PAN	F.11	NMHC	CH4	CO
.002	180.8	≤0.2	1.9	.47

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
2.42	.83	2.97	3.80	2.45	5.29	-1.00	4.39	2.56

F3283

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.254E+02	.154E+00	.587E-02	.950E-02	.363E+02	.924E+05	.807E+03

PAN	F.11	NMHC	CH4	CO
.002	176.0	≤0.2	1.9	.57

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
3.10	1.72	3.01	5.83	3.36	6.64	-1.00	6.56	3.04

82778

F3581

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.173E+02	.243E-01	.172E-01	.145E-01	0.	.103E+06	.111E+04

PAN	F.11	NMHC	CH4	CO
.005	217.6	≤0.2	2.1	.46

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
3.42	2.85	3.15	3.97	3.91	10.87	1.70	10.47	5.37

82778

F3681

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.200E+02	.471E-01	.249E-02	.261E-02	.116E-03	.121E+06	.107E+04

PAN	F.11	NMHC	CH4	CO
≤0.001	169.0	≤0.2	2.1	.41

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE

(Table 10. Continued)

2.02	1.17	1.12	1.68	.86	2.49	-1.00	.53	-1.00

F3682

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.183E+02	.290E-01	.223E-02	.222E-02	0.	.121E+06	.995E+03

PAN	F.11	NMHC	CH4	CO
≤0.001	153.4	≤0.2	2.1	.36

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
1.99	.74	1.19	1.21	.83	1.93	-1.00	-1.00	-1.00

83078

F3781

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.232E+02	.228E-01	.278E-01	.268E-01	0.	.104E+06	.756E+03

PAN	F.11	NMHC	CH4	CO
≤0.001	189.9	≤0.2	2.3	.90

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
4.16	6.54	3.49	12.05	3.94	10.26	2.16	11.86	5.32

F3782

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.218E+02	.197E-01	.398E-01	.441E-01	.435E-02	.105E+06	.946E+03

PAN	F.11	NMHC	CH4	CO
≤0.001	250.3	≤0.2	2.2	.93

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
4.52	7.37	3.38	11.98	42.95	11.20	2.74	13.85	6.33

F3783

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.272E+02	.197E-01	.414E-01	.494E-01	.798E-02	.947E+05	.500E+03

PAN	F.11	NMHC	CH4	CO
.001	312.7	≤0.2	2.4	1.26

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
6.62	11.04	5.54	20.65	8.03	18.69	3.71	23.30	13.59

F3784

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.166E+02	.362E-01	.366E-03	.407E-03	.412E-04	.891E+05	.294E+04

PAN	F.11	NMHC	CH4	CO
≤0.001	128.7	≤0.2	2.2	.33

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
1.43	.30	.68	.41	-1.00	1.49	-1.00	-1.00	-1.00

83078

F3881

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.228E+02	.501E-01	.219E-01	.246E-01	.277E-02	.121E+06	.769E+03

PAN	F.11	NMHC	CH4	CO
.005	184.0	≤0.2	2.2	.72

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
3.56	4.44	3.09	8.75	4.30	10.42	1.37	10.43	4.44

F3882

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.274E+02	.634E-01	.105E-01	.165E-01	.596E-02	.125E+06	.500E+03

PAN	F.11	NMHC	CH4	CO
.006	220.1	≤0.2	2.3	.84

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
5.26	8.03	5.15	14.05	6.62	16.83	1.35	17.32	8.44

83078

(Table 10. Continued)

F3981

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.292E+02	.862E-01	.118E-01	.141E-01	.235E-02	.106E+06	.500E+03
PAN	F.11	NMHC	CH4	CO		
.008	159.0	≤0.2	2.2	.63		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
3.19	2.96	2.34	6.26	2.52	7.21	-1.00	2.25	-1.00

F3982

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.289E+02	.846E-01	.132E-01	.145E-01	.131E-02	.112E+06	.500E+03
PAN	F.11	NMHC	CH4	CO		
.004	247.4	≤0.2	2.2	.63		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
3.22	2.50	2.70	6.55	2.99	7.38	-1.00	6.89	2.86

F3983

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.279E+02	.919E-01	.134E-01	.151E-01	.171E-02	.110E+06	.500E+03
PAN	F.11	NMHC	CH4	CO		
.005	166.0	≤0.2	2.3	.71		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
3.97	2.28	3.08	7.73	2.93	7.60	-1.00	7.76	3.19

F3984

TEMP	OZONE	NOX	NOX+	HNO3	AN	ALT
.252E+02	.101E+00	.126E-01	.152E-01	.261E-02	.104E+06	.500E+03
PAN	F.11	NMHC	CH4	CO		
≤0.001	-1.0	≤0.2	0.0	0.00		

ETHANE	ETHYLENE	PROPANE	ACETYLENE	ISOBUTANE	N-BUTANE	PROPYLENE	ISOPENTANE	N-PENTANE
-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00

TABLE 11. RESULTS OF AIRCRAFT FILTER COLLECTIONS ON HIGH PURITY QUARTZ

Date	Flight	Volume Sampled, (m^3)	NO_3^-, ($\mu g/m^3$)	$SO_4^=$, ($\mu g/m^3$)
8-9-78	3	20.6	<0.2	14.0
8-9-78	4	15.0	<0.3	15.4
8-9-78	5	19.3	<0.3	18.6
8-10-78	6	15.3	0.5	9.5
8-10-78	7	9.0	2.6	10.6
8-11-78	8	8.4	3.3	6.9
8-11-78	9	10.3	2.4	5.2
8-11-78	10	12.2	3.8	8.7
8-14-78	11	15.6	<0.3	16.0
8-14-78	12	14.3	1.5	21.1
8-14-78	13	18.1	0.3	11.4
8-15-78	14	8.1	2.1	6.2
8-15-78	15	13.4	0.7	8.2
8-15-78	16	17.8	<0.3	9.0
8-15-78	17	25.5	<0.2	10.0
8-16-78	18	7.2	1.1	19.6
8-17-78	19	9.0	<0.6	16.2
8-18-78	20	19.6	<0.3	4.8
8-18-78	21	21.2	0.5	3.7
8-18-78	22	27.1	0.2	4.8
8-19-78	23	8.4	<0.6	2.7
8-19-78	24	15.9	<0.3	1.6
8-21-78	25	10.6	<0.5	2.2
8-21-78	26	15.6	<0.3	3.2
8-22-78	27	23.4	<0.2	2.8
8-23-78	29	20.6	0.2	2.4
8-23-78	30	17.1	0.6	3.7
8-23-78	31	23.4	0.7	4.3
8-23-78	32	19.6	<0.3	4.6
8-24-78	33	24.3	<0.2	22.4
8-24-78	34	38.6	<0.1	29.5
8-27-78	35	7.8	<0.6	1.0
8-27-78	36	15.0	<0.3	<0.3
8-30-78	37	16.8	<0.3	4.0
8-30-78	38	19.6	<0.3	7.2
8-30-78	39	18.7	<0.3	5.4

SECTION 6

ANALYSIS AND INTERPRETATION

Analysis of the Boston plume study data has as its objectives a better definition of the distribution and balance of nitrogen species in urban polluted air, and an estimation of the rate of conversion of nitrogen oxides to reaction products. In the following discussion, the ground level air quality and aerosol compositional data will be reviewed first. The rationale for the airborne measurements will then be outlined, followed by discussions of individual experiments on a case study basis.

ANALYSIS OF GROUND STATION RESULTS

Air Quality Data

The air quality data for individual study days are tabulated in Appendix A and summarized in Tables 5-7. To gain a feeling for the general northeastern Massachusetts air quality during the study, composite profiles of selected variables monitored at the mobile laboratory in Beverly are plotted in Figure 5. The figure shows that O_3 peaked during midafternoon at a composite average of 0.069 ppm. The NO_x profile tracks O_3 in an inverse manner. Such negative correlation has been observed in previous studies. The behavior of NO and NO_2 during O_3 formation and transport is complex. The sign of the correlation between O_3 and NO_x can be either positive or negative, depending on site location, proximity of the dominant NO_x source, and meteorological conditions.

Continuous chemiluminescence measurements of gaseous nitric acid at the ground station yielded a composite profile which was always below the 0.002 ppm detection limit. Integrated measurements of $HONO_2$ will be discussed shortly.

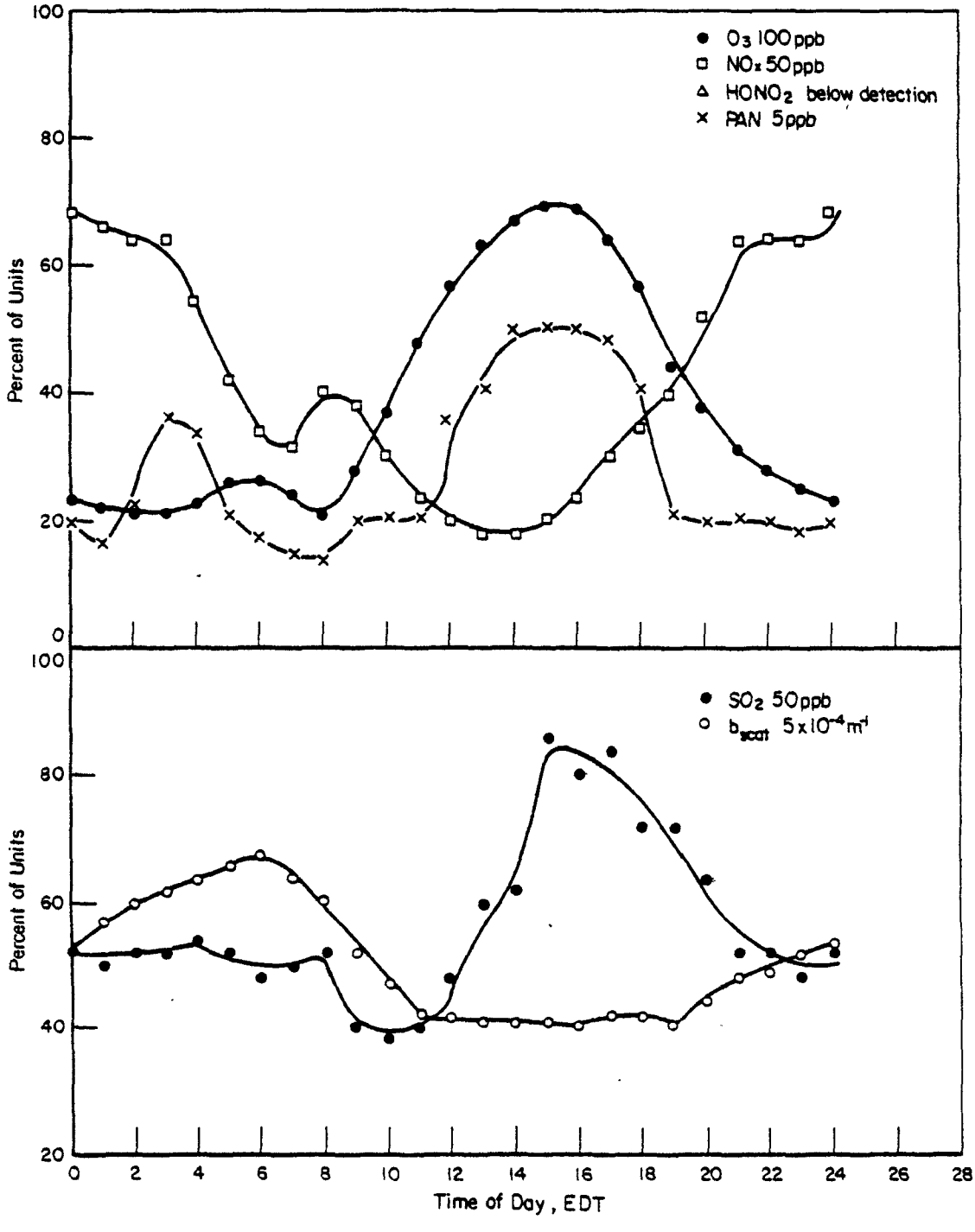

FIGURE 5. COMPOSITE PROFILES OF SELECTED POLLUTANTS AT BEVERLY, MASS.

The composite profile for PAN is included in Figure 5. The composite maximum hourly average PAN concentration reached a peak between 1400-1600 EDT, simultaneously with the O_3 maximum. PAN also showed a peak at 0300 EDT, due to a pollutant transport episode on one of the study days. This episode will be described in more detail in the next paragraphs.

The day to day trends in pollutant concentrations are presented in Figure 6. The nitric acid data were obtained from integrated filter collections. Judging from the trends in Figure 6, neither NO_x nor particulate nitrate are correlated very well on a day to day basis with O_3, $HONO_2$ or PAN. On the other hand, the plots of O_3, $HONO_2$, and PAN track one another reasonably closely. High correlations among these three species have been observed in previous studies. Due to the nature of the smog formation process, it is expected that elevated levels of PAN and $HONO_2$ will accompany high ozone concentrations. At Beverly Airport, this occurred on August 9, 15, 16, 17, and 18. The wind on many of these days was from the southwest quadrant, carrying contaminated Boston air to the ground station in Beverly. Indeed, the peak in ozone and PAN on August 15/16 occurred between 0400-0600 EDT, representing a clean case of transport of polluted air. The extent to which sources upwind of Boston contributed to this transported polluted air cannot be determined from our data. The concentrations of O_3 and PAN, and the light scattering coefficient for this episode are plotted in Figure 7, starting at 1800 EDT on 15 August. The nighttime peaks of O_3, PAN and light scattering aerosol are shown clearly. Higher O_3 and PAN occurred during the afternoon of 16 August, but these increases were not accompanied by changes in b_{scat}.

Returning briefly to Figure 6, it is clear from the PAN, $HONO_2$ and particulate nitrate data that on most days the gas phase dominates atmospheric nitrates. We have observed high ratios of $\frac{\text{gas phase nitrate}}{\text{total nitrate}}$ within and downwind of several urban areas. It now seems likely that the gas phase dominates atmospheric nitrates in most locations in the troposphere. The distribution of nitrogen species at the Beverly ground station will be discussed shortly.

Aerosol Composition

The average particulate mass loading at Beverly, Massachusettes was 32.9 $\mu g/m^3$ as determined by high volume sampling on quartz filters. This very low value is the result of extensive periods of rain during the study, light photochemical smog intensity, and frequent incursions of marine air inland to the Beverly Airport site. Referring to the compositional data in Table 8, carbon is found to make up about 16 percent of the total aerosol

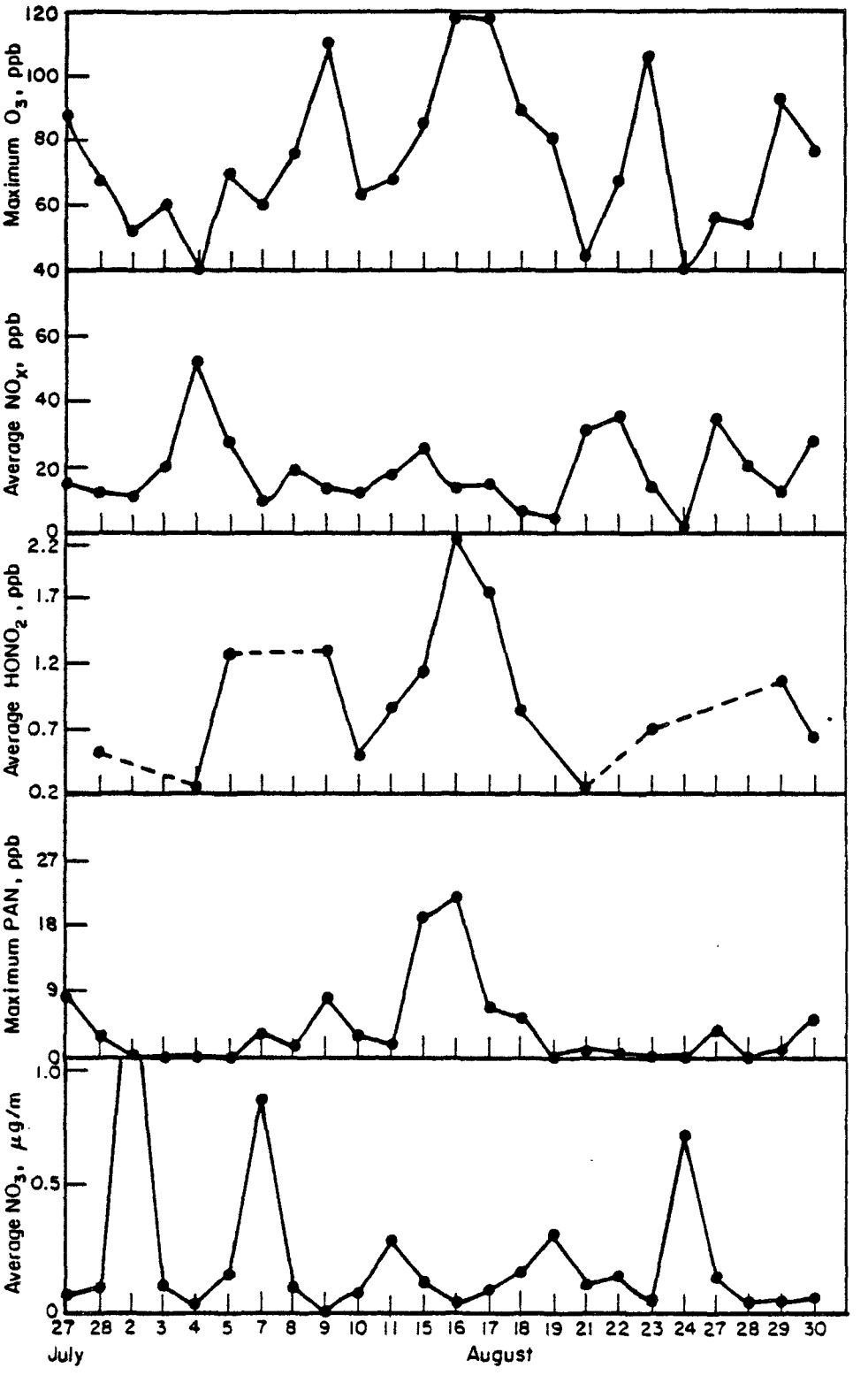

FIGURE 6. DAY-TO-DAY TRENDS IN SELECTED POLLUTANTS (Averages based on 24 hr sampling except as noted in Table 5)

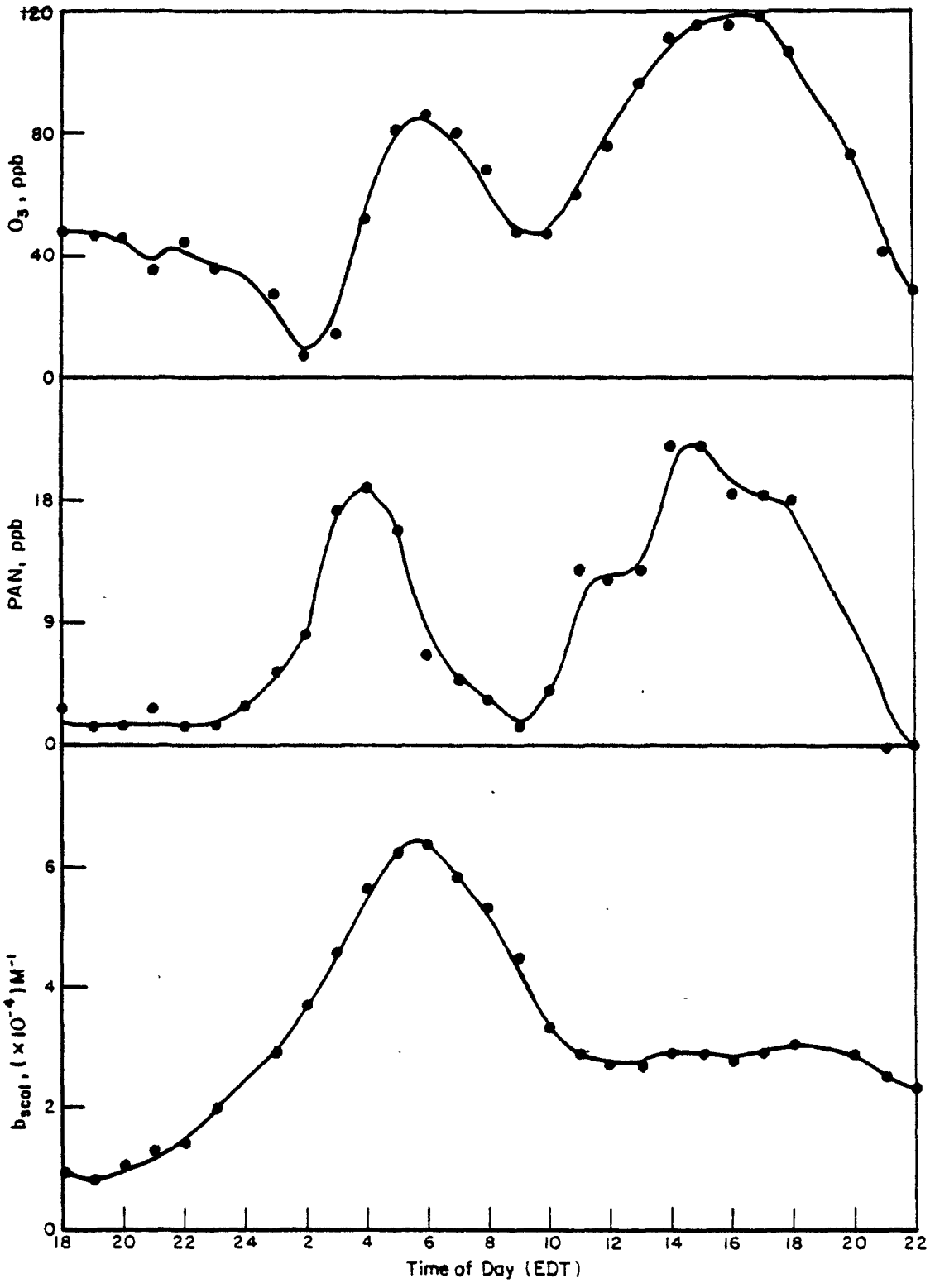

FIGURE 7. SELECTED POLLUTANTS ON AUGUST 15-16, 1978

mass, hydrogen about 5 percent and nitrogen about 5 percent. Sulfate totals 43 percent of the aerosol while nitrate accounts for less than 1 percent. The high percentage of sulfate resulted from the fumigation of the Beverly station by the plume from the Salem power plant, which was ∿5 km SSE of the site. On several days the plume impinged on the Beverly site, as noticed both visually and by the high levels of SO_2 and NO_x. On these days it is likely that a great deal of free sulfuric acid was present in the air and on the high volume filters. The volatilization and loss of particulate nitrate from the filters is likely on these days. However, even on days of very low sulfate, when nitrate loss should not occur, the particulate nitrate values are quite low.

We have observed such low particulate nitrate values at many locations around the country. Laboratory and field results[10,11] indicate that particulate nitrate concentrations are usually quite low; often between 0.5-1.0 $\mu g/m^3$, and that many of the earlier literature values are artifically high due to collection of gaseous nitric acid on the high volume filter. In Beverly, particulate nitrate averaged 0.27 $\mu g/m^3$, while gaseous nitric acid averaged 2.5 $\mu g/m^3$ for the 14 days for which data are available.

The concentrations and percentages of the various aerosol components can be compared with data collected in a similar manner at a number of other geographical locations in Table 12.

Nitrogen Distribution at the Ground Station

Based on the subset of 14 days when nitric acid was determined, the distribution of oxidized nitrogen* at Beverly Airport was:

$NO + NO_2$	18 ppb	(86%)
PAN	1.8 ppb	(9%)
$HONO_2$	1.0 ppb	(5%)
NO_3^-	0.04 ppb	(<1%)

* Excluding N_2O.

TABLE 12. AVERAGE* AEROSOL CONSTITUENTS AT VARIOUS LOCATIONS

Constituent	Beverly		Phoenix		West Covina		St. Louis		Dayton		Bethalto, Ill.		Upland, Calif.	
	μg/m³	W.P.[a]	μg/m³	W.P.[a]	μg/m³	W.P.[a]	μg/m³	W.P.[a]	μg/m³	W.P.[a]	μg/m³	W.P.[a]	μg/m³	W.P.[a]
Carbon	5.2	15.8	7.4	8.6	19.7	19.4	11.0	19	10.4	12	-	-	-	-
Hydrogen	1.6	4.9	0.9	1.0	3.8	3.8	1.8	3.6	2.2	2.5	-	-	-	-
Nitrogen	1.6	4.9	1.4	1.6	5.4	5.3	2.3	4.6	3.7	4.3	-	-	2.9	2.4
Nitrate	.27	0.8	1.2	1.4	1.7	1.7	0.4	0.6	0.3	0.4	0.4	0.6	1.5	1.2
Ammonium	1.1	3.3	0.8	0.9	4.7	4.7	2.7	4.7	4.0	4.6	3.9	6.1	3.1	2.5
Sulfate	14.1	42.8	4.3	5.0	-	-	-	-	20.2	23.3	14.4	22.6	11.7	9.6

(a) Weight percent

* Aerosol results averaged over 4 to 6 weeks of sampling

The percentage of total oxidized nitrogen accounted for by each species is shown in parenthesis. The sum of NO and NO_2 accounted for 86% of the oxidized N burden, PAN for 9%, nitric acid for 5% and particulate nitrate for less than 1%. The nitrogen distribution at Beverly is compared with data collected in a similar manner at several other sites in Table 13. The Beverly results are based on 24 hour a day sampling, whereas the data from the other sites represent 8 hour daylight averages. The fraction of oxidized nitrogen existing as reaction products (i.e. $Fn = \frac{PAN + HONO_2 + NO_3^-}{NO + NO_2 + PAN + HONO_2 + NO_3^-}$) at Beverly averaged 0.14.

One of the most significant changes in our perception of atmospheric nitrates concerns the distribution of nitrate between the gas and aerosol phases. Contrary to popular belief, gaseous nitrates (PAN + $HONO_2$) dominate the atmospheric nitrate burden in most areas. This is shown in Table 14, where the ratio of gaseous/total nitrate is tabulated for a number of locations. In all locations except Rubidoux, Calif., the ratio equals or exceeds 50 percent. Strong sources of NH_3 upwind of Rubidoux are responsible for the lower ratio there due to conversion of gaseous HNO_3 to NH_4NO_3. In most locations gaseous nitrate makes up over 80 percent of the total atmospheric nitrate. Because the health effects and other potentially important effects of nitrates likely depend on the physical state of the nitrates, this new view on the problem is important.

The fact that so much of the nitrate is the gas phase also explains the observation[12,13] that the $NO_3^-/SO_4^=$ ratio in precipitation samples exceeds that in aerosol collections. Much more nitrate is available for scavenging by precipitation than would be indicated by aerosol collection data, since the major fraction of the atmospheric nitrate is gaseous.

TABLE 13. OXIDIZED NITROGEN DISTRIBUTION AT SEVERAL LOCATIONS
(Percent of Total)

	Beverly, Mass. (1978)	St. Louis (1973)	West Covina (1973)	Phoenix (1977)	Temple City	Cable Airport	Rubidoux
NO	86	33	23	45	19	10	--
NO_2		45	57	51	78	66	78
PAN	9	9	13	2	3	22	10
$HONO_2$	5	12	6	--	--	--	--
NO_3^-	<1	1	0.5	2	1	1	12

TABLE 14. ATMOSPHERIC NITRATE DISTRIBUTION

Location	Gaseous/Total NO_3^-
St. Louis, Mo. (1973)	.95
West Covina, Calif. (1973)	.98
Phoenix, Ariz. (1977)	.50
Temple City, Calif. (1976)	.75
Upland, Calif. (1976)	.96
Rubidoux, Calif. (1976)	.45
Beverly, Mass. (1978)	.98
Remote troposphere (above boundary layer)	∿.80

ANALYSIS OF AIRCRAFT DATA

Rationale

The aims of this study are to determine the rate of NO_x* removal and the nitrogen balance in an urban plume. In order to accomplish these goals it is important that the urban plume not be subject to fresh emissions of NO_x and tracer gases once it leaves the city. For this reason the Boston plume was chosen for study.

Conceptually, as a polluted air parcel leaves the dense emission area of the city and moves downwind, several things can happen to the nitrogen oxides. First, NO_x and the other plume constituents will be diluted with the surrounding air, the rate depending on the meteorological stability. Secondly, NO_x can undergo transformations into reaction products. Finally, NO_x (primarily NO_2) can be removed by physical processes (dry deposition, wet scavenging). We are concerned principally with the two latter processes, the chemical and physical removal of NO_x from the plume, but the dilution process so dominates the changes in concentration of NO_x within the plume that it must be carefully accounted for in order to derive information on the slower processes. In the Boston study, we used three inert urban tracers, carbon monoxide, acetylene and fluorocarbon-11, to track dilution of the urban plume during downwind transport.

Referring to Figure 8 we note that the measured concentration (C_m) of a conserved species within the urban plume just as it leaves the city is equal to the sum of the background concentration (C_b) and the urban input (C_o). For a plume transported over areas with minimal sources, the measured concentration of the species as the plume moves downwind is given by

$$C_m = C_o e^{-kt} + C_b$$

where the concentration due to the city is diluted at some rate governed by k. As shown in Figure 8, at infinite dilution the measured concentration will equal the background concentration.

We can now restate the above equation for a conservative tracer and for the reactive species, NO_x.

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* Throughout this report NO_x is defined as $NO + NO_2$.

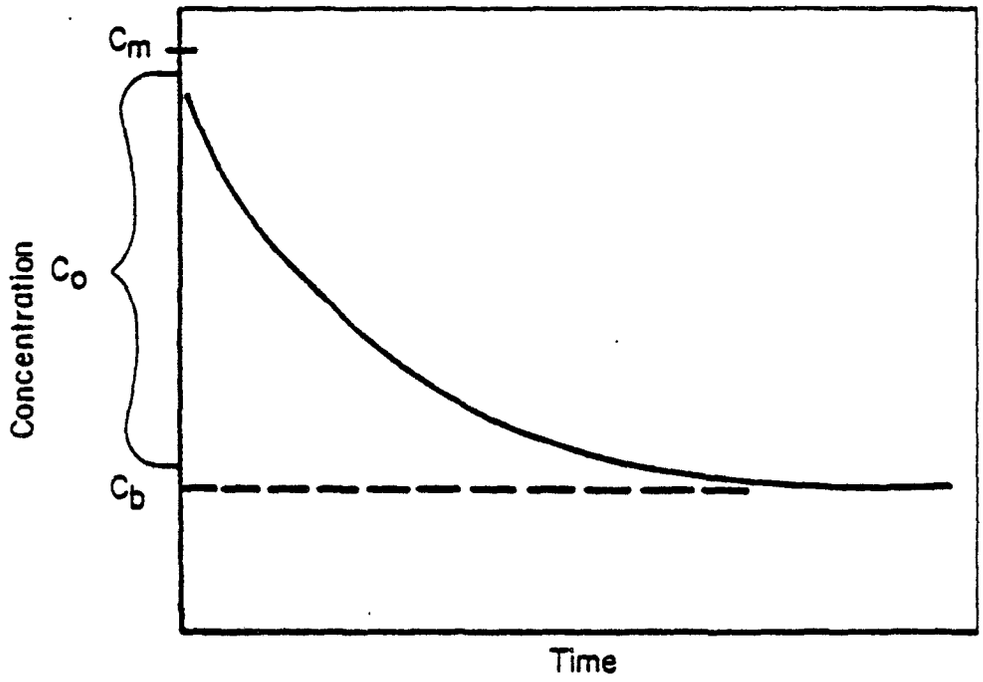


FIGURE 8. TRACER CONCENTRATION WITHIN AN URBAN PLUME

For Conservative Tracer: $[\text{Tracer}]_m = [\text{Tracer}]_o e^{-kt} + [\text{Tracer}]_b$ I

For Reactive Species: $[NO_x]_m + [NO_x]_{loss} = [NO_x]_o e^{-kt} + [NO_x]_b$ II

Note that Equation II has a new term on the left side to account for removal of NO_x, either chemically or physically, from the plume. It is this NO_x loss term which is the object of the analysis.

Since the tracers and NO_x are gases, they will dilute at the same rate, and the term e^{-kt} will be the same in both equations. We therefore rearrange I and II, divide to remove the exponential term, and rearrange again to obtain Equation III.

$$[NO_x]_{loss} = \frac{[\text{Tracer}]_m - [\text{Tracer}]_b}{[\text{Tracer}]_o/[NO_x]_o} - ([NO_x]_m - [NO_x]_b) \qquad \text{III}$$

All of the terms on the right side of Equation III are now measureable, enabling us to determine NO_x loss. Operationally, the background concentration terms are determined by making aircraft measurements outside the plume, the urban input ratio ($[\text{Tracer}]_o/[NO_x]_o$) is determined by making plume cross-section measurements just at the downwind edge of the city (naturally background levels must be subtracted to derive urban input terms), and the $[\text{Tracer}]_m$ and $[NO_x]_m$ terms are measured simultaneously during cross-sections of the plume at successive downwind distances. Note that $[NO_x]_m$, when determined by chemiluminescence, must be corrected for interferences due to PAN and HNO_3.

If the first downwind measurement and successive downwind measurements are made on the same general air parcel (i.e., a Lagrangian mode), the calculation of NO_x loss is relatively straightforward. We will discuss such flights as specific case studies shortly.

In a typical day's experiment, hourly meteorological data from several eastern Massachusetts stations were obtained by telephone several times each day and were used to manually construct working trajectories for Boston's polluted morning air mass. These trajectories were used to define each day's flight patterns. Data were collected during multiple traverses of the plume on each of three or more daily flights in order to bracket the morning air parcel, in this way, data on pollutant concentrations within the selected air parcel were obtained from early morning to late afternoon.

At the conclusion of the field study, an important part of our data interpretation efforts was the construction of surface level wind field grids

from wind speed and direction data from 10 eastern Massachusetts stations. The wind fields were used to compute forward trajectories to pinpoint the position of the air parcel selected for study. The intended use of the trajectories mandates a high resolution wind field grid. An air mass trajectory computer code was modified at Battelle for this purpose. Hand trajectories have also been drawn for selected times for comparison with the computer-derived plots.

The aircraft data which will be used with the trajectories were collected in such a way as to maximize the sensitivity of the experiment for detection of transformation rates. Our earlier research on transformations in the Phoenix plume suggested that one way to improve the experimental design would be to collect the integrated bag samples (for PAN, C2-C5 hydrocarbons and CO) near the midpoint of the urban plume, rather than integrating the collection across the entire plume. The dilution of the sample which accompanies collection near the edges of the plume results in lower measured concentrations of tracers and NO_x reaction products. Subtraction of background values from the concentrations of the pertinent species introduces considerable uncertainty, since two similar numbers are being subtracted. Thus the overall accuracy and sensitivity of the transformation analysis is impaired. Integrations across the plume were required in previous studies because, even when trajectories were constructed before each flight, it was never possible to predict exactly where the highest plume concentrations would be found. Consequently a preplanned flight pattern was drawn with fixed sample collection coordinates. Because of this, even when high plume concentrations were observed and sampled during part of the collection period, the remainder of the collection time diluted the samples.

To resolve this problem during the Boston study, we actually made two complete passes through the Boston plume for each collection. On the first pass, the concentrations of O_3, NO_x, and CNC were observed and noted on recorders. On the return pass the bag samples were collected over the 5-10 miles of the plume where the concentrations were highest. Trajectories were still prepared before each flight to indicate the position of the particular air parcel we were tracking (usually the 7-8 a.m. emissions bulge). The traverses were then preplanned to bracket the predicted position of the

parcel. However, the collection locations and times were not prespecified but were determined from observations during the "scouting" pass through the plume.

In order to conserve flight time, background air measurements were not made on every flight. The upwind concentrations of NO_x and the three tracers can be estimated from several flights for which upwind data were collected. These upwind concentrations are given in Table 15. These data, together with clean air results of other investigators has led to the selection of the following values to represent clean air dilution around Boston:

$$NO_x = 0.002 \text{ ppm}$$
$$CO = 0.17 \text{ ppm}$$
$$C_2H_2 = 0.001 \text{ ppmC}$$
$$F\text{-}11 = 129 \text{ ppt.}$$

TABLE 15. CONCENTRATIONS FROM SEVERAL FLIGHTS UPWIND OF BOSTON

NO_x, ppm	CO, ppm	C_2H_2, ppmC	F-11, ppt
0.003	0.20	0.0019	147
0.004	0.35	0.0030	165
0.002	0.17	0.0009	144
0.004	0.33	0.0004	129
0.002	0.17	0.0009	144
0.004	0.33	0.0004	129

An example of one day's flights is included in Figure 9a-c. Each figure represents a continuous flight; there were three flights on August 18 at progressively farther downwind distances. The bag sample and filter sample collection points are noted in the figures. Each solid line in the figures represents two passes through the plume. There are two plume traverses per flight, for a total of 4 passes through the plume. The purpose of the two traverses is to bracket the predicted position of the air parcel and thereby minimize errors introduced by the limited data base used to predict air parcel positions. For the transformation analysis we have used the data from

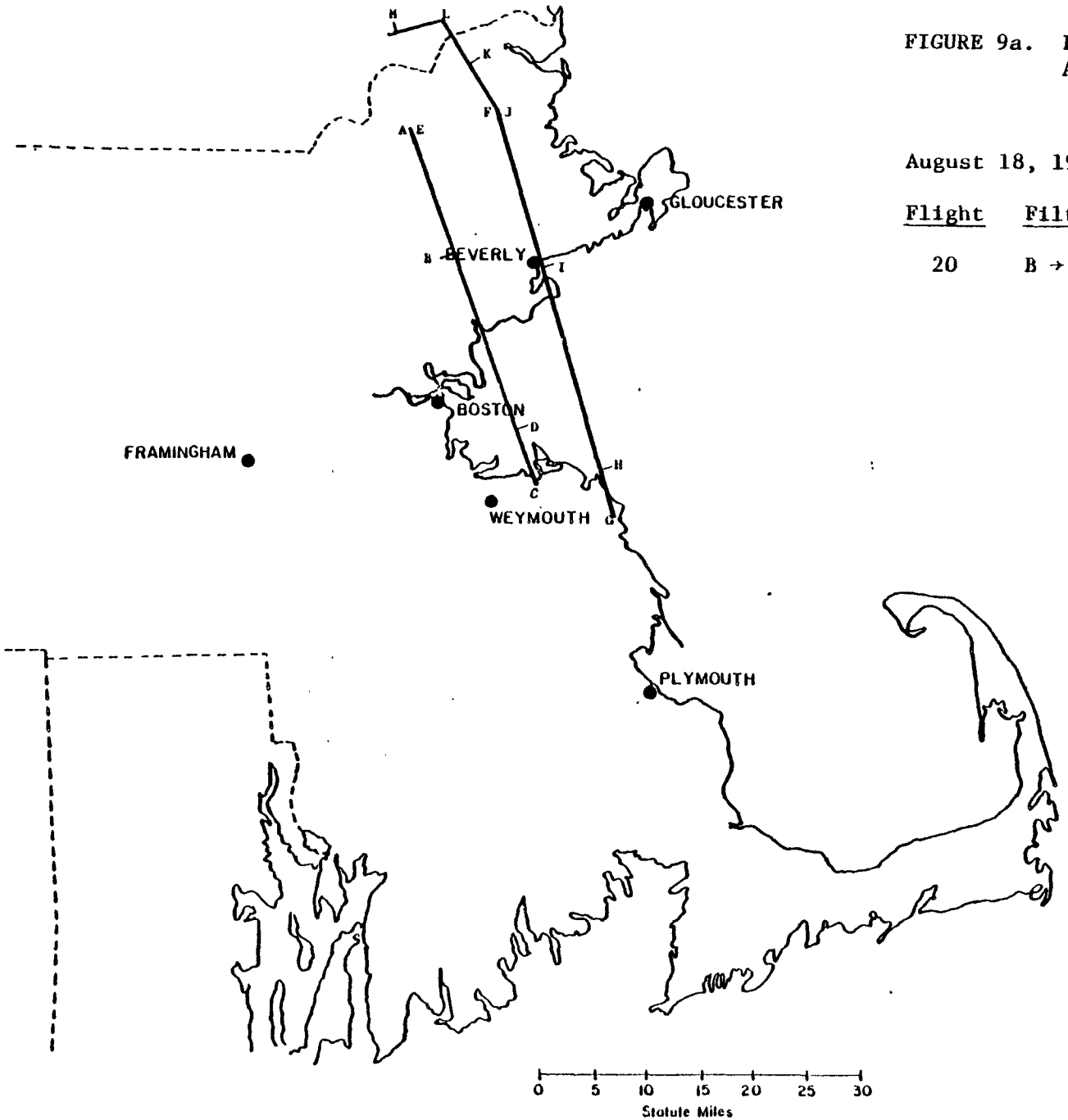
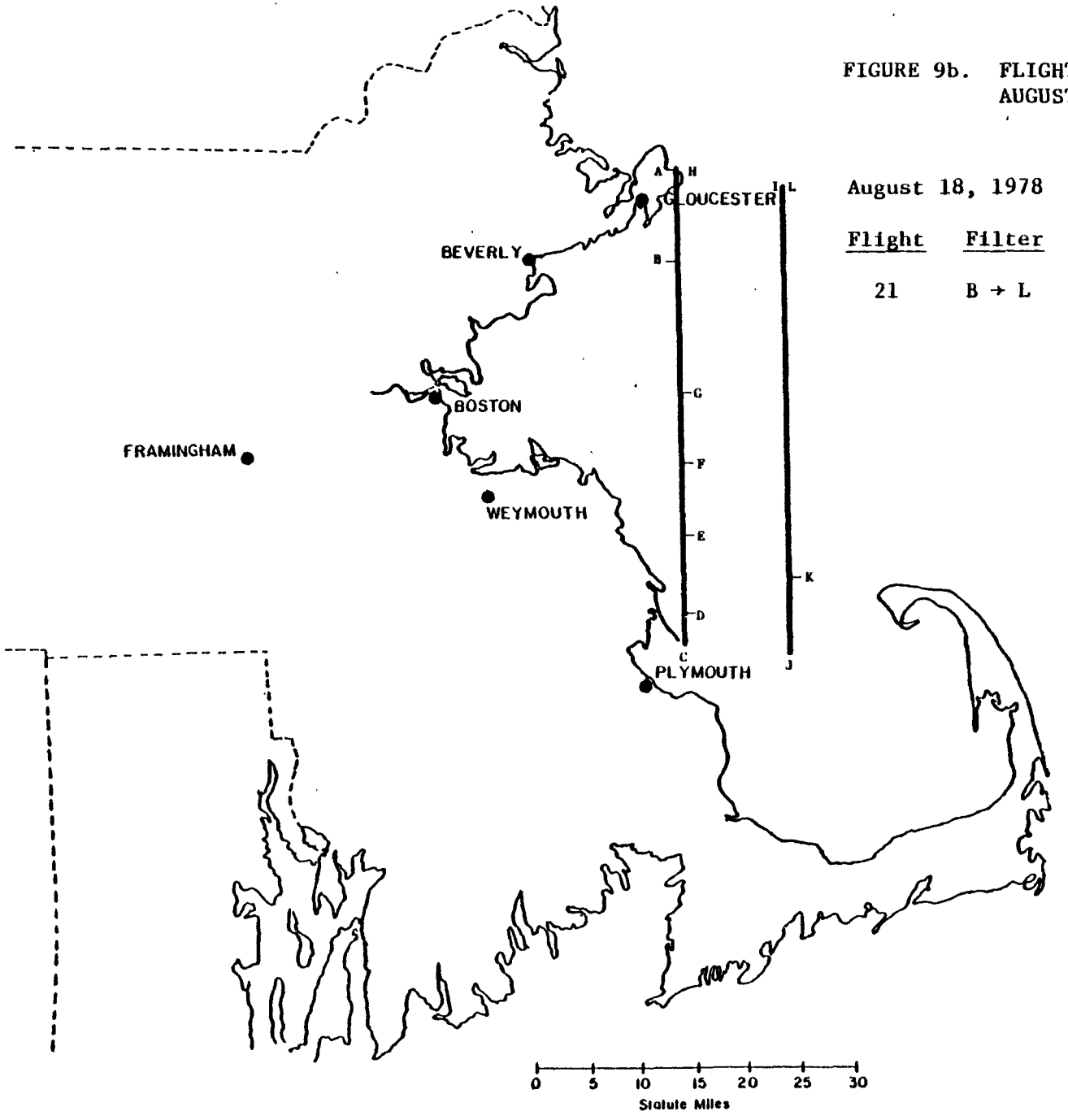


FIGURE 9a. FLIGHT PATTERN FOR AUGUST 18, 1978

August 18, 1978

Flight	Filter	Bag 1	Bag 2	Bag 3
20	B → K	C → D	G → H	I

FIGURE 9b. FLIGHT PATTERN FOR AUGUST 18, 1978



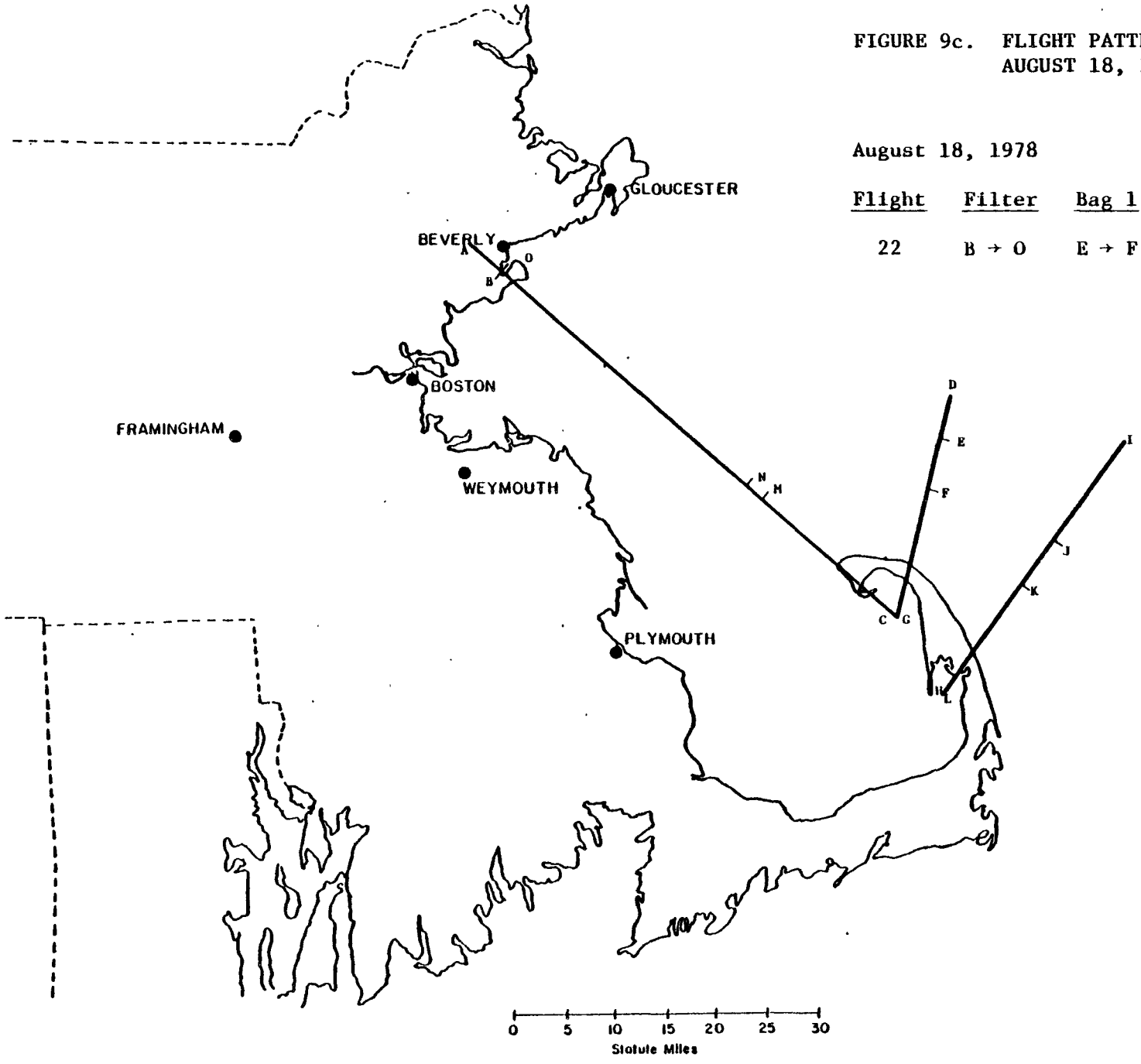
August 18, 1978

Flight	Filter	Bag 1	Bag 2	Bag 3
21	B → L	D → E	F → G	J → K

FIGURE 9c. FLIGHT PATTERN FOR AUGUST 18, 1978

August 18, 1978

Flight	Filter	Bag 1	Bag 2	Bag 3
22	B → O	E → F	J → K	M → N



the traverse which lies closest to the actual air parcel position. This determination was based on the more accurate trajectories discussed earlier.

Case Study No. 1: August 18, 1978

August 18, 1978, was a warm, sunny, clear day in eastern Massachusetts. The maximum ozone recorded at Beverly airport was 0.089 ppm at 1600 EDT. PAN also reached its maximum value of 5 ppb at this time. The nitric acid concentration averaged 0.84 ppb over the 8-hour daylight sampling period. Winds were a brisk 8-10 mph from the west and northwest during much of the day, making the day well suited for a study of urban plume reactions east of Boston over the ocean.

Figure 10 shows the calculated ocean trajectory for the Boston plume* and the positions of our aircraft bag collections. As shown by the flight maps in Appendix B, full traverses of the plume were conducted; Figure 10 shows the position of bag collections along a given traverse, rather than the entire traverse. As an example, the ozone profile from the plume traverse along which Sample 22-2 was collected is depicted in Figure 11. The ozone concentration profile across the plume is reminiscent of ozone plumes from New York(14), Phoenix(5), and St. Louis(4). The plume character of the profile is obvious. The interval over which Sample 22-2 was collected is noted on the O_3 profile. This collection interval is represented on the flight map (Figure 10), as a solid line labeled 22-2.

Of all the plume traverses carried out on August 18, those shown in Figure 10 yield the best match of time and position such that a Lagrangian framework is approximated. Even so, there are mismatches of up to an hour, so we were not monitoring exactly the same air parcel throughout the day. Assuming that the tracer/NO_x emissions ratios averaged over all of Boston do not change rapidly over the course of an hour, then exact time and position matches are not critical. Since the greatest fraction of the CO, C_2H_2, and NO_x emitted in the urban center during the morning hours is from automobiles (as judged by the CO/NO_x and C_2H_2/NO_x ratios), it is unlikely that the emissions ratios will change substantially during an hour.**

Using Sample 20-1 to derive the urban input ratios and employing the background air concentrations of NO_x and tracers discussed earlier, we

* The plume width is not defined by the trajectory calculation; we have approximated the plume width and given sides to the plume in this and subsequent figures for clarity.

** Emissions from large point sources were generally not a factor, probably because our 500-1000 foot flight altitude was below the plume height. A case where a power plant was observed is discussed next.

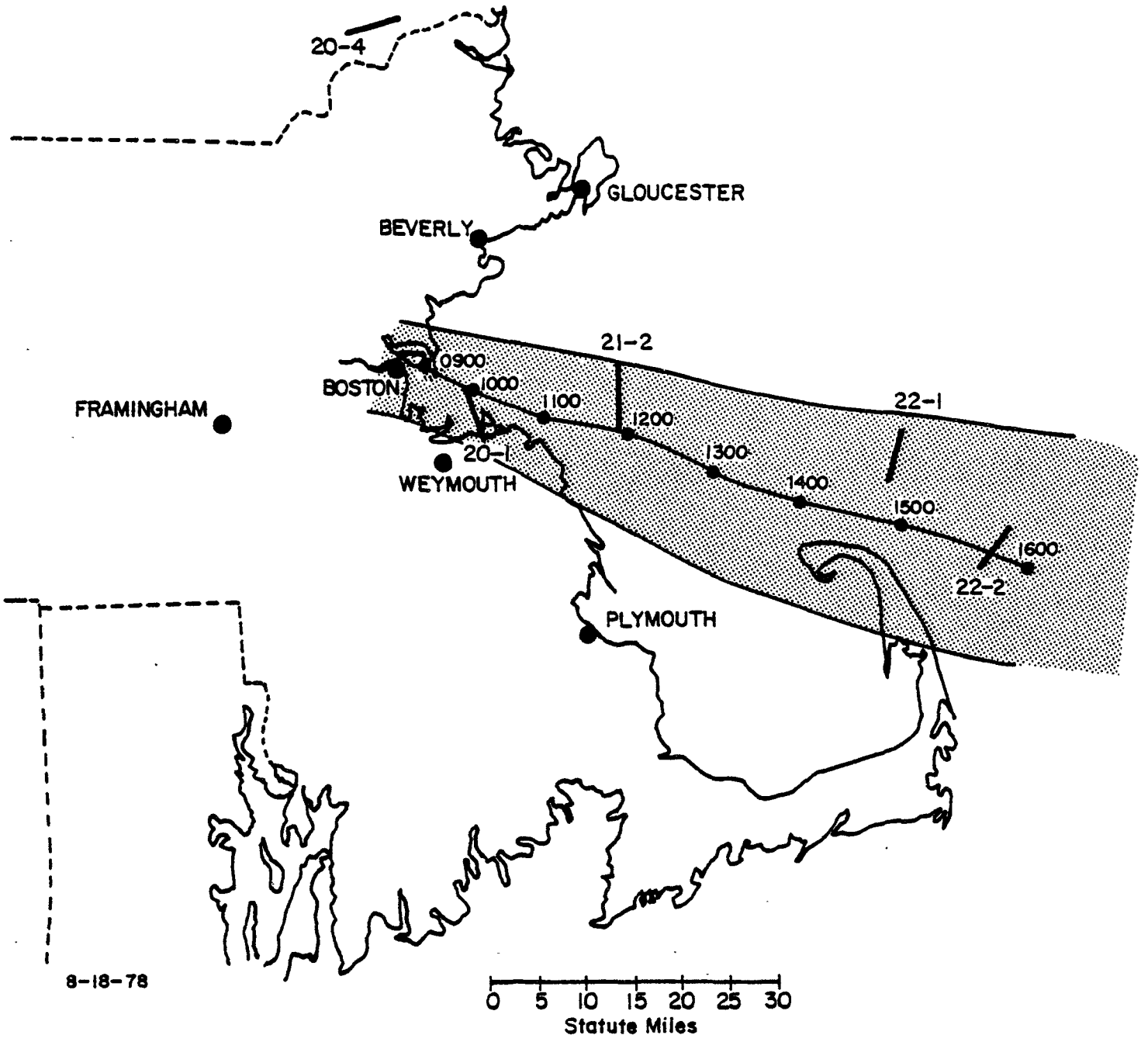


FIGURE 10. AIR PARCEL TRAJECTORY AND AIRCRAFT SAMPLE POSITIONS FOR 18 AUGUST, 1978

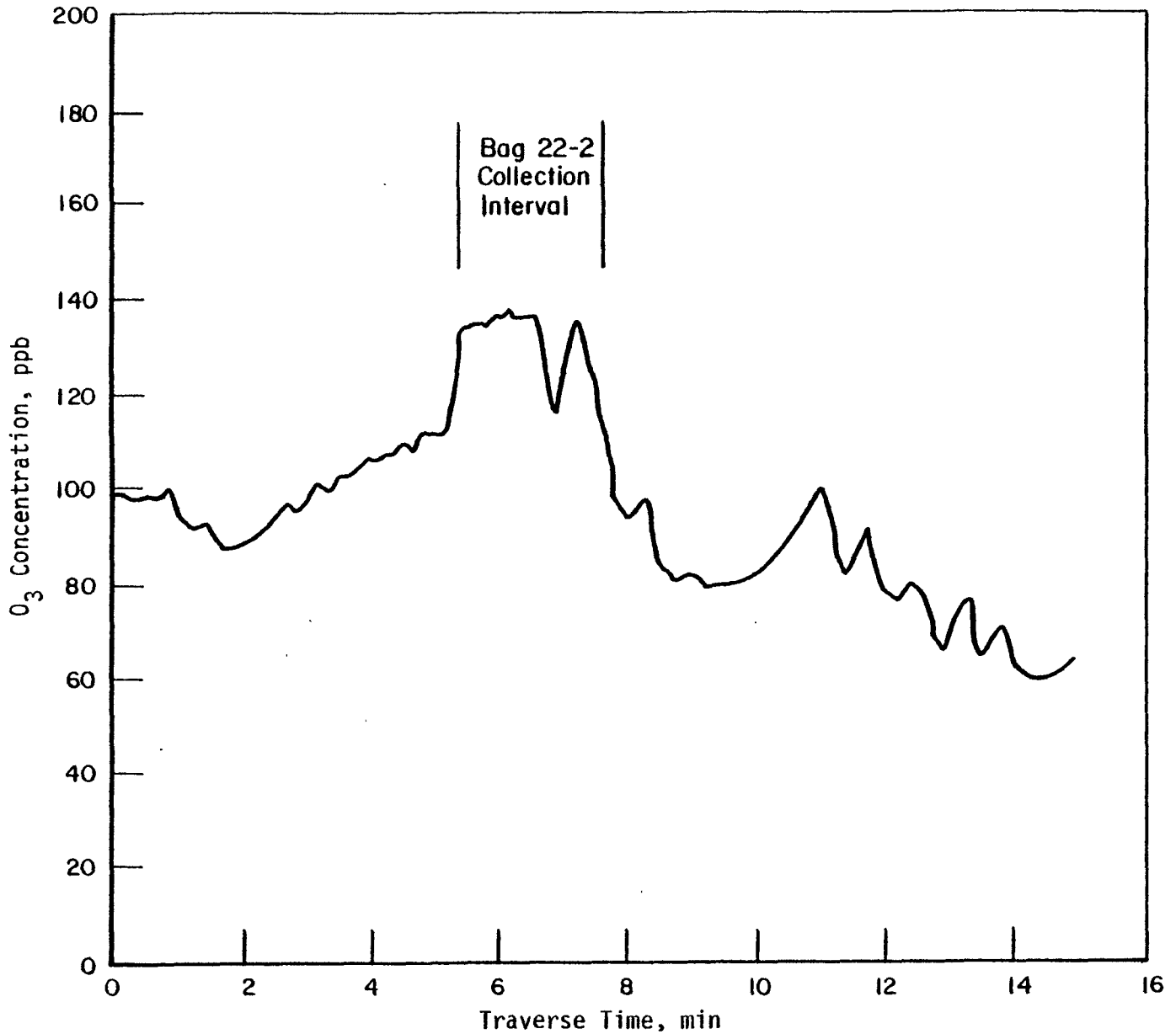


FIGURE 11. OZONE PROFILE FROM FLIGHT 22 SHOWING COMPLETE TRAVERSE OF PLUME AND INTERVAL OF BAG 22-2 COLLECTION

can calculate NO_x deficits for Samples 21-2, 22-1, and 22-2 using Equation III. The deficits are shown for the three tracers in Table 16. The data for these calculations was given earlier in Table 10.

TABLE 16. NO_x DEFICITS FOR FLIGHTS 20-22

Sample No.	Reaction Time*	NO_x Deficit (ppm) Based On: CO	C_2H_2	F-11
21-2	3.0 hours	.030	.010	.016
22-1	6.4 hours	.012	.010	.010
22-2	6.9 hours	.012	.009	.018

* Based on sample 20-1 as T = 0.

Considering the inaccuracies inherent in the analytical methods together with inaccuracies introduced by the correction for background concentrations of tracers, the deficits based on acetylene and CO should be given the greatest credence, with the value based on C_2H_2 being slightly favored. The F-11 values are shown merely for comparison. In most cases the F-11 results agree with the CO and C_2H_2 data, but they are not considered to be as reliable.*

The nitrogen balance for the three downwind samples is shown in Table 17. The NO_x deficits based on CO and C_2H_2 have been averaged, except for Sample 21-2, where the CO-derived value appeared unreasonable.

The sum of the measured reaction products, PAN, nitric acid and particulate nitrate account for less than, about the same as, and more than the calculated deficit, respectively for the three samples. Considering the low concentrations involved, the sensitivities of the analytical methods and the uncertainties in the deficit calculation, the agreement between the NO_x deficit and the measured reaction product concentration is reasonable.

* F-11 is considered a less reliable tracer because its source is different from NO_x. The initial F-11/NO_x ratios of different air parcels are likely to show more variation than ratios of constituents from the same source. Both F-11 and CO also suffer from high background concentrations relative to the plume concentrations. This tends to introduce uncertainty into the Equation III calculation. Due to its much lower background and better measurement precision, C_2H_2 is considered the more reliable tracer.

TABLE 17. NITROGEN BALANCE IN THE BOSTON PLUME DURING TRANSPORT — August 18, 1978

Sample No.	Reaction Time, hrs.	$[O_3]$, ppm	NO_x Deficit, ppm	$(PAN + HONO_2 + NO_3^-)$ ppm
21-2	3.0	.068	.010	.005
22-1	6.4	.125	.011	.012
22-2	6.9	.129	.011	.015

The processes which lower the NO_x concentration in the air parcel include dilution, conversion to products (e.g. PAN, $HONO_2$, NO_3^-) and deposition. Dilution is taken into account by the use of inert tracers, so this discussion can focus on transformation and deposition losses. Calculation of a rate of NO_x removal is not straightforward due to the complexity of the chemical processes involved and the interconversion of NO and NO_2. An average rate of loss can be calculated from the NO_x deficits and the reaction times shown in Table 16. The rate varies from .0016 to .0033 ppm hr^{-1} depending on the reaction time selected.

The NO_x loss rate is expected to be faster or slower depending on whether NO_2 or NO is the predominant oxide present. Little NO_x loss is expected while NO is undergoing oxidation to NO_2, however, once the interconversion is largely complete, several chemical and physical processes will compete to remove NO_2. For these reasons, the rate of NO_x removal from a transported air mass is expected to be highly variable, with an induction period likely during the initial stages of reaction as NO is converted to NO_2. In this and subsequent case studies, NO_x removal kinetics will be determined by plotting the plume data in the integrated form of the first order rate equation and using the slope to calculate a removal rate constant (also referred to as the removal "rate" in reciprocal hours by common usage in the field of atmospheric chemistry).

The first order rate equation used to describe these experiments is is

$$\ln \frac{(NO_x)_e}{(NO_x)_t} = kt$$

where $(NO_x)_e$ is the expected concentration of NO_x, or the concentration which should be present in the air parcel at time t after dilution is taken into account, and $(NO_x)_t$ is the actual amount of NO_x (i.e. $NO + NO_2$) measured at time t. $(NO_x)_e$ is determined from the first term on the right side of Equation III, after correction for the background levels of tracer and NO_x in the dilution air.

For Flights 20-22 on August 18, 1978, the first order plot is shown in Figure 12. The data conform reasonably well to the first order form. The slope of the line yields a pseudo-first order rate

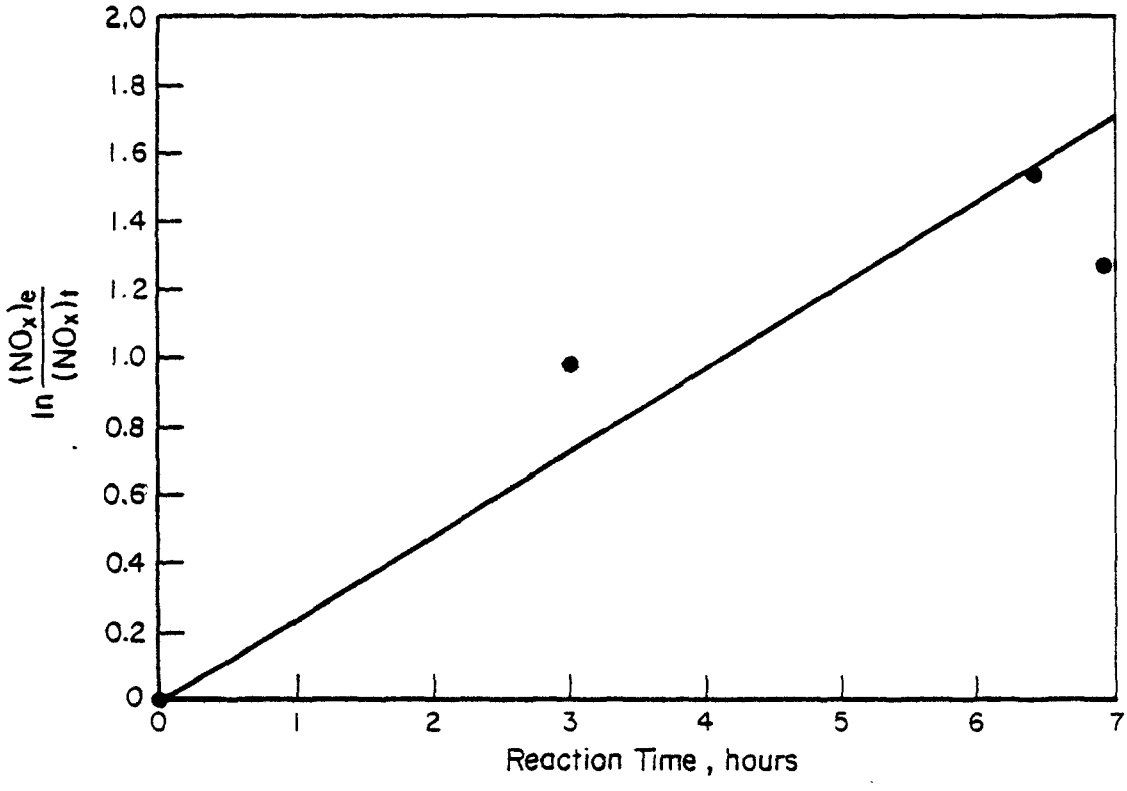


FIGURE 12. FIRST ORDER PLOT FOR FLIGHTS 20-22, AUGUST 18, 1978

constant of 0.24 hr^{-1}*. Additional case studies will be presented shortly in an attempt to verify both the first order fit and the removal rate.

We expect the major portion of NO_x removal to occur via transformation to reaction products (i.e. PAN, HNO_3, NO_3^-). The rate of transformation has been estimated above by the use of inert tracers to account for dilution. It is also possible to calculate a conversion rate based on the change in the distribution ratio, F_n, with time as the air parcel reacts during transport. F_n, defined as $\frac{PAN + HONO_2 + NO_3^-}{NO + NO_2 + PAN + HONO_2 + NO_3^-}$, can be used to calculate exactly the rate of conversion to products if the sum of the measured oxidized nitrogen compounds (the denominator of F_n) is conserved. Since deposition processes are known to remove some of these compounds, F_n can only provide an estimate of the conversion rate. We expect that deposition losses will lower the apparent F_n, leading to a conversion rate estimate which is a lower limit. However, the effect of deposition losses on F_n should not be great (since the compounds most likely to be deposited appear in both the numerator and denominator), and we therefore expect the conversion rate estimated by F_n to be a reasonable approximation of the true conversion rate. A semilog plot of F_n versus reaction time for Flights 20-22 is shown in Figure 13. The slope of the line yields a pseudo-first order conversion rate of 0.23 hr^{-1}, in excellent agreement with the overall NO_x loss rate calculated above of 0.24 hr^{-1}.

Case Study No. 2: August 23, 1978

August 23 was a cool, clear, sunny day in eastern Massachusetts. Winds had shifted from easterly on the previous day to a steady westerly flow. At the Beverly Airport, gaseous and aerosol pollutant concentrations were generally low with the exception of O_3, which reached .106 ppm.

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* Some curvature might be expected during the early portion of the reaction as NO is converted to NO_2, with little net loss of NO_x. To avoid this difficulty, our measurements were initiated after this process was largely complete.

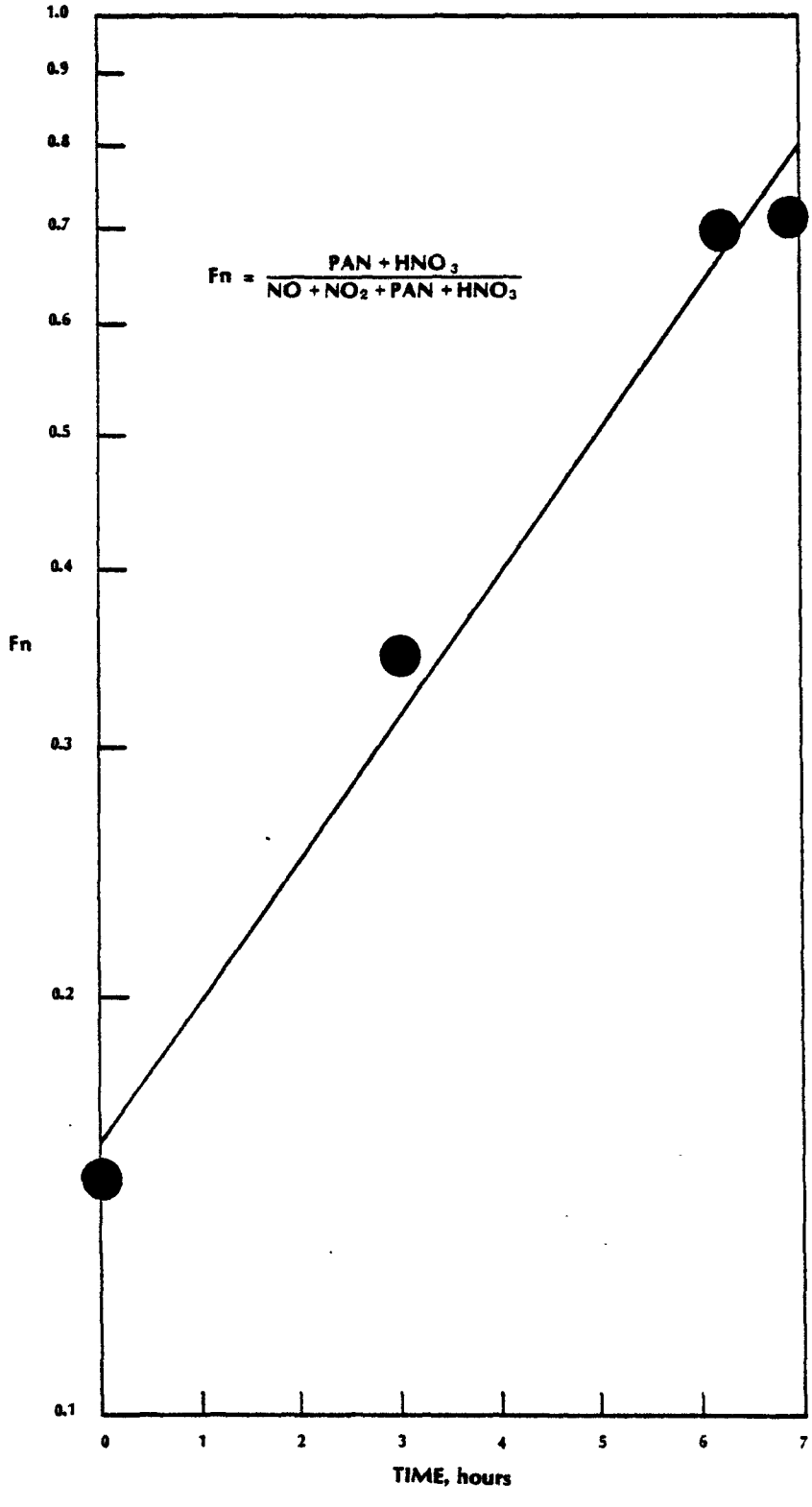

FIGURE 13. SEMILOG PLOT OF F_n VS REACTION TIME FOR FLIGHTS 20-22 ON AUGUST 18, 1978

Four multiple-traverse flights were carried out on 23 August in an attempt to define the rate of NO_x removal from the Boston plume under transport conditions. The flights were conducted over a 9 hour period from 0900 to 1800 EDT. Unfortunately the chromatographic system for PAN determination was not operating well during this portion of the study and the PAN data are not reliable as a consequence. While it will not be possible to derive nitrogen balances from these flights, the NO_x removal rate can be estimated from the tracer and NO_x data. These data may be found in Table 10.

The trajectory of the morning Boston air mass is depicted in Figure 14 together with the appropriate sample positions from the flights. For the most part the time and position matches of the air parcel location and the aircraft sample positions are quite good. Two exceptions are Samples 29-5 and 32-3. Sample 29-5 matches very well in time; that is, it was collected at 0955 EDT at the downwind distance where the 0800 EDT air parcel should have been located, but the sample position in Figure 14 appears to be outside the plume to the north. However, the plume width dimensions are drawn only for visual clarity. From the traverse data it is clear that Sample 29-5 was actually within the plume. Sample 32-3 was collected at 1800 EDT at the 1600-1630 EDT position of the air parcel. These times are considered to be too dissimilar for use in the rate computations. All of the other samples shown in Figure 14 match the air parcel position and time quite well.

August 23 was an especially good day for measurements of the type needed here because a low inversion which formed before dawn trapped pollutants very close to the surface. The resulting high concentrations permitted very precise measurements. Samples 29-5, 30-1 and 30-2 all were collected within 150 feet of the ocean surface. On the later Flights, 31 and 32, samples were obtained at altitudes of 300-500 feet.

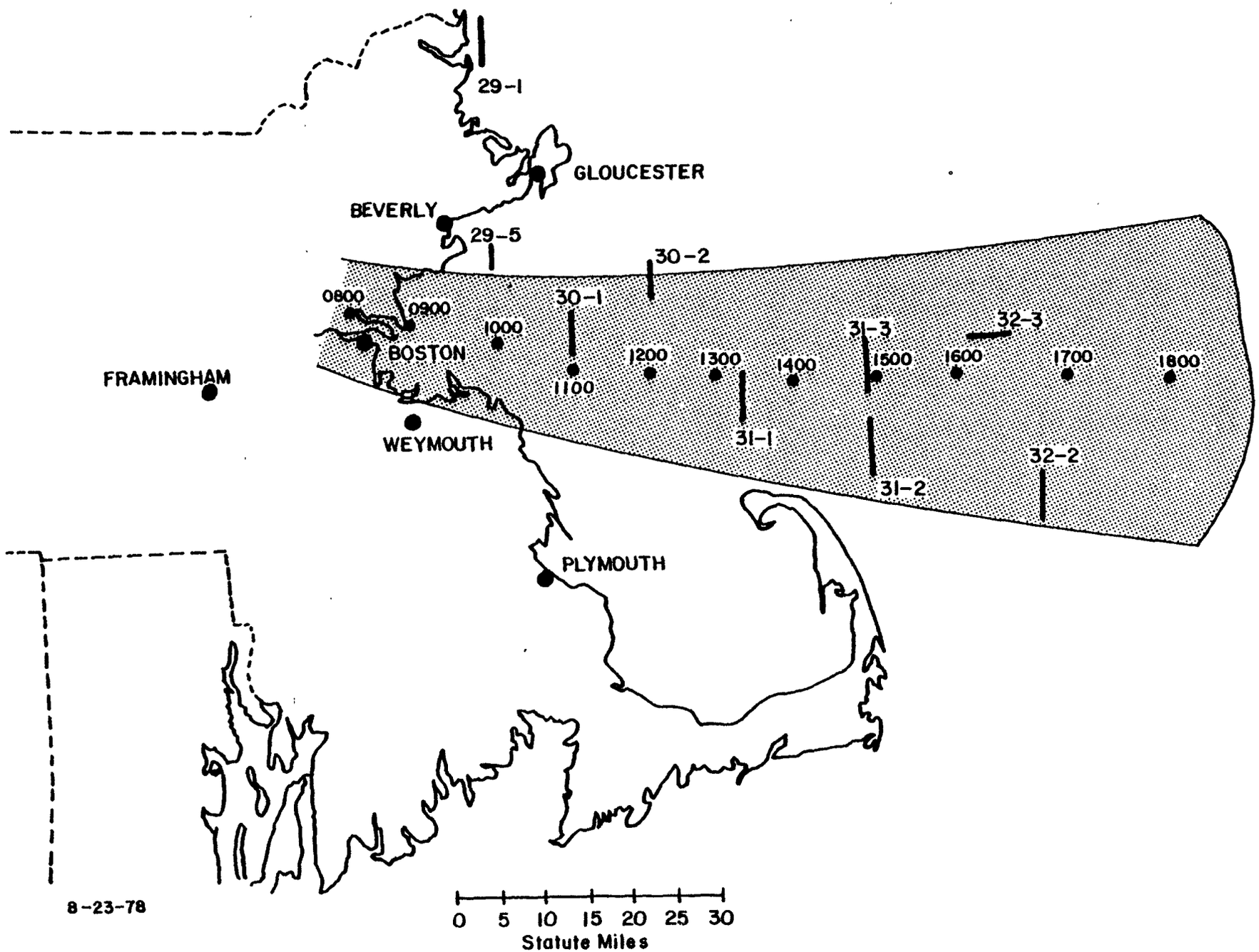

FIGURE 14. AIR PARCEL TRAJECTORY AND AIRCRAFT SAMPLE POSITIONS FOR AUGUST 23, 1978

Using the high pollutant concentrations measured at 1000 EDT (Sample 29-5) to define the urban emissions ratios, the background concentration data discussed earlier, and Equation III, one can calculate NO_x deficits for various transport times for the 23 August Boston plume. These deficits are listed together with reaction time in Table 18. Once again, the F-11 results are considered to be inferior to the CO and C_2H_2 data because F-11 arises from a completely different source than NO_x and because of the large background air correction. It is clear from the negative values in Table 18 that the NO_x deficits based on F-11 are completely unreliable, at least for this flight. The results derived from CO and C_2H_2 are reasonably consistent.

The NO_x deficits are plotted along with ozone concentration and C_2H_4/C_2H_2 ratio in Figure 15. The CO and C_2H_2 based deficits have been averaged for this plot, except for Sample 32-2 where only the CO-based value was used. The plot of NO_x deficit suggests the possibility of an induction time during which NO_x removal is minimal. It seems likely that this induction period may be the time required to convert NO to NO_2. This explanation is consistent with the build-up in O_3 from .028 to .063 ppm during the first 1-1/2 hours of reaction. After the induction period, a rapid loss of NO_x is observed. After about 5 hours of reaction there is no evidence for further loss of NO_x, suggesting that most of the original urban NO_x has been removed by chemical or physical processes. It is noteworthy that ozone reaches its maximum concentration at 5 hours and declines thereafter. If nearly all of the NO_x were consumed at this time, O_3 accumulation would be expected to cease and the NO_x deficit would remain constant, as observed after 5 hours of reaction. The validity of this explanation is uncertain, since the C_2H_4/C_2H_2 ratio indicates that at least some reactions which consume hydrocarbons continue after 5 hours. It may be that nearly all of the NO_x has been converted to products and/or deposited on the surface by the fifth hour, thereby terminating further reaction, but without valid PAN results this can not be proven. As the data now stand, 40-50 percent of the urban NO_x appears to have been lost after 5 hours of reactions. This is a lower limit because we are unable to correct the NO_x data for PAN interference.

TABLE 18. REACTION TIMES AND NO_x DEFICITS FOR FLIGHTS ON 23 AUGUST, 1978

Sample No.	Reaction Time,* hrs.	NO_x Deficit Based on: CO (ppm)	C_2H_2 (ppm)	F-11 (ppm)
30-1	1.6	-.002	.003	-.015
30-2	2.2	.011	.012	-.012
31-1	4.6	.016	.012	-.002
31-2	5.2	.016	.013	-.004
31-3	5.2	.013	.010	-
32-2	8.0	.012	.005	.006

*Using 29-5 as T = 0.

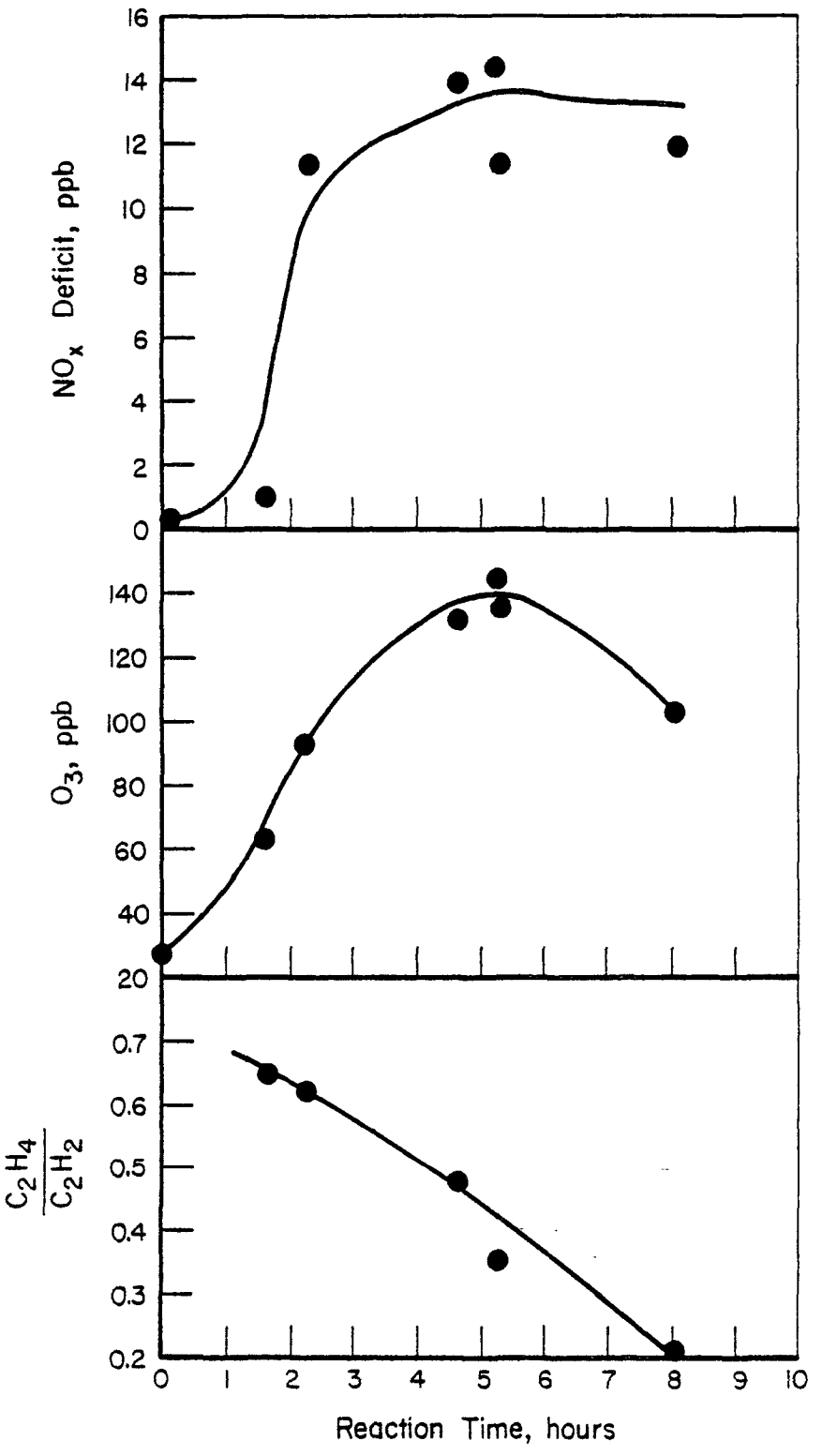

FIGURE 15. NO_x DEFICIT, O_3 AND C_2H_4/C_2H_2 VS REACTION TIME FOR FLIGHTS 29-32, AUGUST 23, 1978

The pertinent data from Flights 29-32 (Table 10) were converted to a form suitable for graphical analysis, as described earlier on page 70. The results have been plotted in a first order form in Figure 16. Most of the data points fall along a straight line passing through zero. The slope of this line yields a rate constant of 0.15 hr^{-1}.

Loss rates on the order of .15 hr^{-1} during strong photochemical activity in an urban plume are consistent with previous studies in Los Angeles,[4] model estimates, and recent smog chamber data.[15] Other flights during this investigation also confirm that the rate can be this high under appropriate conditions. Before turning to another such flight however, there is a special feature of Flights 29-32 which must be mentioned.

During the flights of 23 August, several of the urban plume traverses detected the plume from the Salem power plant. This plant is located about 5 km south of Beverly Airport, and its plume is expected to parallel the Boston urban plume on this day.

Figure 17 shows the positions of traverses from Flights 29, 30, and 31. On each of these traverses we observed both the urban plume from Boston and the Salem power plant plume. The power plant plume was observed at 10, 25, and 79 km downwind (east) of the plant at 1003, 1140, and 1510 EDT, respectively. The concentrations of NO_x, O_3 and condensation nuclei recorded during the complete traverses are also shown in Figure 17 and are keyed to the appropriate traverse. In all three cases, both the urban and the power station plume appear in the data. For Flight 29, the urban plume is clearly observed in the NO_x plot. The location of Sample 29-5 collection is noted. Just north of the polluted urban air, a sharp spke in the NO_x and condensation nuclei (CN) levels and a concurrent reduction in O_3 indicate the presence of the power station plume. A similar situation is observed along the traverse from Flight 30. Just north of the urban plume (Sample 30-1), a NO_x and CN spike and an O_3 decrease mark the plume from the Salem plant. The NO_x and O_3 indicators are not as dramatic as they might be because the plane's altitude was not exactly matched with that of the plume. The plane was sampling at 150 feet above the ocean's surface and apparently just skimmed the underside of the plume.

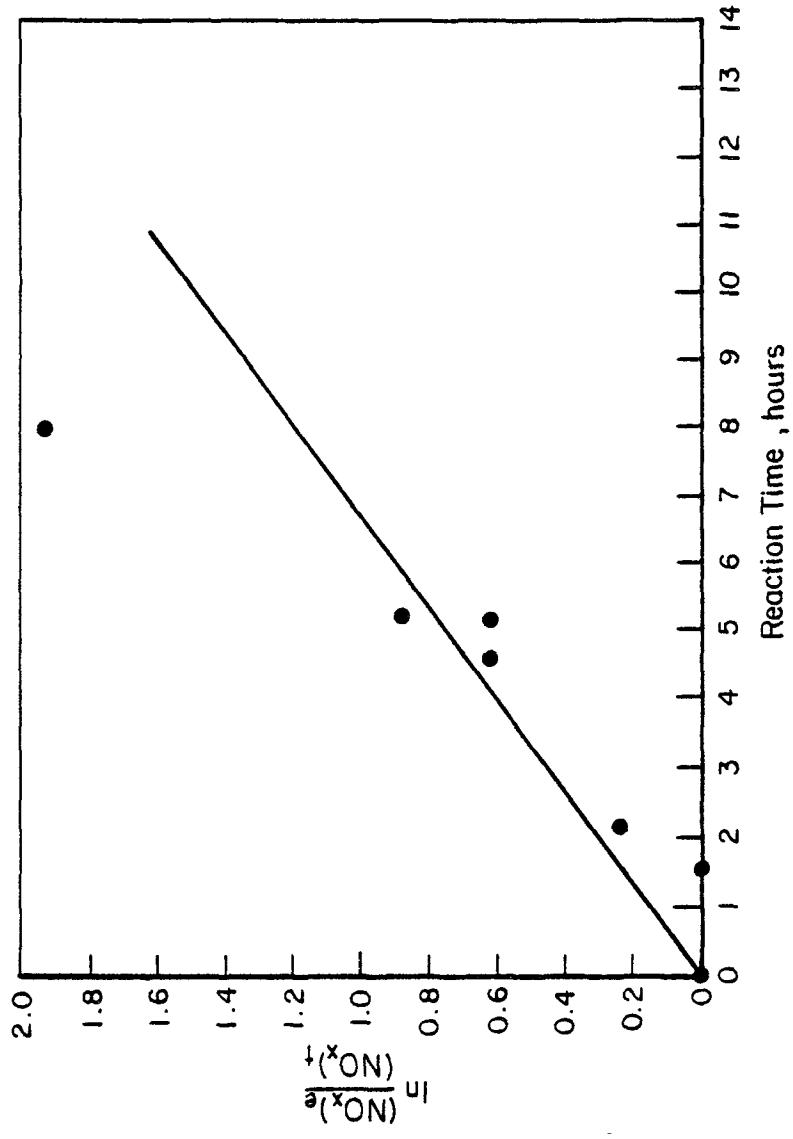

FIGURE 16. FIRST ORDER PLOT FOR FLIGHTS 29-32, AUGUST 23, 1978

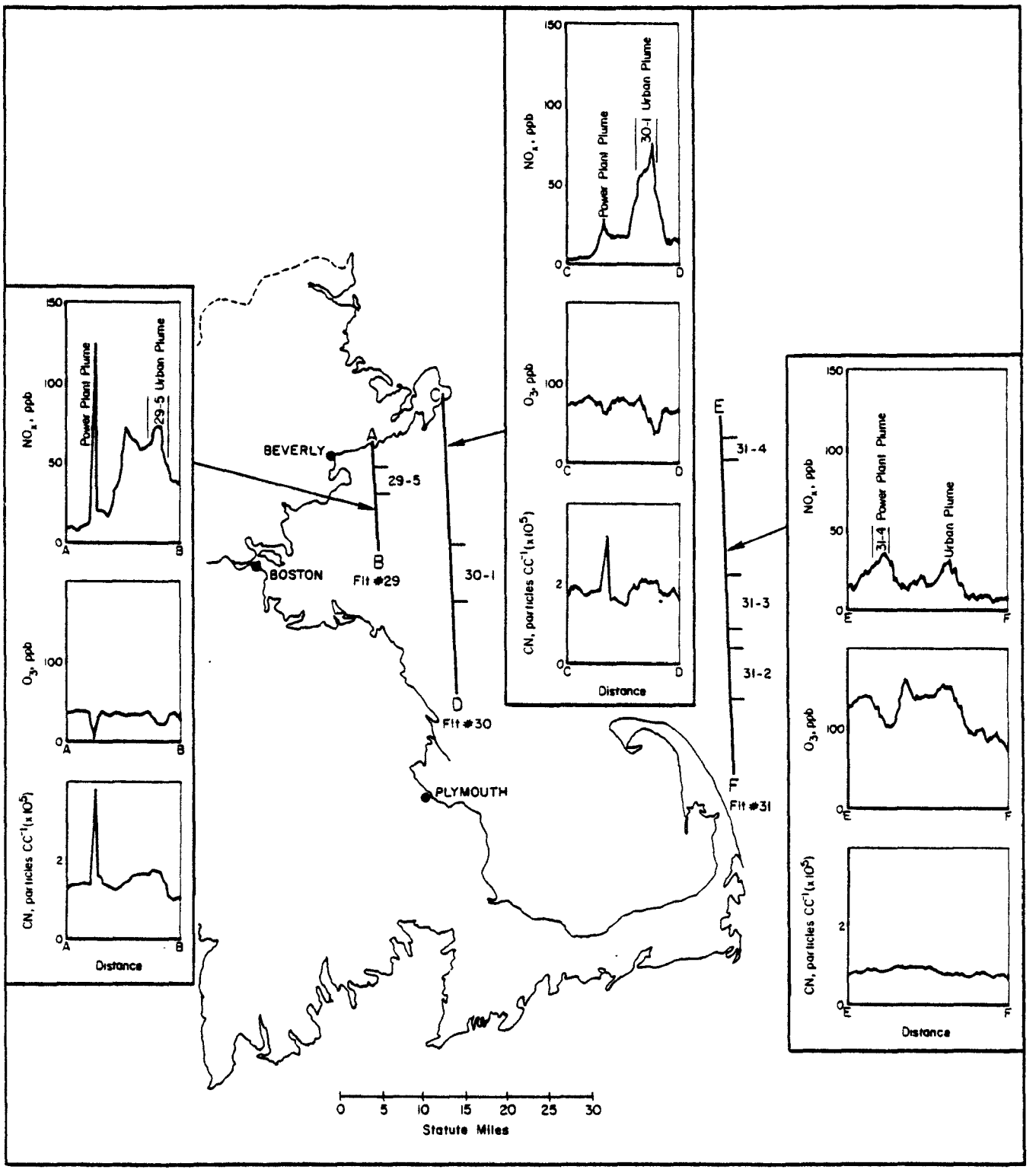

FIGURE 17. TRAVERSE POSITIONS AND CONTINUOUS DATA RECORDS FOR FLIGHTS 29-31, AUGUST 23, 1978

The traverse for Flight 31 also showed both the urban and power station plumes. The width of the power plant plume has increased greatly as observed from the NO_x and O_3 signals from the 10, 25, and 79 km traverses. Under the conditions of these flights no O_3 bulges were observed; in fact there was still an O_3 deficit of ∿40 ppb even after 79 km of transport. The increase in O_3 concentration in the urban plume stands out clearly from traverse to traverse. There is some indication from the final traverse of an increase in O_3 at the edges of the power plant plume, although the data are insufficient to discuss plume fringe versus core in any detail.

The reactions and fate of nitrogen oxides in power plant plumes are at least as uncertain as their urban plume analogs. The subject of NO_x reactions in the plumes from electric generating plants has been treated in other reports[16,17], but is still far from understood. Any information pertaining to this subject is therefore of interest. Fortunately, the Salem plume was sampled directly during Flight 31 at a point 79 km from the stack. This sample (31-4) yields some interesting insights into the composition and reactions in transported power plant plumes.

The features of the power plant plume sample can best be illuminated by comparing it with the urban plume sample, No. 31-3, taken 20 miles to the south. The bag and integrated flight data from Table 10 are reproduced in Table 19. The differences between the two samples are few, as expected from the fact that both plumes are largely diluted after 79 km of transport. The power plant plume contains about twice as much NO_x as its urban counterpart, and shows suppression of O_3, as mentioned earlier. Perhaps the most significant feature is a 50 percent higher concentration of nitric acid in the reacted power plant exhaust. The absolute PAN values are uncertain, but based on relative peak heights there was more PAN in the power plant plume than in the urban plume. Because of the unreliable PAN data it is not possible to present PAN and $HONO_2$ distributions and ratios in the two plumes. This is unfortunate since such information would be very valuable. Nevertheless, the higher concentrations of $HONO_2$ and PAN are intriguing. These findings are consistent with current smog chamber studies of NO_x reactions in power plant plumes.

TABLE 19. RESULTS FOR SAMPLES 31-3 AND 31-4

	Urban Plume 31-3	Power Plant Plume 31-4
O_3, ppb	137	117
NO_x, ppb	10.7	19.4
$HONO_2$, ppb	4.0	6.0
CO, ppm	.62	.61
F-11, ppt	-	242
ethane, ppbC	3.6	3.9
ethylene, ppbC	2.7	4.9
acetylene, ppbC	8.0	7.8
isobutane, ppbC	5.7	5.0
n-butane, ppbC	11.8	11.0
isopentane, ppbC	11.7	14.6
n-penetane, ppbC	5.3	5.8

Case Study No. 3: August 30, 1978

Cool, clear sunny weather prevailed over eastern Massachusetts on August 30, 1978. Winds were from the west and northwest during the day. Since Beverly Airport is northeast of Boston, it was unaffected by Boston's emissions and the pollutant levels remained relatively low throughout the day. Maximum hourly O_3 was .076 ppm, accompanied by 5 ppb of PAN. Twenty-four hour averaged nitric acid was .64 ppb, compared to a particulate nitrate concentration corresponding to .02 ppb. As on other days, gaseous nitrate (PAN + $HONO_2$) dominates the total atmospheric nitrate burden. Weather and air quality data for 30 August have been summarized in Table 5. Detailed ground monitoring results may be found in Appendix A.

The trajectory of the 0800 EDT Boston air mass was computed using wind records. The air mass trajectory is depicted in Figure 18, along with the positions of selected samples from three monitoring flights conducted during the period from 0830 EDT to 1500 EDT. The gas phase data from these flights is reported in Table 10; the aerosol results are presented in Table 11. The particulate nitrate levels were very low ($<0.3 \mu g/m^3$) during all flights and showed no tendency to increase with reaction time. The sulfate concentration varied from 4.0 to 7.2 $\mu g/m^3$, consistent with the 7.4 $\mu g/m^3$ observed outside the urban plume at Beverly Airport. The changes in $SO_4^=$ followed no consistent pattern.

The time and position matches for the samples shown in Figure 18 were quite good. The greatest discrepancy involved Sample 39-1, which missed the computed air parcel position by ∿45 minutes. Considering all the other uncertainties and imponderables, even this match is acceptable. All the others were nearly exact.

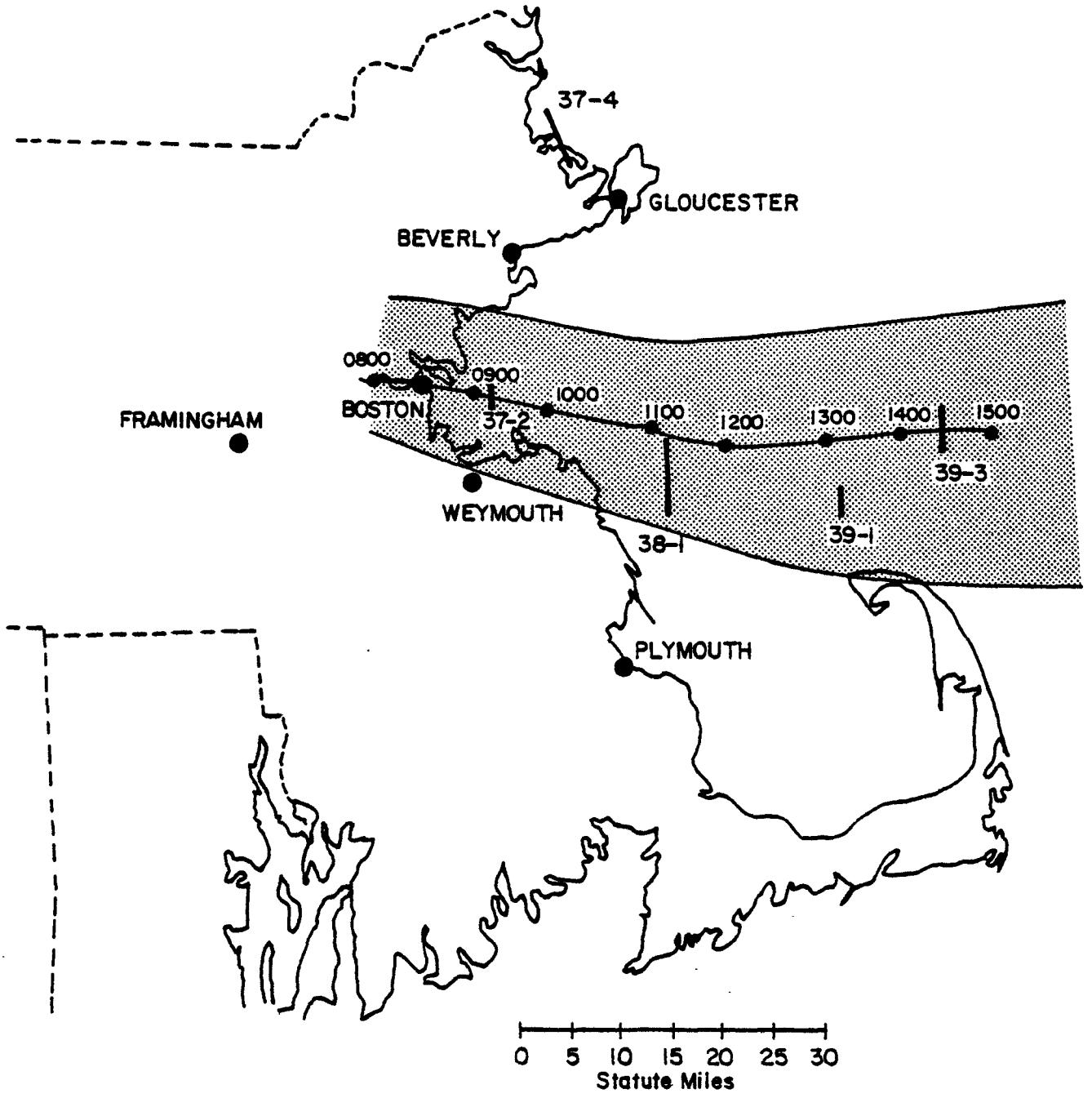

FIGURE 18. AIR PARCEL TRAJECTORY AND AIRCRAFT SAMPLE POSITIONS FOR FLIGHTS 37-39, AUGUST 30, 1978

Sample 37-4 was a good clean background sample and was used in deriving the general background values used throughout the study. Sample 37-2, collected 200 feet above the surface of the Bay at 0856 EDT will serve to define the urban ratios of CO/NO_x, C_2H_2/NO_x and $F\text{-}11/NO_x$. This sample was collected as close to the urban center as Logan Airport's air traffic would permit.

Using the background concentrations, the urban ratios from Sample 37-2, and Equation III, we have calculated the NO_x deficits for the Boston plume on August 30. The deficits are shown along with reaction time in Table 20.

TABLE 20. NO_x DEFICITS FOR FLIGHTS 37-39, AUGUST 30, 1978

Sample No.	Reaction Time,* Hrs.	NO_x Deficit (ppm) Based On: CO	C_2H_2	F-11
38-1	2.3	.008	.007	-.003
39-1	5.1	.013	.008	-.001
39-3	5.6	.016	.012	.001

*Based on Flight 37-2 as T = 0

The deficits derived from CO and C_2H_2 measurements are in reasonable agreement and suggest a continuous loss of NO_x over the 5.6 hour reaction interval studied. The results based on F-11 are once again unreasonable and are not included in the subsequent discussion. The NO_x deficit obtained by averaging the CO and C_2H_2 results is plotted in Figure 19 against reaction time. A line has been drawn through the data, the slope of the line indicating an average NO_x loss of 2.5 ppb per hour. This is in good agreement with the results of the other case studies. Since the NO_x concentration averaged .022 ppm over the 5.6 hour period, the data from Flights 37-39 suggest an average NO_x removal rate of 0.11 hr^{-1}. This rate can be checked using the data at 5.6 hours from Sample 39-3. For this sample, the averaged tracer results estimated that .025 ppm of NO_x should have been observed. Since 56 percent (.014 out of .025 ppm) of the NO_x has been lost in 5.6 hours, the average loss rate was 0.1 hr^{-1}. The first order plot of the NO_x results from these flights are shown in Figure 20. The data fit the first order form almost exactly. The slope of the line suggests a first order removal rate constant of 0.14 hr^{-1}.

Three other data sets are plotted in Figure 19 . The ozone concentrations for the urban plume samples are graphed against reaction time. Ozone increases continuously over the 5.6 hour reaction time at a rate of .012 ppm per hour. Ozone appears to be increasing linearly even after 5.6 hours of reaction, indicating that the air parcel still contains NO_x. The C_2H_4/C_2H_2 ratio shown in Figure 19 also demonstrates that the reaction is proceeding even after 5 hours. In fact, the slope of the C_2H_4/C_2H_2 line indicates that ethylene may be removed at about the same relative rate as NO_x, that is $\sim$0.1 hr^{-1}.

Also shown in Figure 19 is a plot of the oxidized nitrogen distribution function,. F_n. The F_n data show that with an exception, the reaction products PAN and $HONO_2$ make up a continuously increasing fraction of the oxidized nitrogen burden. The linear increase in F_n is in agreement with the NO_x deficit data in demonstrating that conversion of NO_x to reaction products continues unabated for at least 5 hours. As described earlier, particulate nitrate production in the urban plume was so low as to be undetectable.

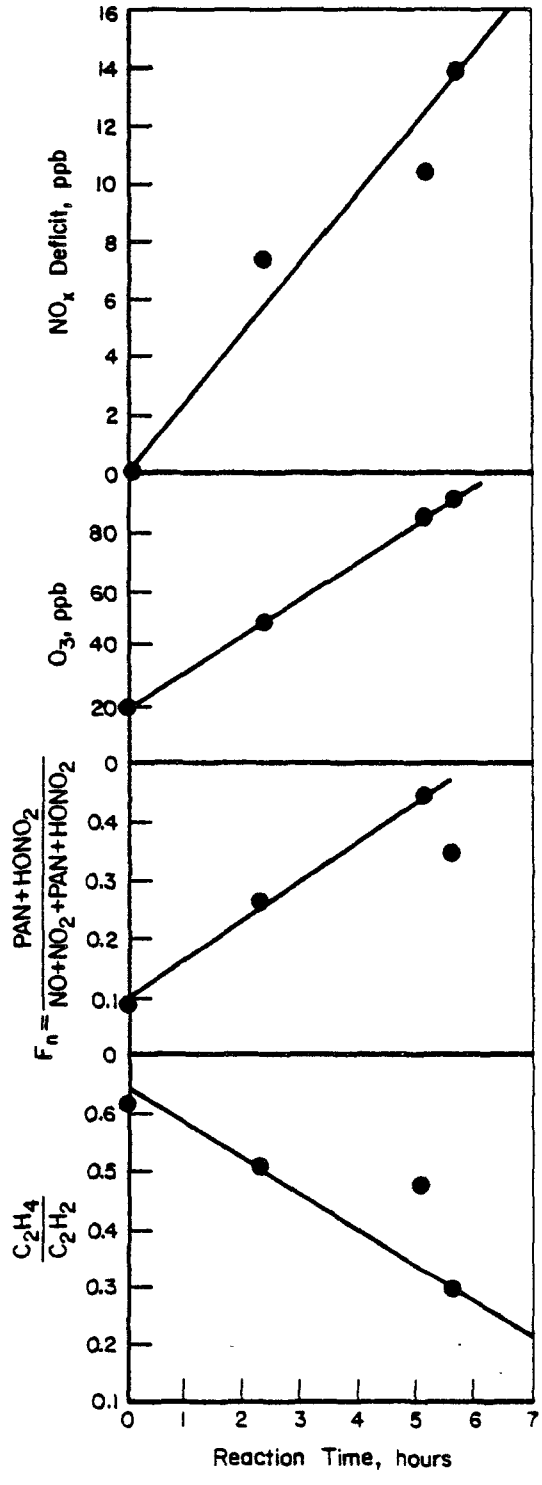

FIGURE 19. SELECTED VARIABLES VS REACTION TIME FOR FLIGHTS 37-39, AUGUST 30, 1978

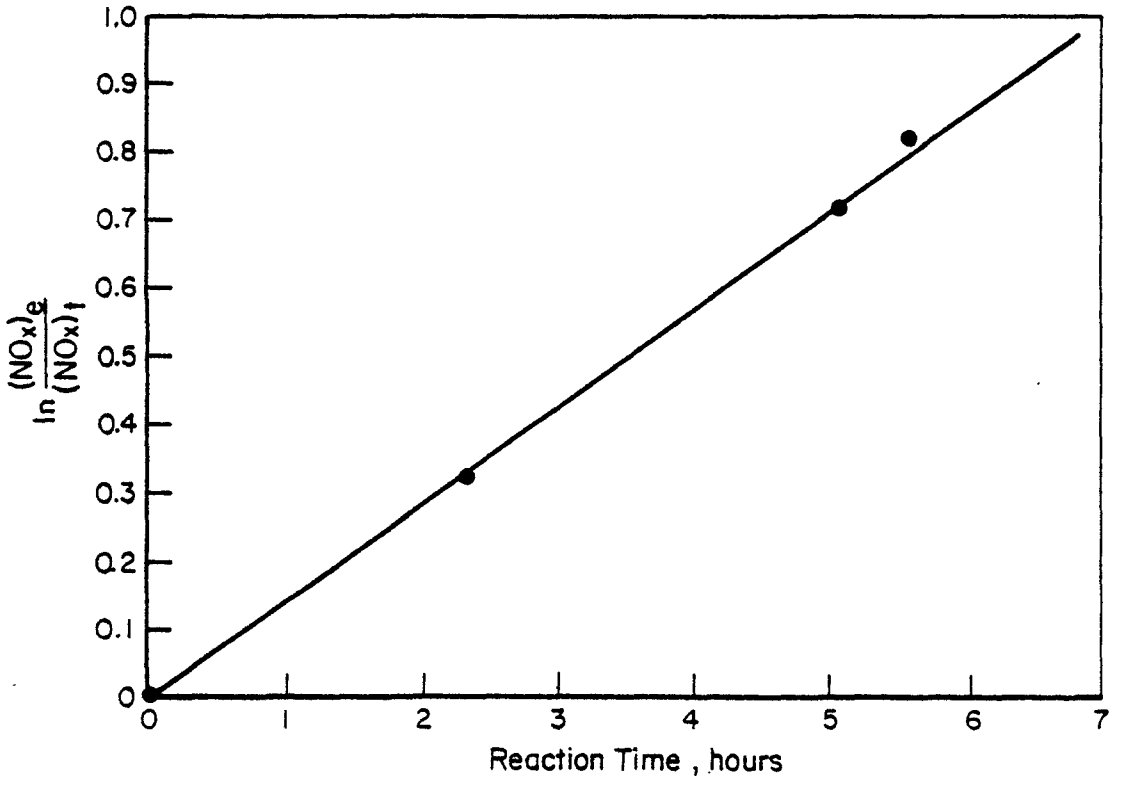

FIGURE 20. FIRST ORDER PLOT FOR FLIGHT 37-39, AUGUST 30, 1978

A nitrogen balance can be determined for the 30 August Boston plume by comparing the sum of the measured nitrogen species (i.e., NO, NO_2, PAN, and $HONO_2$) with the concentration of oxidized nitrogen which should be present in some form. This latter estimate is derived from the tracer results and is simply the first term on the right side of Equation III. To this prediction of the amount of urban NO_x present must be added the NO_x background concentration. This comparison is made for the three downwind flight cross-section in Figure 21. The equivalence line which would indicate a perfect nitrogen balance is also plotted on the figure. Two of the points lie on the line, with the third somewhat below. The data in Figure 21 demonstrate that the nitrogen balance is excellent for two of the plume traverses. About 75 percent of the expected nitrogen is accounted for in the remaining sample. Within the limits of uncertainty of these experiments we believe that an adequate nitrogen balance exists and that the combined concentrations of PAN and $HONO_2$ reasonably account for the missing NO_x, with some small losses due to deposition accounting for any missing NO_x.

Ratios of pollutant concentrations are frequently useful as predictors and in some cases serve to elucidate underlying chemical processes. The ratio O_3/PAN has been discussed by Lonneman[9], Spicer[2] and Jorgen et al[18]. During peak periods of photochemical activity in urban areas this ratio frequently lies in the range 5-15. Using urban plume Sample 39-1 from 30 August, we find an O_3/PAN ratio of 11. This sample was selected over 39-3 because the reaction product data seem more reliable judging by the excellent nitrogen mass balance.

Ozone/$HONO_2$ ratios in polluted atmospheres have been observed in the range 15-30 during peak smog periods. The ratio of ozone to nitric acid for Sample 39-1 was slightly outside this range at 36. PAN/$HONO_2$ ratios have been reported for smog chamber experiments[15,19] and urban studies[2,20]. This ratio is dependent on the type and reactivity of the hydrocarbon precursors, the extent of reaction, availability of surface for reaction/depletion, relative humidity, NMHC/NO_x ratio, and perhaps other factors. For Sample 39-1 the PAN/$HONO_2$ ratio was about 3.

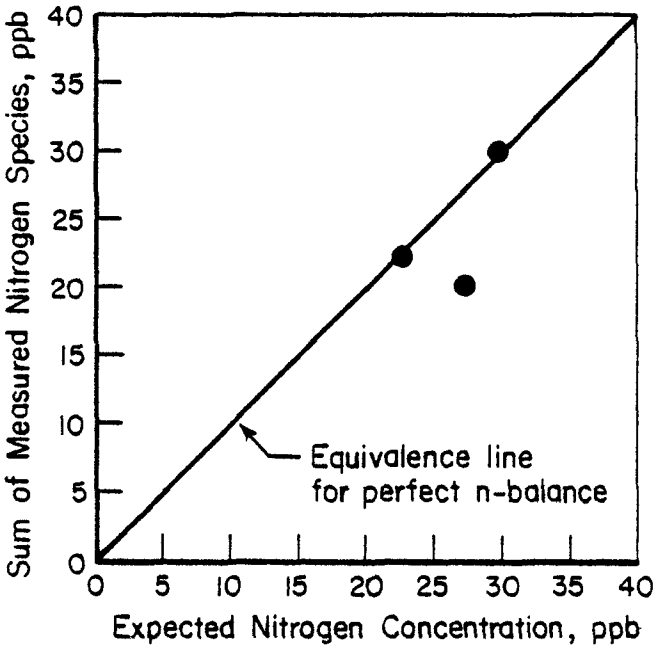

FIGURE 21. SUM OF THE MEASURED NITROGEN COMPOUNDS VS PREDICTED TOTAL NITROGEN

Earlier in the flight, Sample 38-1 provided the following ratios:

$$O_3/PAN = 10$$
$$O_3/HONO_2 = 18$$
$$PAN/HONO_2 = 2$$

Discussion of secondary pollutant ratios will be continued in a later case study.

Case Study No. 4: August 14, 1978

August 14, 1978, was a hot, humid, hazy day in the Boston area. Ground station data from Beverly Airport are not available due to breakdown of the primary and backup data acquisition systems in the mobile lab. The gas chromatographic system for PAN also was performing poorly so the PAN data are considered suspect. Nevertheless, the meteorological conditions were well suited to a study of NO_x decay in Boston's plume, and three flights were conducted with this goal. Westerly winds prevailed during the day, carrying the polluted urban air eastward over the ocean. The trajectory for the 1100 EDT Boston air is pictured in Figure 22. During the first flight sequence (Flight 11) Boston's emissions were trapped beneath a very low surface inversion. Safety considerations precluded sampling at such low altitudes; heavy traffic from low flying fish-spotting planes was the root of the problem. Later in the afternoon, two flights were completed which matched well with the air parcel time and position. The pertinent samples are 12-1 and 13-2, obtained at 1316 EDT and 1632 EDT, respectively. Undoubtedly a good deal of the NO_x emitted earlier in the morning has reacted by 1316 EDT. Consequently, this discussion will deal with the later stages of reaction. Of primary interest is the average rate of NO_x depletion between 1316 and 1632 EDT (Samples 12-1 and 13-2, respectively).

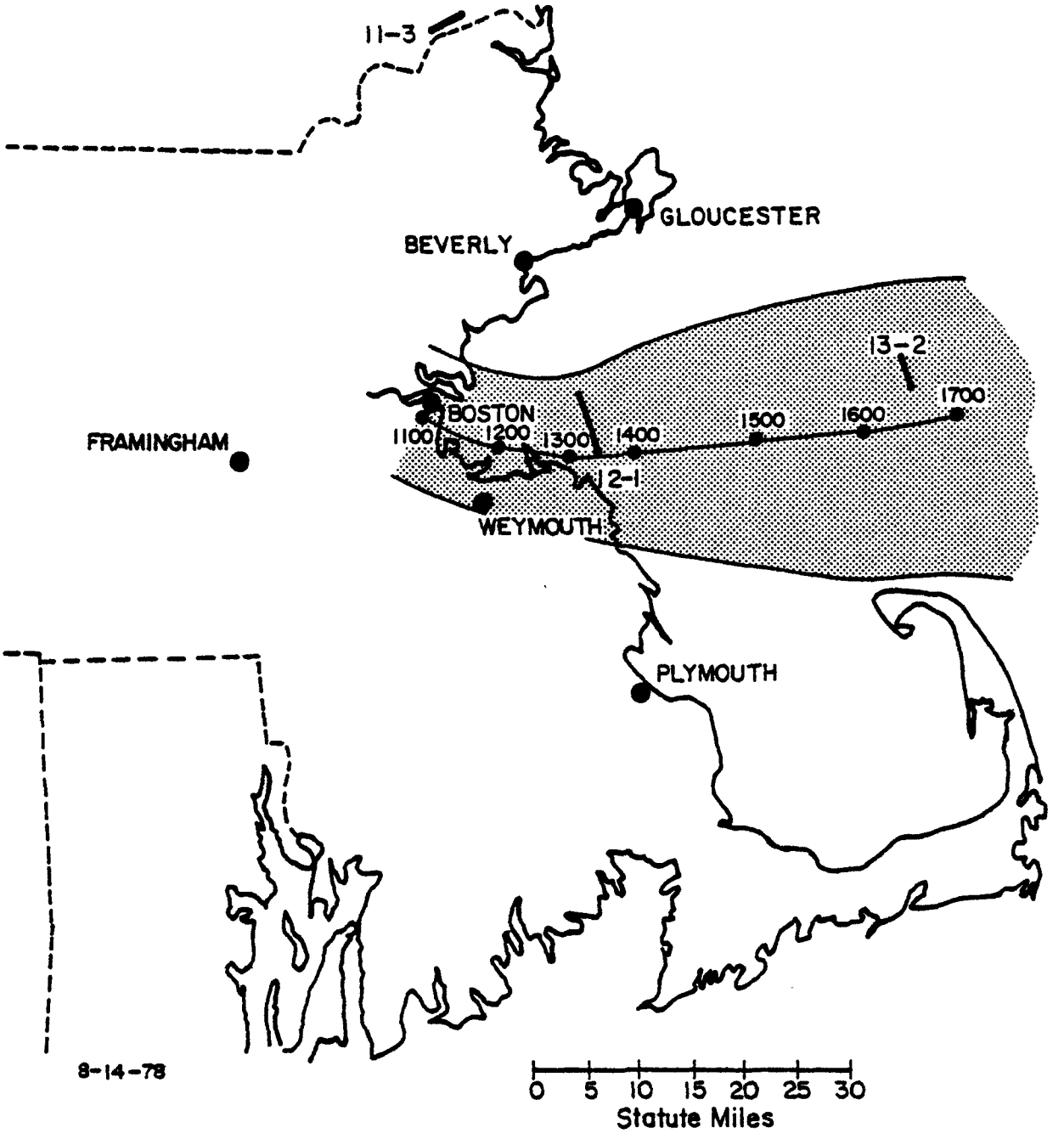

FIGURE 22. AIR PARCEL TRAJECTORY AND AIRCRAFT SAMPLE POSITIONS FOR 14 AUGUST, 1978

Using the general background concentrations and the measurements from Sample 12-1 as input data for Equation III, the NO_x deficits shown in Table 21 have been calculated. All three tracers are in reasonable

TABLE 21. NO_x DEFICITS FOR FLIGHTS 12 AND 13, AUGUST 14, 1978

Sample No.	Reaction Time, hours	NO_x Deficit Based On:		
		CO	C_2H_2	F-11
13-2	3.3	.006 ppm	.002 ppm	.005 ppm

agreement; the average NO_x deficit is .004 ppm whether the F-11 results are included or not. Since Equation III predicts that .008 ppm of NO_x should have been present, it can be concluded that 50 percent of the NO_x present in the air at 1316 EDT has been lost after an additional 3.3 hours of reaction. Using the first-order rate equation, we calculate a pseudo-first order rate constant for NO_x removal of 0.20 hr^{-1} for the 3.3 hour interval. The C_2H_4/C_2H_2 ratio decreased from .43 to .17 over the same 3.3 hour reaction interval. As reported earlier, the average rate of ethylene removal appears similar to the NO_x decay rate. By comparison, the ratios of less reactive hydrocarbons like propane, isobutane and n-butane to acetylene changed very little over the 3.3 hour reaction period.

An example of the ozone and nitric acid profile of Boston's plume is included as Figure 23. The figure was constructed from the continuous instantaneous O_3 and $HONO_2$ data recorded during the plume traverse in which Sample 12-1 was collected. The traverse was flown about 30 km downwind of Boston shortly after 1300 EDT. The plume character of the ozone profile is clear. Ozone concentrations on the fringe of the plume were 85-95 ppb. In

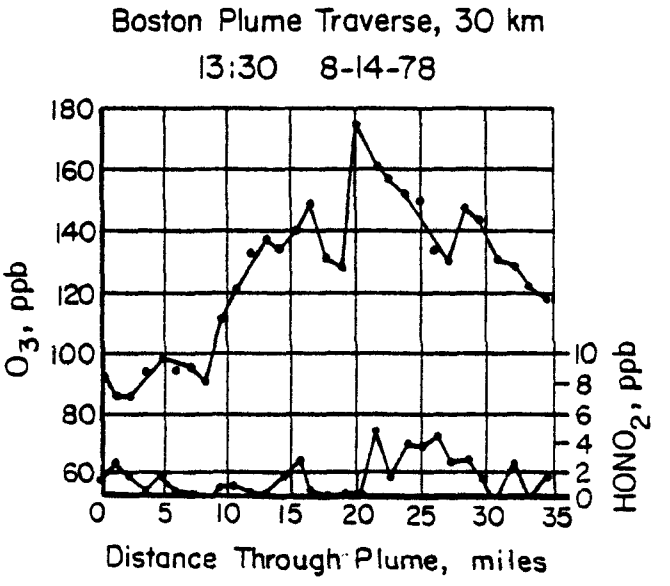

FIGURE 23. OZONE AND $HONO_2$ DURING URBAN PLUME TRAVERSE

the center of the plume O_3 exceeded .160 ppm. The nitric acid profile also displays a definite plume character, tracking O_3 reasonably well. Nitric acid was generally below 2 ppb outside the center of the urban plume, but averaged about 4 ppb near the plume center. The $O_3/HONO_2$ ratio was ∿35.

Summary of Case Studies

In previous sections we have described four case studies in which NO_x reactions were followed in a Lagrangian fashion in Boston's urban plume. All four experiments were conducted by instrumented aircraft on days when the urban plume was transported eastward over the ocean. This strategy was employed to eliminate fresh emissions into the air parcel during transport; such fresh emissions would greatly complicate the interpretation of the reaction rate data. The case studies were conducted on August 14, 18, 23 and 30, 1978. Inert tracers of opportunity (CO, C_2H_2, F-11) were used to account for air mass dilution, and the resulting data were plotted using the form of the first order rate equation. Once NO is largely converted to NO_2, further chemical reaction and physical scavenging processes can remove NO_x from the air. Data for the four case study experiments yielded reasonable straight line fits to the first-order equation. A tabulation summarizing the results of the four case studies is included as Table 22. The peak

TABLE 22. SUMMARY OF RATE DATA FOR CASE STUDY EXPERIMENTS

Date	Reaction Interval (hrs)	Maximum Transport Distance Observed (km)	Rate Constant for NO_x Removal (hr^{-1})
August 15, 1978	3	83	0.20
August 18, 1978	7	122	0.24
August 23, 1978	7.5	142	0.15
August 30, 1978	5.5	95	0.14

ozone concentrations in the plume during these four days ranged from 90 to 140 ppb. The pseudo-first order rate constants ranged from 0.14 to 0.24 for the four experiments, and averaged 0.18 hr^{-1}. For one case study, the conversion ratio, F_n, was used to calculate a rate of NO_x conversion to products of 0.23 hr^{-1}.

The NO_x removal rates for the four case studies indicate lifetimes (1/k) of from 4.2 to 7.1 hours, with an average of from 4.2 to 7.1 hours, with an average of 5.5 hours. We believe these values represent the first accurate determination of NO_x removal rate and lifetime in urban air. The data are applicable to sunny, moderately polluted urban air. These results should be validated and extended by further studies under similar as well as different environmental conditions.

The Philadelphia Urban Plume: August 24, 1978

Simultaneously with the Boston Plume Study, EPA sponsored a program on oxidant transport in the Philadelphia area. The Philadelphia investigation was aimed at evaluating methodology for quantifying ozone transport into and out of an urban area. To assist EPA and their contractors in this effort, we participated in a one day collaborative experiment during which we made aircraft measurements to help define the extent of Philadelphia's ozone plume and concentrations of pollutants therein. This experiment is included as a case study because it obtained for perhaps the first time simultaneous vertical profiles of nitric acid, O_3, NO_x and condensation nuclei in a transported urban plume.

The experiment was conducted on 24 August, a hot hazy day throughout the northeast U.S. The flights on 24 August were designed to provide a cross-section of the Philadelphia urban plume approximately 30 km downwind of the city at two different times. Weather was poor on departure from the Boston area, with heavy haze and low visibility prevailing throughout the flight. As shown in Figure 24, three vertical profiles as well as horizontal data at 1000' AGL were obtained downwind of the city in the late morning. After refueling, a second cross-sectional pattern was attempted, but had to be aborted after two vertical patterns due to IFR conditions and thunderstorms. The horizontal data and spiral locations from this second flight are shown in Figure 25. Vertical data on altitude, temperature, ozone concentration, NO_x concentration and particle concentration are presented in Tables 23 and 24 for Flight 33 and 34, respectively. The data represent one minute averages of the various measurements. The first set of profiles were obtained between 1140-1300 EDT, while Flight 34 profiles were taken between 1430-1530 EDT.

The horizontal data from Flight 33 (Figure 24) show high ozone concentrations pervading an area from Philadelphia to western Connecticut. With westerly winds, the ozone concentration downwind of Philadelphia reached 150 ppb during the late morning flight and nearly 200 ppb during afternoon monitoring. These levels are consistent with earlier studies of urban plumes in the northeast.[14]

A strong inversion at about 5000 feet MSL served to control the pollutant levels on 24 August. The temperature inversion does not show up very clearly in some of the vertical profile data in Tables 23 and 24 due to the data averaging. There is a clear drop in O_3, CN and in most cases NO_x at this altitude in all the spirals conducted on 24 August, indicating the presence of the inversion. In all cases, high concentrations of O_3 were observed beneath the inversion. Ozone levels above the inversion were in the 40-60 ppb range characteristic of the relatively unpolluted troposphere during midafternoons. The concentration of nitrogen oxides above the inversion layer was near the limit of detection of the chemiluminescence monitor used in these flights. The concentration of condensation nuclei increased significantly between the morning and afternoon profiles, both within and

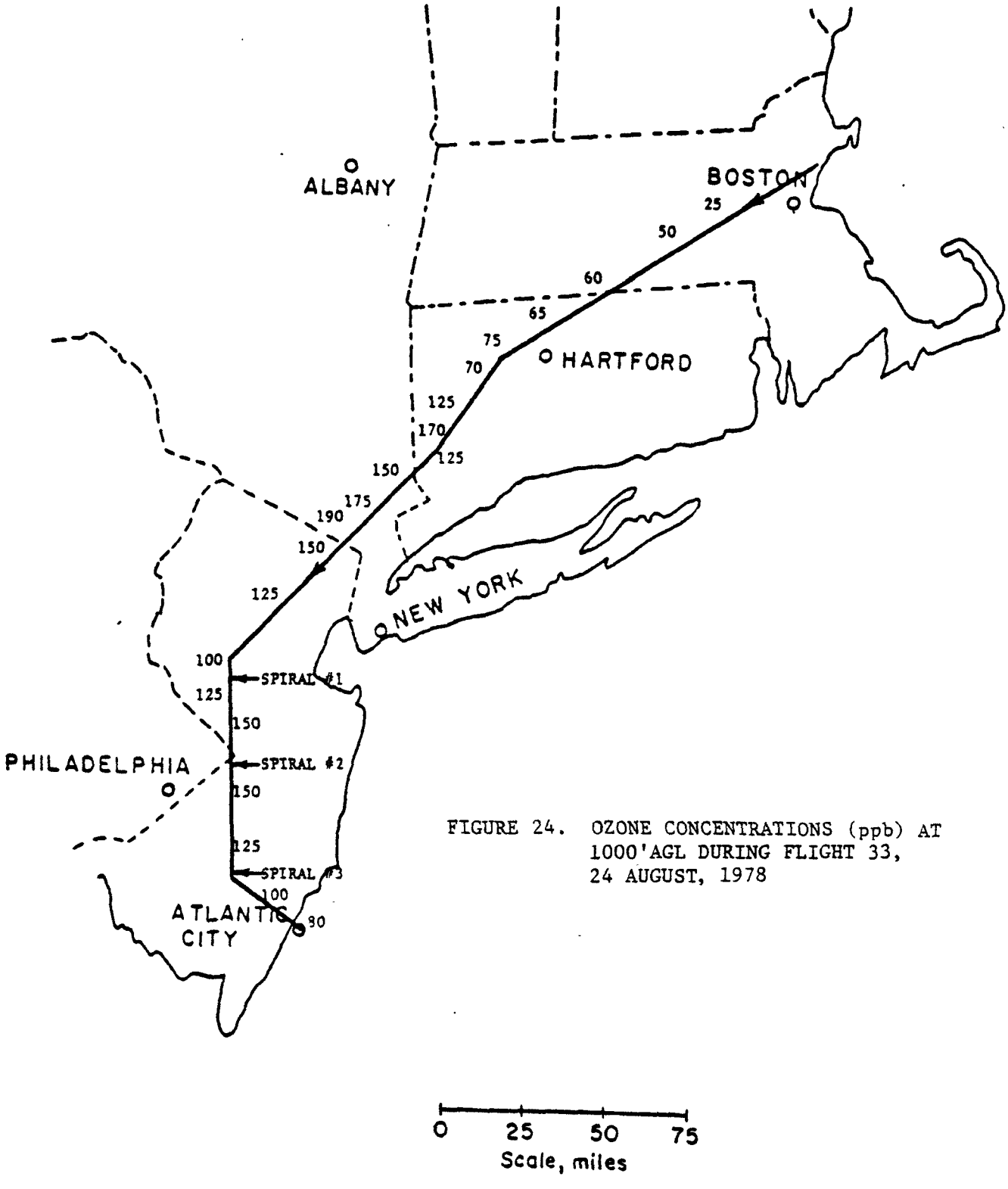

FIGURE 24. OZONE CONCENTRATIONS (ppb) AT 1000'AGL DURING FLIGHT 33, 24 AUGUST, 1978

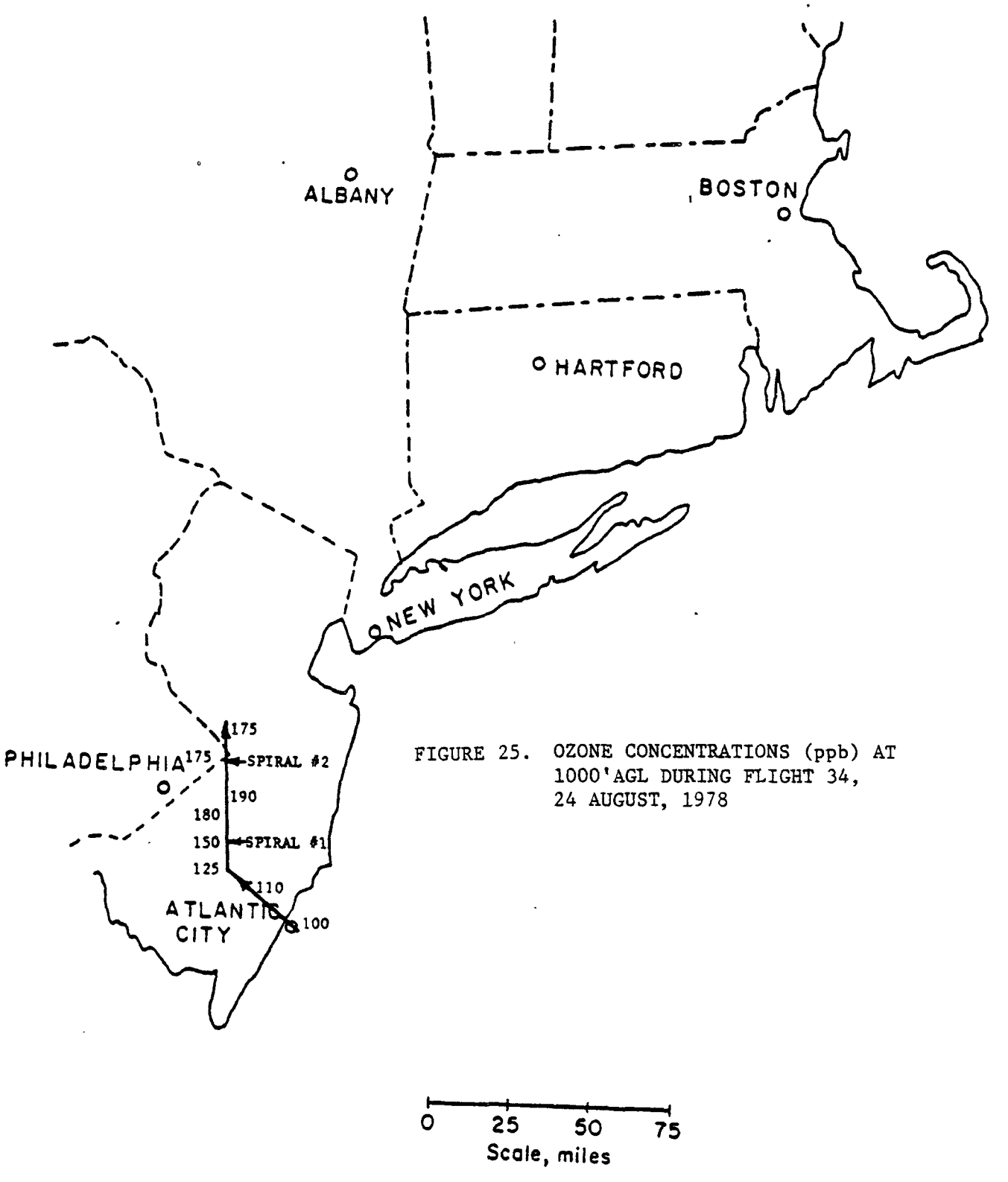

FIGURE 25. OZONE CONCENTRATIONS (ppb) AT 1000'AGL DURING FLIGHT 34, 24 AUGUST, 1978

TABLE 23. RESULTS OF VERTICAL PROFILES FROM FLIGHT 33, 24 AUGUST, 1978

Time (EDT)	Altitude (Feet MSL)	Temperature (°C)	O_3 (ppm)	NO_x (ppm)	CNC (10^4 particles/cc)
		Spiral 1			
1142	1,470	24.3	.109	.006	4.2
1143	1,540	24.1	.109	.008	3.2
1144	1,730	23.3	.105	.009	2.9
1145	1,890	22.7	.111	.008	3.9
1146	1,980	22.7	.112	.007	4.4
1147	2,310	22.1	.122	.005	4.1
1148	2,700	21.1	.124	.005	2.9
1149	2,880	20.7	.122	.005	2.1
1150	3,030	20.7	.120	.005	1.1
1151	3,380	19.9	.115	.004	1.2
1152	3,800	18.9	.109	.003	-
1153	4,030	18.1	.117	.005	0.9
1154	4,700	17.6	.065	.003	-
1155	5,230	17.1	.045	.001	-
1156	5,600	16.0	.049	.002	-
1157	6,090	14.3	.047	.002	-
1158	6,510	13.1	.044	.001	-
1159	6,870	11.9	.046	.002	-
1200	7,110	11.2	.045	.002	-
		Spiral 2			
1222	1,350	25.9	.155	.014	4.3
1223	1,580	25.1	.151	.019	3.2
1224	1,930	23.7	.155	.019	4.6
1225	2,390	22.2	.149	.018	4.3
1226	2,940	20.5	.137	.014	3.3
1227	3,140	20.1	.108	.006	4.4
1228	3,600	18.7	.089	.004	-
1229	4,110	17.3	.107	.003	1.1
1230	4,570	16.6	.075	.002	.2
1231	5,010	17.3	.037	.004	.02
1232	5,340	16.9	.053	.002	.4
1233	5,800	15.3	.057	.002	.3
1234	6,120	14.3	.049	.002	.3
1235	6,560	12.7	.046	.001	.5
1236	6,870	11.9	.044	.001	.2
1237	7,050	-	.046	.001	.01

TABLE 23. (Continued)

Time (EDT)	Altitude (Feet MSL)	Temperature (°C)	O_3 (ppm)	NO_x (ppm)	CNC 10^4 particles/cc)
			Spiral 3		
1246	1,600	26.1	.117	.006	3.8
1247	1,770	25.2	.111	.005	4.7
1248	2,400	22.4	.108	.006	3.3
1249	2,740	21.7	.105	.006	3.7
1250	3,250	19.6	.109	.006	2.0
1251	3,690	18.9	.087	.003	0.8
1252	4,040	17.7	.095	.004	0.6
1253	4,630	17.4	.078	.002	0.1
1254	5,190	17.2	.046	.002	0.6
1255	5,590	16.1	.053	.002	0.6
1256	6,160	14.2	.048	.002	0.5
1257	6,660	12.8	.050	.003	0.3
1258	6,930	11.8	.047	.002	0.1

TABLE 24. RESULTS OF VERTICAL PROFILES FROM FLIGHT 34, 24 AUGUST, 1978

Time (EDT)	Altitude (Feet MSL)	Temperature °C	O_3 (ppm)	NO_x (ppm)	CNC (10^4 particles/cc)
		Spiral 1			
1432	1,460	27.0	.152	.005	7.8
1433	1,660	25.8	.148	.005	9.0
1434	2,000	24.7	.146	.006	9.3
1435	2,370	23.2	.148	.006	10.5
1436	2,800	21.9	.147	.006	9.2
1437	3,120	20.9	.144	.006	8.7
1438	3,470	19.4	.154	.007	9.1
1439	3,780	18.3	.149	.006	8.9
1440	4,130	17.2	.145	.007	8.6
1441	4,550	16.5	.117	.007	9.0
1442	4,970	18.4	.040	.001	4.5
1443	5,290	17.3	.054	.001	4.4
1444	5,570	16.5	.052	<.001	4.8
1445	5,750	16.3	.050	.001	3.9
1446	6,150	14.9	.049	.003	3.9
1447	6,460	13.5	.053	.001	3.8
1448	6,810	12.8	.049	.003	3.5
1449	7,180	11.7	.045	.001	3.6
		Spiral 2			
1512	1,260	27.8	.179	.013	10.6
1513	1,410	27.1	.178	.012	11.0
1514	1,680	26.5	.177	.013	11.3
1515	2,090	24.9	.173	.013	11.5
1516	2,470	23.7	.178	.012	11.2
1517	2,850	22.4	.171	.014	10.3
1518	3,240	20.9	.171	.011	11.4
1519	3,550	19.7	.170	.011	11.6
1520	3,970	18.6	.159	.012	11.5
1521	4,500	17.5	.122	.009	11.2
1522	4,880	18.8	.042	.002	9.7
1523	5,300	18.3	.049	.001	6.1
1524	5,650	17.5	.061	.002	8.1
1525	6,010	16.3	.066	.003	10.4
1526	6.410	15.0	.065	.002	8.2
1527	6,730	14.4	.064	.001	8.7
1528	7,120	14.2	.050	.002	8.3

above the inversion. However, the instrument performance was not entirely satisfactory during the morning flight, and these data are included with a caveat.

A better representation of the data from these flights is obtained by plotting instantaneous data points against altitude. Such a plot for spiral No. 1 of Flight 34 is presented in Figure 26. The temperature structure of the atmosphere as well as pollutant concentration behavior becomes much clearer when the unaveraged data are employed.

The inversion is pictured quite clearly in the temperature profile in Figure 26. The concentrations of O_3, NO_x, $HONO_2$ and CN all drop significantly above the inversion. The nitric acid concentration averages approximately 6 ppb in the polluted layer and drops to about 2 ppb above the inversion. The concentration above the inversion is somewhat uncertain due to the instrumental detection limit. The $O_3/HONO_2$ ratio within the polluted layer below 5000 feet averages about 25. This is within the range we have observed for this ratio in other urban areas and is similar to the ratio reported earlier for the transported Boston plume for 30 August.

The data from these two flights are being interpreted by others as part of the analysis of the Philadelphia study data base. The data have been reported briefly here because of their relevance to the issue of atmospheric nitrates.

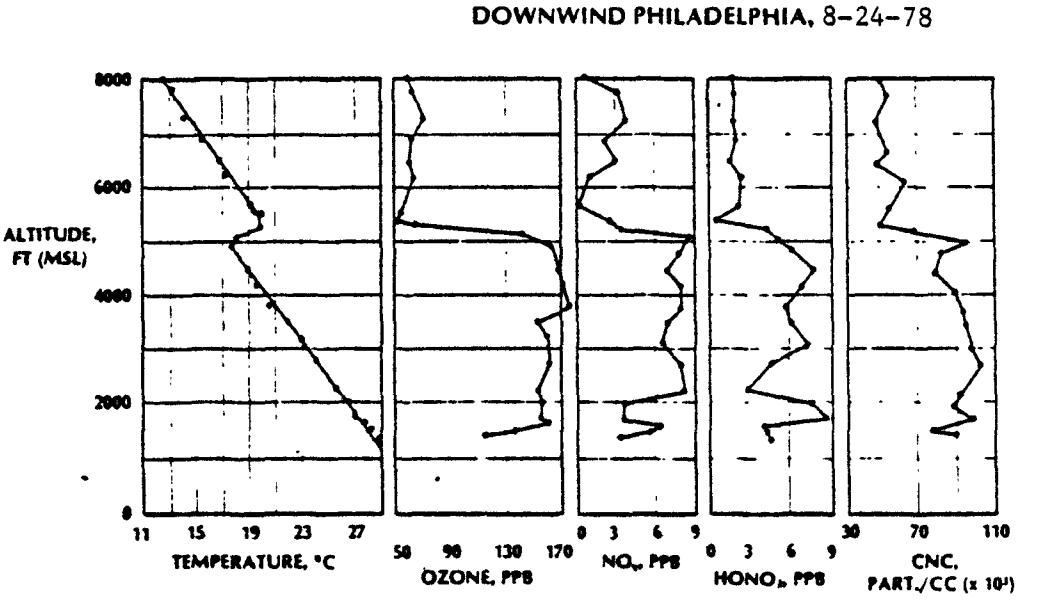

FIGURE 26. VERTICAL PROFILES DOWNWIND OF PHILADELPHIA

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APPENDIX A

GROUND LEVEL DATA FROM BEVERLY AIRPORT

BEVERLY AIRPORT, MA.

JULY 27, 1978

	9	10	11	12	13	14	15	16	17	18	19	20
IRAD - LANGLEY/M	-1.000	.507	.516	.588	.545	.562	.545	.434	.241	.182	.126	.037
WIND SPEED - MPH	-1.00	10.40	11.40	11.14	10.50	7.13	10.63	10.10	11.17	8.23	9.93	10.87
WIND DIR - DEG	-1.	211.	225.	235.	229.	230.	244.	244.	243.	231.	228.	229.
TEMP - DEG C	-1.0	3.3	6.3	8.3	9.7	11.0	11.2	10.9	10.3	9.5	8.9	7.1
RH - %	-1.0	73.7	69.3	66.1	62.1	60.4	58.4	58.8	59.8	61.8	63.0	66.8
O3 - PPM	-1.000	.043	.063	.083	.087	.084	.085	.080	.077	.068	.066	.059
NOX - PPM	-1.000	.016	.011	.006	.005	.004	.006	.009	.009	.013	.012	.015
TOTAL OXIDIZED N	-1.000	.016	.010	.005	.004	.004	.005	.008	.009	.012	.011	.013
HNO3 - PPM	-1.000	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	-1.00	1.69	1.72	2.57	2.80	2.74	2.95	2.65	2.33	2.21	2.21	2.16
PAN-PPM	-1.000	-1.000	.005	.007	.008	.008	.007	.006	-1.000	-1.000	-1.000	-1.000

	21	22	23	24	1	2	3	4	5	6	7	8
IRAD - LANGLEY/M	.014	.012	.012	.010	.012	.013	.014	.013	.013	.015	.045	.164
WIND SPEED - MPH	8.87	8.70	8.13	6.68	9.40	3.97	3.77	1.90	3.20	4.80	3.73	6.50
WIND DIR - DEG	212.	201.	197.	184.	208.	264.	245.	189.	184.	210.	233.	228.
TEMP - DEG C	4.9	2.6	1.8	.6	1.9	8.1	19.1	18.2	17.8	17.7	17.8	19.2
RH - %	70.8	76.9	82.9	88.9	88.2	92.1	94.1	94.1	94.1	94.1	94.1	94.1
O3 - PPM	.047	.025	.019	.019	.026	.032	.042	.036	.029	.030	.023	.015
NOX - PPM	.023	.031	.032	.026	.019	.010	.006	.006	.009	.011	.020	.038
TOTAL OXIDIZED N	.021	.030	.029	.024	.017	.009	.005	.005	.007	.009	.018	.036
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	2.17	2.03	2.22	2.55	3.34	4.52	1.43	1.62	2.02	2.53	2.88	2.38
PAN - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000

DAILY AVERAGE

IRAD - LANGLEY/M	.201
WIND SPEED - MPH	7.84
WIND DIR - DEG	222.
TEMP - DEG C	9.9
RH - %	76.7
O3 - PPM	.049
NOX - PPM	.015
TOTAL OXIDIZED N	.013
HNO3 - PPM	≤ .002
BSCAT - 1/M	2.43

BEVERLY AIRPORT, MA.

JULY 28, 1978

	9	10	11	12	13	14	15	16	17	18	19	20
IRAD - LANGLEY/M	.347	.510	.334	.609	.454	.293	.389	.488	.413	.235	.117	.037
WIND SPEED - MPH	6.13	6.57	4.80	3.51	4.77	2.80	3.50	5.17	5.43	3.53	2.80	1.28
WIND DIR - DEG	228.	258.	248.	265.	302.	251.	313.	236.	243.	278.	306.	279.
TEMP - DEG C	22.3	24.9	24.5	26.4	25.9	25.5	25.8	26.5	26.3	22.7	24.5	23.3
RH - %	89.6	74.7	74.5	70.1	67.1	64.9	64.3	62.0	58.0	65.8	59.2	67.1
O3 - PPM	.025	.047	.061	.065	.067	.056	.060	.057	.056	.043	.042	.034
NOX - PPM	.036	.025	.012	.010	.006	.009	.008	.008	.007	.012	.013	.018
TOTAL OXIDIZED N	.033	.023	.011	.009	.007	.008	.006	.007	.006	.011	.011	.016
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	1.01	.80	.95	1.13	1.25	1.24	1.32	1.31	1.02	.67	.74	.92
PAN - PPM	-1.000	≤0.001	≤0.001	≤0.001	.001	.001	.002	.003	.002	≤0.001	≤0.001	≤0.001

	21	22	23	24	1	2	3	4	5	6	7	8
IRAD - LANGLEY/M	.016	.011	.010	.010	.010	.010	.009	.010	.010	.013	.087	.244
WIND SPEED - MPH	4.10	2.93	1.90	2.33	1.70	2.60	2.00	4.33	3.57	3.89	1.83	2.57
WIND DIR - DEG	261.	251.	151.	241.	174.	175.	277.	67.	284.	239.	147.	185.
TEMP - DEG C	21.5	20.0	18.9	17.7	16.8	15.8	14.7	14.6	14.1	13.5	15.3	17.8
RH - %	75.8	78.2	73.7	78.3	79.5	79.0	81.5	79.5	77.3	78.8	73.1	65.4
O3 - PPM	.021	.021	.017	.011	.009	.014	.012	.018	.022	.021	.020	.021
NOX - PPM	.025	.014	.013	.017	.019	.015	.015	.010	.007	.006	.006	.008
TOTAL OXIDIZED N	.022	.012	.011	.015	.018	.014	.014	.009	.006	.005	.006	.007
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	1.04	.71	.77	.78	.68	.54	.50	.42	.38	.39	.36	.37
PAN - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000

DAILY AVERAGE

IRAD - LANGLEY/M	.197
WIND SPEED - MPH	3.50
WIND DIR - DEG	236.
TEMP - DEG C	20.8
RH - %	72.1
O3 - PPM	.034
NOX - PPM	.013
TOTAL OXIDIZED N	.012
HNO3 - PPM	≤ .002
BSCAT - 1/M	.80

BEVERLY AIRPORT, MA.

AUGUST 2, 1978

	9	10	11	12	13	14	15	16	17	18	19	20
IRAD - LANGLEY/M	.108	.139	.146	.199	.274	.358	.309	.145	.227	-1.000	.051	.030
WIND SPEED - MPH	5.47	5.40	5.77	6.07	6.63	7.10	5.23	4.37	3.13	-1.00	4.40	1.93
WIND DIR - DEG	32.	91.	49.	51.	56.	72.	68.	126.	77.	-1.	160.	183.
TEMP - DEG C	16.7	17.3	17.5	17.7	18.3	19.0	19.9	19.2	20.3	-1.0	18.3	18.0
RH - %	93.6	93.7	93.6	93.7	93.6	92.8	87.5	91.9	87.6	-1.0	92.5	93.5
O3 - PPM	.020	.028	.031	.032	.038	.047	.052	.043	.049	-1.000	.026	.021
NOX - PPM	.011	.005	.008	.004	.004	.002	.002	.013	.006	-1.000	.020	.020
TOTAL OXIDIZED N	.010	.005	.007	.004	.003	≤ .002	≤ .002	.012	.007	-1.000	.020	.020
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	-1.000	≤ .002	≤ .002
BSCAT - 1/M	2.96	3.05	2.90	2.74	2.10	1.90	1.47	1.53	1.38	-1.00	.79	.53
PAN - PPM	-1.000	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001

	21	22	23	24	1	2	3	4	5	6	7	8
IRAD - LANGLEY/M	.020	.018	.017	.016	.016	.015	.016	.016	.015	.016	.023	.050
WIND SPEED - MPH	1.97	3.67	2.97	3.13	2.60	1.30	1.47	2.17	3.07	4.37	3.10	4.23
WIND DIR - DEG	183.	165.	158.	181.	172.	186.	163.	163.	165.	157.	158.	161.
TEMP - DEG C	17.6	17.3	16.7	16.7	16.7	16.7	16.9	17.1	16.9	16.7	17.0	16.1
RH - %	93.5	93.6	93.7	93.6	93.6	93.5	93.7	93.6	93.6	93.6	93.6	93.7
O3 - PPM	.011	.019	.019	.018	.014	.017	.016	.015	.019	.017	.015	.010
NOX - PPM	.030	.021	.012	.011	.015	.012	.011	.009	.006	.006	.010	.019
TOTAL OXIDIZED N	.029	.020	.012	.011	.014	.010	.010	.009	.006	.005	.009	.019
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	.52	.71	.89	.78	.94	1.21	1.33	1.44	1.87	2.95	2.90	2.30
PAN - PPM	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001

DAILY AVERAGE

IRAD - LANGLEY/M	.097
WIND SPEED - MPH	3.89
WIND DIR - DEG	129.
TEMP - DEG C	17.6
RH - %	92.9
O3 - PPM	.025
NOX - PPM	.011
TOTAL OXIDIZED N	.011
HNO3 - PPM	≤ .002
BSCAT - 1/M	1.70

BEVERLY AIRPORT, MA.

AUGUST 3, 1978

	9	10	11	12	13	14	15	16	17	18	19	20
IRAD - LANGLEY/M	.117	.154	.326	.172	.515	.342	.585	.347	.394	.210	.095	.040
WIND SPEED - MPH	4.44	3.97	5.33	7.33	9.57	7.30	9.96	12.20	13.87	12.20	9.27	8.27
WIND DIR - DEG	104.	186.	230.	195.	224.	221.	218.	229.	214.	220.	202.	198.
TEMP - DEG C	14.9	19.6	23.3	24.5	26.3	27.5	28.4	28.6	28.7	27.8	26.4	25.1
RH - %	93.7	93.7	91.7	86.1	78.8	71.2	63.8	60.4	58.3	61.1	67.7	73.7
O3 - PPM	.010	.009	.017	.018	.033	.052	.059	.060	.053	.049	.031	.008
NOX - PPM	.024	.031	.039	.026	.020	.011	.007	.009	.007	.013	.023	.036
TOTAL OXIDIZED N	.023	.029	.038	.026	.019	.010	.006	.009	.007	.013	.021	.035
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	2.51	3.45	1.95	1.22	.85	.91	.85	.87	.69	.65	.92	.99
PAN - PPM	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001

	21	22	23	24	1	2	3	4	5	6	7	8
IRAD - LANGLEY/M	.018	.016	.013	.013	.013	.011	.012	.011	.012	.013	.027	.195
WIND SPEED - MPH	7.50	8.23	7.87	7.40	9.43	10.37	5.77	7.90	6.49	7.33	8.33	6.93
WIND DIR - DEG	213.	194.	188.	199.	213.	226.	206.	213.	231.	219.	225.	222.
TEMP - DEG C	24.2	23.3	22.2	22.4	22.6	21.9	21.2	22.0	22.0	20.8	21.2	22.6
RH - %	78.2	82.6	86.6	87.6	87.1	86.8	93.6	93.6	91.1	93.7	93.7	90.9
O3 - PPM	.003	≤ .001	≤ .001	≤ .001	≤ .001	.011	.007	.002	.013	.021	.018	.010
NOX - PPM	.032	.041	.044	.032	.028	.008	.009	.014	.004	.003	.006	.013
TOTAL OXIDIZED N	.031	.041	.042	.032	.019	.008	.009	.013	.003	.003	.005	.012
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	1.17	1.45	1.72	1.73	1.36	.95	1.50	1.69	1.51	1.52	1.19	1.56
PAN - PPM	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001

DAILY AVERAGE

IRAD - LANGLEY/M	.152
WIND SPEED - MPH	8.22
WIND DIR - DEG	211.
TEMP - DEG C	23.6
RH - %	81.9
O3 - PPM	.020
NOX - PPM	.020
TOTAL OXIDIZED N	.019
HNO3 - PPM	≤ .002
BSCAT - 1/M	1.38

BEVERLY AIRPORT, MA.

AUGUST 4, 1978

	9	10	11	12	13	14	15	16	17	18	19	20
IRAD - LANGLEY/M	.232	.244	.361	.172	.078	.060	.180	.081	.103	.079	.052	.039
WIND SPEED - MPH	8.97	8.17	8.60	10.93	4.50	2.80	1.23	2.57	4.43	4.10	2.90	2.37
WIND DIR - DEG	224.	232.	230.	238.	279.	260.	269.	224.	217.	229.	228.	231.
TEMP - DEG C	23.8	23.9	24.5	23.5	19.1	18.9	19.9	19.0	17.6	17.2	17.0	17.2
RH - %	86.0	80.3	76.3	76.5	92.4	93.5	93.5	93.5	93.5	93.5	93.5	93.5
O3 - PPM	.013	.020	.029	.035	.038	.035	.032	.023	.010	.007	.001	≤ .001
NOX - PPM	.015	.012	.009	.009	.007	.013	.018	.024	.049	.055	.085	.100
TOTAL OXIDIZED N	.014	.012	.008	.008	.006	.012	.017	.024	.048	.055	.085	.099
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	1.58	1.85	.88	1.10	.85	1.25	1.22	1.13	1.00	.99	1.68	1.83
PAN - PPM	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001

	21	22	23	24	1	2	3	4	5	6	7	8
IRAD - LANGLEY/M	.027	.026	.024	.025	.024	.025	.026	.029	.029	.029	.042	.106
WIND SPEED - MPH	2.87	1.63	.70	1.60	1.50	1.00	1.90	2.03	1.03	1.10	1.50	2.93
WIND DIR - DEG	223.	230.	268.	213.	242.	293.	319.	228.	305.	239.	226.	126.
TEMP - DEG C	16.7	16.1	15.8	15.4	15.4	15.7	16.0	16.5	16.5	16.9	17.0	16.3
RH - %	93.6	93.6	93.6	93.6	93.6	93.6	93.7	93.6	93.6	93.6	93.7	93.6
O3 - PPM	≤ .001	≤ .001	≤ .001	≤ .001	≤ .001	≤ .001	≤ .001	≤ .001	≤ .001	≤ .001	.002	.007
NOX - PPM	.185	.124	.109	.105	.077	.068	.065	.046	.036	.032	.028	.020
TOTAL OXIDIZED N	.135	.121	.109	.108	.078	.070	.065	.046	.035	.032	.028	.020
HNO3 - PPM	≤ .002	≤ .002	≤ .002	.002	≤ .002	.002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	2.01	2.01	1.96	2.07	2.14	2.08	2.51	2.86	3.13	4.27	3.92	2.25
PAN - PPM	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001

DAILY AVERAGE

IRAD - LANGLEY/M	.087
WIND SPEED - MPH	3.89
WIND DIR - DEG	241.
TEMP - DEG C	18.1
RH - %	91.5
O3 - PPM	.010
NOX - PPM	.052
TOTAL OXIDIZED N	.051
HNO3 - PPM	≤ .002
BSCAT - 1/M	1.90

BEVERLY AIRPORT, MA.

AUGUST 5, 1978

	9	10	11	12	13	14	15	16	17	18	19	20
IRAD - LANGLEY/M	.356	.487	.556	.466	.412	.387	.311	-1.000	-1.000	-1.000	.093	.036
WIND SPEED - MPH	4.29	6.10	-1.00	6.05	5.08	5.73	6.63	-1.00	-1.00	-1.00	3.80	4.30
WIND DIR - DEG	127.	61.	-1.	60.	82.	150.	167.	-1.	-1.	-1.	202.	142.
TEMP - DEG C	18.5	19.5	20.8	20.9	20.2	19.7	17.8	20.0	-1.0	-1.0	17.4	16.5
RH - %	93.6	85.8	68.7	58.8	64.4	69.8	77.8	74.0	-1.0	-1.0	84.9	90.4
SO2 - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	.006	.010	-1.000	-1.000	.150	.145
O3 - PPM	.016	.029	-1.000	.050	.058	.055	.070	.067	-1.000	-1.000	.055	.049
NOX - PPM	.013	.007	.005	.005	.006	.017	.017	.022	-1.000	-1.000	.030	.032
TOTAL OXIDIZED N	.012	.007	.004	.005	.006	.017	.017	.022	-1.000	-1.000	.031	.032
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	-1.000	-1.000	≤ .002	≤ .002
BSCAT - 1/M	1.49	1.12	-1.00	.55	.66	.82	1.09	1.42	-1.00	-1.00	1.91	2.23
PAN - PPM	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001

	21	22	23	24	1	2	3	4	5	6	7	8
IRAD - LANGLEY/M	.022	.020	.019	.019	.019	.019	.020	.020	.020	.020	.029	.034
WIND SPEED - MPH	2.93	3.20	2.27	2.03	2.33	1.10	2.97	2.54	1.87	1.10	2.67	2.80
WIND DIR - DEG	175.	178.	197.	205.	193.	284.	225.	226.	227.	248.	236.	225.
TEMP - DEG C	15.6	16.2	16.2	16.3	16.6	17.2	18.1	18.8	18.6	18.1	18.9	19.6
RH - %	93.9	93.9	93.9	93.9	93.9	93.9	93.9	93.9	93.9	93.9	93.9	93.9
SO2 - PPM	.061	.054	.049	.048	.051	.068	.071	.062	.059	.050	.046	.050
O3 - PPM	.041	.031	.023	.014	.006	≤ .001	≤ .001	.003	.015	.012	.016	.014
NOX - PPM	.029	.032	.036	.039	.045	.068	.072	.044	.024	.019	.013	.013
TOTAL OXIDIZED N	.030	.033	.037	.039	.047	.070	.074	.046	.024	.020	.013	.013
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	.002	.002	.003	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	2.13	2.13	2.47	2.94	3.05	3.57	3.93	3.59	2.99	3.09	2.46	2.15
PAN - PPM	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001

DAILY AVERAGE

IRAD - LANGLEY/M	.160
WIND SPEED - MPH	3.49
WIND DIR - DEG	176.
TEMP - DEG C	18.3
RH - %	86.1
SO2 - PPM	.061
O3 - PPM	.030
NOX - PPM	.027
TOTAL OXIDIZED N	.027
HNO3 - PPM	≤ .002
BSCAT - 1/M	2.18

BEVERLY AIRPORT, MA.

AUGUST 7, 1978

	9	10	11	12	13	14	15	16	17	18	19	20
IRAD - LANGLEY/M	.156	.187	.244	.271	.363	.167	.294	.213	.118	.098	.042	.031
WIND SPEED - MPH	2.66	4.23	7.20	5.77	3.11	4.00	7.17	6.80	5.70	6.10	4.93	3.97
WIND DIR - DEG	118.	62.	56.	71.	123.	137.	68.	55.	45.	82.	96.	71.
TEMP - DEG C	20.9	21.9	22.4	21.8	23.3	22.7	22.0	21.7	20.7	20.7	20.5	19.6
RH - %	93.9	93.9	94.0	93.9	93.1	90.9	92.6	93.3	94.0	93.9	94.0	93.9
SO2 - PPM	.057	.041	.044	.034	.047	.061	.046	.046	.045	.045	.044	.033
O3 - PPM	.010	.021	.032	.042	.044	.051	.061	.060	.057	.059	.055	.045
NOX - PPM	.026	.014	.010	.006	.014	.013	.007	.010	.009	.011	.014	.010
TOTAL OXIDIZED N	.025	.013	.011	.006	.014	.013	.007	.009	.008	.012	.013	.009
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	1.18	.75	.91	1.23	1.17	1.28	1.36	1.51	1.85	2.00	2.21	1.94
PAN - PPM	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	.003	.003	.002	≤0.001

	21	22	23	24	1	2	3	4	5	6	7	8
IRAD - LANGLEY/M	.030	.021	.017	.016	.016	.015	.015	.014	.015	.015	.018	.035
WIND SPEED - MPH	3.60	3.00	3.40	1.20	1.70	1.73	2.00	4.13	3.23	2.67	3.73	2.77
WIND DIR - DEG	75.	158.	29.	120.	177.	160.	142.	163.	227.	327.	87.	71.
TEMP - DEG C	19.5	19.2	17.4	17.5	17.3	17.0	16.9	18.3	17.8	18.2	17.9	18.6
RH - %	94.0	94.0	94.0	94.0	94.0	94.0	94.1	94.0	93.9	94.1	93.9	94.1
SO2 - PPM	.028	.035	.038	.047	.047	.040	.042	.056	.055	.035	.031	.028
O3 - PPM	.040	.035	.038	.039	.033	.028	.025	.013	.006	.005	.023	.025
NOX - PPM	.007	.008	.005	.003	.003	.003	.004	.013	.019	.020	.006	.004
TOTAL OXIDIZED N	.006	.007	.005	.003	.003	.003	.004	.013	.018	.020	.005	.004
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	1.16	1.94	1.90	1.98	2.14	1.31	1.25	1.31	2.53	2.33	1.60	1.53
PAN - PPM	.002	.002	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001

DAILY AVERAGE

IRAD - LANGLEY/M	.101
WIND SPEED - MPH	3.95
WIND DIR - DEG	113.
TEMP - DEG C	19.7
RH - %	93.7
SO2 - PPM	.043
O3 - PPM	.035
NOX - PPM	.010
TOTAL OXIDIZED N	.009
HNO3 - PPM	≤ .002
BSCAT - 1/M	1.60

BEVERLY AIRPORT, MA.

AUGUST 8, 1978

	9	10	11	12	13	14	15	16	17	18	19	20
IRAD - LANGLEY/M	.196	.151	.511	.569	.530	.512	.588	.394	.174	.298	.123	.048
WIND SPEED - MPH	2.33	1.57	2.09	3.00	4.44	5.23	7.10	6.53	5.40	3.73	3.67	2.83
WIND DIR - DEG	241.	135.	116.	212.	174.	207.	168.	169.	186.	158.	176.	184.
TEMP - DEG C	19.4	20.5	23.0	26.5	25.9	28.6	26.0	23.4	21.4	22.7	22.7	21.1
RH - %	94.1	94.0	92.8	82.6	80.5	67.7	73.4	81.6	90.5	93.5	90.9	93.9
SO2 - PPM	.037	.038	.039	.052	.122	.121	.356	.329	.246	.187	.117	.098
O3 - PPM	.018	.017	.028	.042	.062	.076	.064	.065	.056	.048	.044	.038
NOX - PPM	.012	.016	.023	.019	.024	.014	.034	.026	.031	.033	.031	.036
TOTAL OXIDIZED N	.012	.015	.023	.019	.023	.012	.033	.026	.038	.033	.031	.037
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	1.08	.78	.61	.45	.82	1.00	.93	1.01	1.16	1.16	1.14	1.25
PAN - PPM	≤0.001	≤0.001	≤0.001	≤0.001	.001	.001	.001	.001	.001	.001	.001	.001

	21	22	23	24	1	2	3	4	5	6	7	8
IRAD - LANGLEY/M	.024	.020	.015	.015	.014	.013	.013	.010	.010	.012	.027	.208
WIND SPEED - MPH	3.63	6.17	4.50	3.53	2.73	2.33	4.20	3.00	2.00	2.43	2.87	4.87
WIND DIR - DEG	198.	225.	233.	239.	251.	253.	266.	287.	265.	249.	239.	233.
TEMP - DEG C	21.6	23.4	23.0	22.3	21.8	21.1	20.6	19.7	19.0	18.7	19.4	21.2
RH - %	93.9	89.8	90.0	94.0	90.8	84.3	88.9	82.4	85.8	87.0	84.8	80.3
SO2 - PPM	.102	.094	.091	.085	.078	.080	.081	.083	.084	.084	.091	.106
O3 - PPM	.022	.070	.067	.061	.051	.048	.050	.049	.046	.046	.045	.027
NOX - PPM	.051	.025	.023	.020	.015	.010	.006	.005	.005	.006	.008	.019
TOTAL OXIDIZED N	.052	.025	.023	.020	.016	.010	.007	.005	.005	.006	.009	.019
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	1.63	1.91	1.91	2.04	2.14	2.08	2.80	2.17	2.39	2.62	2.70	2.61
PAN - PPM	.001	.001	.001	.001	.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001

DAILY AVERAGE

IRAD - LANGLEY/M	.186
WIND SPEED - MPH	3.76
WIND DIR - DEG	213.
TEMP - DEG C	22.2
RH - %	86.6
SO2 - PPM	.116
O3 - PPM	.047
NOX - PPM	.020
TOTAL OXIDIZED N	.020
HNO3 - PPM	≤ .002
BSCAT - 1/M	1.56

BEVERLY AIRPORT, MA.

AUGUST 9, 1978

	9	10	11	12	13	14	15	16	17	18	19	20
IRAD - LANGLEY/M	.378	.542	.697	.737	.835	.794	.580	.428	.393	.288	.133	.042
WIND SPEED - MPH	3.43	4.67	6.70	6.30	5.18	7.13	6.08	5.70	8.71	6.18	5.43	5.73
WIND DIR - DEG	256.	259.	243.	255.	266.	261.	246.	257.	236.	235.	228.	226.
TEMP - DEG C	23.4	25.0	26.3	27.5	27.7	28.6	28.9	27.9	27.3	27.1	26.1	24.5
RH - %	74.5	68.8	61.9	54.1	47.0	44.6	42.9	45.8	48.6	50.4	50.9	55.1
SO2 - PPM	.011	.011	.013	.017	.021	.025	.022	.017	.014	.014	.013	.015
O3 - PPM	.071	.054	.053	.101	.097	.100	.103	.109	.110	.107	.100	.098
NOX - PPM	.021	.023	.012	.010	.006	.006	.007	.009	.010	.014	.015	.022
TOTAL OXIDIZED N	.022	.024	.013	.011	.006	.006	.008	.010	.013	.016	.018	.024
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	.002	≤ .002	.003	.002
BSCAT - 1/M	2.49	2.19	1.94	1.86	1.71	1.70	1.62	1.73	1.91	2.01	2.19	3.05
PAN - PPM	≤0.001	≤0.001	.002	.003	.002	.002	.004	.004	.006	.006	.004	.004

	21	22	23	24	1	2	3	4	5	6	7	8
IRAD - LANGLEY/M	.018	.016	.014	.013	.013	.012	.012	.013	.011	.013	.021	.119
WIND SPEED - MPH	5.30	6.13	3.80	4.47	5.17	3.47	2.03	2.60	2.90	2.03	1.93	2.07
WIND DIR - DEG	230.	233.	247.	234.	245.	254.	243.	245.	270.	248.	255.	273.
TEMP - DEG C	23.3	22.9	22.1	21.4	21.0	20.3	19.7	19.3	19.0	18.9	19.1	21.2
RH - %	61.7	66.6	70.3	73.1	75.3	79.6	81.9	84.3	85.1	85.4	84.9	77.0
SO2 - PPM	.015	.014	.016	.017	.017	.017	.017	.017	.016	.016	.015	.015
O3 - PPM	.077	.075	.069	.070	.083	.078	.070	.066	.063	.059	.052	.047
NOX - PPM	.026	.023	.024	.022	.018	.015	.013	.011	.009	.007	.010	.013
TOTAL OXIDIZED N	.028	.024	.025	.024	.019	.015	.014	.013	.009	.009	.011	.014
HNO3 - PPM	.003	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	3.58	4.06	4.39	4.66	4.95	5.46	5.77	6.07	5.94	5.93	5.58	4.47
PAN - PPM	.005	.004	.005	.007	.004	.006	.008	.005	.005	.005	.005	.005

DAILY AVERAGE

IRAD - LANGLEY/M	.255
WIND SPEED - MPH	4.71
WIND DIR - DEG	248.
TEMP - DEG C	23.7
RH - %	65.4
SO2 - PPM	.016
O3 - PPM	.082
NOX - PPM	.014
TOTAL OXIDIZED N	.016
HNO3 - PPM	≤ .002
BSCAT - 1/M	3.55

BEVERLY AIRPORT, MA.

AUGUST 10, 1978

	9	10	11	12	13	14	15	16	17	18	19	20
IRAD - LANGLEY/M	.243	.309	.539	.649	.756	.867	.707	.464	.418	.285	.135	.034
WIND SPEED - MPH	4.57	3.60	3.43	5.46	3.48	4.18	4.53	3.43	4.63	6.10	3.83	1.87
WIND DIR - DEG	259.	285.	265.	256.	223.	285.	321.	254.	269.	179.	282.	181.
TEMP - DEG C	22.6	22.9	24.9	25.8	26.5	27.7	27.2	27.8	27.0	25.9	25.3	22.6
RH - %	70.3	68.6	59.8	51.8	45.1	38.5	41.7	34.5	38.8	39.1	38.9	45.1
SO2 - PPM	.011	.009	.008	.011	.011	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
O3 - PPM	.046	.042	.048	.060	.061	.060	.063	.061	.062	.056	.047	.037
NOX - PPM	.017	.019	.009	.007	.004	.006	.006	.005	.005	.005	.007	.011
TOTAL OXIDIZED N	.019	.021	.010	.008	.006	.008	.007	.007	.007	.007	.008	.012
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	.002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	2.75	1.77	.95	.59	.38	≤ .23	.39	.25	.63	.56	.50	.49
PAN - PPM	.002	.001	≤0.001	≤0.001	≤0.001	≤0.001	.002	.002	.002	≤0.001	≤0.001	≤0.001

	21	22	23	24	1	2	3	4	5	6	7	8
IRAD - LANGLEY/M	.018	.014	.013	.012	.012	.012	.011	.011	.010	.013	.042	.217
WIND SPEED - MPH	2.90	2.50	2.37	2.07	1.93	2.00	2.17	2.50	2.40	1.47	.83	2.03
WIND DIR - DEG	180.	292.	237.	331.	216.	239.	285.	114.	302.	189.	279.	259.
TEMP - DEG C	19.8	18.8	17.5	15.3	16.2	14.9	14.3	13.5	13.0	11.9	13.6	17.9
RH - %	54.0	59.1	63.9	61.7	64.6	78.7	73.8	78.2	80.5	83.8	80.6	64.0
SO2 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
O3 - PPM	.025	.018	.012	.014	.009	.005	.010	.011	.012	.011	.007	.008
NOX - PPM	.015	.017	.019	.017	.019	.021	.015	.012	.011	.011	.016	.023
TOTAL OXIDIZED N	.015	.017	.020	.017	.019	.022	.016	.013	.011	.010	.016	.024
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	.58	.52	.51	.43	.42	.46	.43	.45	.43	.44	.44	.39
PAN - PPM	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001

DAILY AVERAGE

IRAD - LANGLEY/M	.241
WIND SPEED - MPH	3.09
WIND DIR - DEG	249.
TEMP - DEG C	20.5
RH - %	58.6
SO2 - PPM	.002
O3 - PPM	.033
NOX - PPM	.012
TOTAL OXIDIZED N	.013
HNO3 - PPM	≤ .002
BSCAT - 1/M	.62

BEVERLY AIRPORT, MA.

AUGUST 11, 1978

	9	10	11	12	13	14	15	16	17	18	19	20
IRAD - LANGLEY/M	.325	.519	.580	.639	.712	.556	.546	.599	-1.000	-1.000	-1.000	-1.000
WIND SPEED - MPH	2.43	1.37	3.46	5.17	6.17	8.40	8.13	8.90	-1.00	-1.00	-1.00	-1.00
WIND DIR - DEG	130.	171.	156.	161.	149.	172.	163.	135.	-1.	-1.	-1.	-1.
TEMP - DEG C	20.4	23.6	23.1	23.0	22.8	19.4	23.2	26.5	-1.0	-1.0	-1.0	-1.0
RH - %	55.0	45.7	40.9	35.9	35.6	38.1	39.5	38.3	-1.0	-1.0	-1.0	-1.0
SO2 - PPM	≤ .002	≤ .002	≤ .002	.021	.023	.016	.028	.028	-1.000	-1.000	-1.000	-1.000
O3 - PPM	.020	.047	.065	.060	.060	.068	.061	.064	-1.000	-1.000	-1.000	-1.000
NOX - PPM	.022	.010	.009	.030	.020	.012	.022	.023	-1.000	-1.000	-1.000	-1.000
TOTAL OXIDIZED N	.021	.009	.010	.030	.020	.024	.025	.024	-1.000	-1.000	-1.000	-1.000
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	.012	≤ .002	.002	-1.000	-1.000	-1.000	-1.000
BSCAT - 1/M	.34	.36	.40	.49	.39	.42	.47	.63	-1.00	-1.00	-1.00	-1.00
PAN - PPM	.002	.002	.002	.002	.002	.002	.001	.001	-1.000	-1.000	-1.000	-1.000

	21	22	23	24	1	2	3	4	5	6	7	8
IRAD - LANGLEY/M	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
WIND SPEED - MPH	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
WIND DIR - DEG	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.
TEMP - DEG C	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
RH - %	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
SO2 - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
O3 - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
NOX - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
TOTAL OXIDIZED N	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
HNO3 - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
BSCAT - 1/M	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
PAN - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000

DAILY AVERAGE

IRAD - LANGLEY/M	.560
WIND SPEED - MPH	5.50
WIND DIR - DEG	155.
TEMP - DEG C	22.7
RH - %	41.1
SO2 - PPM	.015
O3 - PPM	.056
NOX - PPM	.018
TOTAL OXIDIZED N	.021
HNO3 - PPM	.002
BSCAT - 1/M	.44

BEVERLY AIRPORT, MA.

AUGUST 15, 1978

	9	10	11	12	13	14	15	16	17	18	19	20
IRAD - LANGLEY/M	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	.426	.269	.100	.032
WIND SPEED - MPH	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	7.93	7.10	5.93	4.50
WIND DIR - DEG	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	170.	165.	173.	163.
TEMP - DEG C	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	24.6	23.4	21.5	19.9
RH - %	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	40.1	55.6	61.5	70.0
SO2 - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	.011	.017	.008	.003
O3 - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	.052	.046	.047	.046
NOX - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	.013	.017	.014	.015
TOTAL OXIDIZED N	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	.014	.017	.014	.015
HNO3 - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	.56	.69	.81	1.02
PAN - PPM	≤0.001	.001	.001	.001	-1.000	.008	.003	.003	.003	.003	.001	.001

	21	22	23	24	1	2	3	4	5	6	7	8
IRAD - LANGLEY/M	.018	.016	.014	-1.000	.014	.014	.014	.014	.013	.013	.013	.023
WIND SPEED - MPH	3.70	3.86	1.93	-1.00	2.40	1.63	1.73	1.90	2.67	3.07	3.07	3.23
WIND DIR - DEG	165.	171.	173.	-1.	159.	230.	249.	234.	226.	226.	220.	203.
TEMP - DEG C	18.9	19.0	18.9	-1.0	19.1	18.8	18.7	18.6	18.1	18.4	18.4	18.8
RH - %	79.9	81.3	85.9	-1.0	90.5	94.3	94.2	94.3	94.2	94.3	94.1	94.3
SO2 - PPM	≤ .002	≤ .002	≤ .002	-1.000	.004	.008	.010	.010	.009	.010	.014	.012
O3 - PPM	.035	.044	.036	-1.000	.028	.007	.015	.052	.081	.086	.081	.069
NOX - PPM	.023	.018	.025	-1.000	.034	.055	.071	.044	.021	.014	.011	.017
TOTAL OXIDIZED N	.023	.018	.026	-1.000	.035	.056	.071	.045	.021	.013	.011	.017
HNO3 - PPM	≤ .002	≤ .002	≤ .002	-1.000	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	1.29	1.42	1.98	-1.00	2.90	3.69	4.60	5.62	6.22	6.39	5.82	5.31
PAN - PPM	.003	.001	.001	.003	.008	.017	.019	.016	.016	.007	.005	.003

DAILY AVERAGE

IRAD - LANGLEY/M	.066
WIND SPEED - MPH	3.65
WIND DIR - DEG	198.
TEMP - DEG C	19.7
RH - %	82.2
SO2 - PPM	.008
O3 - PPM	.048
NOX - PPM	.026
TOTAL OXIDIZED N	.026
HNO3 - PPM	≤ .002
BSCAT - 1/M	3.24

BEVERLY AIRPORT, MA.

AUGUST 16, 1978

	9	10	11	12	13	14	15	16	17	18	19	20
IRAD - LANGLEY/M	.147	.416	.547	.571	.696	.578	.453	.483	.354	.216	-1.000	.038
WIND SPEED - MPH	8.50	7.57	6.50	6.14	6.47	8.06	4.47	7.47	7.89	9.83	-1.00	8.67
WIND DIR - DEG	222.	236.	246.	250.	233.	232.	246.	223.	224.	226.	-1.	215.
TEMP - DEG C	20.8	23.5	25.6	26.8	27.2	27.8	28.6	28.6	28.2	27.6	-1.0	24.9
RH - %	94.2	90.2	81.4	76.1	73.3	71.1	67.7	65.6	64.1	65.6	-1.0	74.4
SO2 - PPM	.012	.009	.012	.009	.010	.010	.008	.007	.007	.006	-1.000	≤ .002
O3 - PPM	.047	.047	.060	.076	.095	.111	.116	.116	.118	.107	-1.000	.074
NOX - PPM	.028	.023	.020	.013	.013	.011	.010	.011	.012	.013	-1.000	.016
TOTAL OXIDIZED N	.030	.024	.021	.014	.013	.012	.011	.012	.013	.014	.016	.016
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	-1.000	≤ .002
BSCAT - 1/M	4.47	3.35	2.88	2.66	2.68	2.87	2.89	2.81	2.86	3.04	-1.00	2.89
PAN - PPM	.002	.004	.013	.012	.013	.02	.022	.018	.018	.017	-1.000	-1.000

	21	22	23	24	1	2	3	4	5	6	7	8
IRAD - LANGLEY/M	.018	.016	.015	.015	.013	.014	.014	.014	.013	.014	.026	.110
WIND SPEED - MPH	7.63	8.40	12.40	7.10	7.46	7.37	5.00	7.43	7.00	7.37	8.90	5.83
WIND DIR - DEG	212.	229.	222.	228.	216.	223.	238.	234.	221.	220.	225.	231.
TEMP - DEG C	24.1	23.4	22.9	22.7	22.1	21.8	22.1	22.1	21.8	22.2	22.7	23.8
RH - %	80.4	86.4	87.8	87.9	89.4	91.1	91.4	93.7	94.3	94.4	94.3	94.3
SO2 - PPM	.009	.007	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	.004
O3 - PPM	.042	.029	.036	.038	.034	.039	.045	.045	.043	.042	.043	.039
NOX - PPM	.029	.024	.016	.011	.011	.007	.005	.005	.005	.006	.008	.015
TOTAL OXIDIZED N	.029	.025	.017	.011	.011	.007	.006	.005	.004	.006	.008	.015
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	2.50	2.31	2.42	2.31	2.16	2.13	2.31	2.54	2.85	3.16	3.47	3.68
PAN - PPM	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001

DAILY AVERAGE

IRAD - LANGLEY/M	.208
WIND SPEED - MPH	7.51
WIND DIR - DEG	228.
TEMP - DEG C	24.4
RH - %	83.0
SO2 - PPM	.005
O3 - PPM	.063
NOX - PPM	.014
TOTAL OXIDIZED N	.014
HNO3 - PPM	≤ .002
BSCAT - 1/M	2.84

BEVERLY AIRPORT, MA.

AUGUST 17, 1978

	9	10	11	12	13	14	15	16	17	18	19	20
IRAD - LANGLEY/M	.244	.371	.503	.660	.639	.551	.696	.565	.298	.237	.125	.032
WIND SPEED - MPH	8.34	7.34	6.14	7.89	8.77	9.10	8.17	7.53	7.54	5.00	4.20	1.93
WIND DIR - DEG	228.	235.	240.	235.	249.	237.	231.	252.	240.	268.	311.	239.
TEMP - DEG C	24.9	26.2	27.9	28.7	29.2	30.0	31.0	31.2	29.9	29.5	27.6	25.5
RH - %	89.8	85.1	75.2	69.6	62.0	56.9	53.2	46.3	47.0	42.8	49.2	57.2
SO2 - PPM	.006	.009	.009	.011	.014	.014	.016	.015	.012	.008	.004	≤ .002
O3 - PPM	.043	.054	.079	.097	.110	.114	.115	.113	.118	.098	.079	.059
NOX - PPM	.019	.019	.013	.011	.010	.010	.010	.009	.012	.011	.012	.017
TOTAL OXIDIZED N	.019	.018	.013	.011	.010	.009	.010	.010	.012	.011	.013	.018
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	3.60	3.63	3.27	3.15	2.91	2.76	2.55	2.12	2.19	1.72	1.57	1.43
PAN - PPM	≤0.001	.002	.002	.006	.007	.006	.007	.007	-1.000	-1.000	.002	.001

	21	22	23	24	1	2	3	4	5	6	7	8
IRAD - LANGLEY/M	.017	.016	.014	.012	.013	.012	.012	.011	.012	.012	.027	.172
WIND SPEED - MPH	1.63	2.37	1.54	1.53	2.43	1.49	1.20	1.67	2.57	1.77	2.97	4.67
WIND DIR - DEG	310.	299.	290.	275.	314.	279.	232.	301.	287.	287.	295.	283.
TEMP - DEG C	23.5	22.9	21.8	20.6	19.8	18.7	17.7	17.1	17.0	16.4	17.0	19.2
RH - %	65.5	64.8	64.4	69.0	73.2	78.8	84.9	86.1	86.1	87.5	84.3	75.4
SO2 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
O3 - PPM	.039	.035	.037	.035	.029	.027	.025	.028	.029	.026	.023	.022
NOX - PPM	.026	.024	.019	.019	.020	.018	.017	.012	.009	.009	.013	.018
TOTAL OXIDIZED N	.027	.024	.018	.019	.020	.018	.016	.011	.009	.010	.013	.017
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	1.53	1.17	1.09	1.20	1.34	1.41	1.49	1.41	1.37	1.32	1.17	.99
PAN - PPM	.001	≤0.001	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000

DAILY AVERAGE

IRAD - LANGLEY/M	.219
WIND SPEED - MPH	4.55
WIND DIR - DEG	267.
TEMP - DEG C	23.9
RH - %	68.9
SO2 - PPM	.005
O3 - PPM	.060
NOX - PPM	.015
TOTAL OXIDIZED N	.015
HNO3 - PPM	≤ .002
BSCAT - 1/M	1.93

BEVERLY AIRPORT, MA.

AUGUST 18, 1978

	9	10	11	12	13	14	15	16	17	18	19	20
IRAD - LANGLEY/M	-1.000	.561	.718	.577	.575	.892	.550	.254	-1.000	-1.000	-1.000	-1.000
WIND SPEED - MPH	-1.00	3.50	4.10	6.51	3.63	4.14	6.30	6.60	-1.00	-1.00	-1.00	-1.00
WIND DIR - DEG	-1.	235.	249.	197.	258.	211.	196.	155.	-1.	-1.	-1.	-1.
TEMP - DEG C	-1.0	22.6	24.3	24.4	24.7	27.1	25.8	24.3	-1.0	-1.0	-1.0	-1.0
RH - %	-1.0	65.0	59.7	56.6	54.5	49.7	52.1	55.7	-1.0	-1.0	-1.0	-1.0
SO2 - PPM	-1.000	≤ .002	.005	.009	.006	.013	.018	.012	-1.000	-1.000	-1.000	-1.000
O3 - PPM	-1.000	.039	.050	.056	.059	.063	.077	.089	-1.000	-1.000	-1.000	-1.000
NOX - PPM	-1.000	.011	.008	.005	.004	.005	.007	.010	-1.000	-1.000	-1.000	-1.000
TOTAL OXIDIZED N	-1.000	.011	.008	.005	.004	.004	.007	.010	-1.000	-1.000	-1.000	-1.000
HNO3 - PPM	-1.000	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	-1.000	-1.000	-1.000	-1.000
BSCAT - 1/M	-1.00	.64	.53	.47	.45	.46	.51	.64	-1.00	-1.00	-1.00	-1.00
PAN - PPM	≤0.001	≤0.001	≤0.001	.002	.002	.002	.004	.005	-1.000	-1.000	-1.000	-1.000

	21	22	23	24	1	2	3	4	5	6	7	8
IRAD - LANGLEY/M	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
WIND SPEED - MPH	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
WIND DIR - DEG	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.
TEMP - DEG C	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
RH - %	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
SO2 - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
O3 - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
NOX - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
TOTAL OXIDIZED N	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
HNO3 - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
BSCAT - 1/M	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
PAN - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000

DAILY AVERAGE

IRAD - LANGLEY/M	.589
WIND SPEED - MPH	4.97
WIND DIR - DEG	222.
TEMP - DEG C	24.8
RH - %	56.2
SO2 - PPM	.009
O3 - PPM	.062
NOX - PPM	.007
TOTAL OXIDIZED N	.007
HNO3 - PPM	≤ .002
BSCAT - 1/M	.53

BEVERLY AIRPORT, MA.

AUGUST 19, 1978

	9	10	11	12	13	14	15	16	17	18	19	20
IRAD - LANGLEY/M	.345	.585	.727	.774	.852	.815	.753	.642	-1.000	-1.000	-1.000	-1.000
WIND SPEED - MPH	7.77	8.85	8.40	6.88	4.57	8.28	8.53	6.88	-1.00	-1.00	-1.00	-1.00
WIND DIR - DEG	44.	52.	45.	60.	115.	134.	159.	163.	-1.	-1.	-1.	-1.
TEMP - DEG C	18.8	20.5	22.0	23.4	23.8	23.4	22.0	22.0	-1.0	-1.0	-1.0	-1.0
RH - %	67.6	55.7	44.6	37.6	30.7	34.2	37.7	39.4	-1.0	-1.0	-1.0	-1.0
SO2 - PPM	≤ .002	.004	.007	.011	.012	.015	.005	≤ .002	-1.000	-1.000	-1.000	-1.000
O3 - PPM	.044	.059	.066	.070	.072	.080	.075	.075	-1.000	-1.000	-1.000	-1.000
NOX - PPM	.004	.003	.004	.004	.004	.008	.007	.010	-1.000	-1.000	-1.000	-1.000
TOTAL OXIDIZED N	.004	.003	.003	.003	.003	.008	.007	.010	-1.000	-1.000	-1.000	-1.000
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	-1.000	-1.000	-1.000	-1.000
BSCAT - 1/M	.51	.40	.28	≤ .23	≤ .23	.27	.23	.26	-1.00	-1.00	-1.00	-1.00
PAN - PPM	-1.000	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	-1.000	-1.000	-1.000	-1.000

	21	22	23	24	1	2	3	4	5	6	7	8
IRAD - LANGLEY/M	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
WIND SPEED - MPH	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
WIND DIR - DEG	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.
TEMP - DEG C	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
RH - %	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
SO2 - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
O3 - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
NOX - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
TOTAL OXIDIZED N	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
HNO3 - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
BSCAT - 1/M	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
PAN - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000

DAILY AVERAGE

IRAD - LANGLEY/M	.687
WIND SPEED - MPH	7.50
WIND DIR - DEG	96.
TEMP - DEG C	22.0
RH - %	43.4
SO2 - PPM	.007
O3 - PPM	.068
NOX - PPM	.005
TOTAL OXIDIZED N	.005
HNO3 - PPM	≤ .002
BSCAT - 1/M	.30

BEVERLY AIRPORT, MA.

AUGUST 21, 1978

	9	10	11	12	13	14	15	16	17	18	19	20
IRAD - LANGLEY/M	.241	.479	.710	.725	.773	.792	.724	.611	.477	.271	.125	.026
WIND SPEED - MPH	11.07	11.10	10.35	10.23	8.73	6.77	6.43	7.57	9.96	7.50	5.37	3.27
WIND DIR - DEG	85.	37.	40.	39.	68.	62.	77.	119.	172.	164.	177.	186.
TEMP - DEG C	16.3	17.3	18.0	18.5	18.5	20.2	20.3	20.9	19.5	18.6	18.3	16.3
RH - %	64.7	61.5	59.4	57.2	55.0	50.9	48.2	48.0	50.6	53.9	52.9	57.6
SO2 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	.008	.015	.013	.011	.012	.020	≤ .002	≤ .002
O3 - PPM	.028	.031	.034	.040	.041	.040	.042	.045	.039	.027	.026	.013
NOX - PPM	.002	.003	.002	.003	.002	≤ .002	≤ .002	.006	.007	.019	.013	.024
TOTAL OXIDIZED N	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	.004	.005	.018	.012	.022
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	≤ .23	≤ .23	≤ .23	≤ .23	≤ .23	≤ .23	≤ .23	≤ .23	≤ .23	≤ .23	≤ .23	≤ .23
PAN - PPM	-1.000	≤0.001	.001	.001	.001	.001	.001	≤0.001	.001	.001	.001	≤0.001

	21	22	23	24	1	2	3	4	5	6	7	8
IRAD - LANGLEY/M	-1.000	.014	.013	.012	.012	.012	.012	.012	.011	.012	.014	.187
WIND SPEED - MPH	-1.00	2.00	1.77	.70	.53	.87	.63	.57	1.43	1.83	2.62	3.40
WIND DIR - DEG	-1.	184.	170.	235.	251.	217.	278.	266.	315.	119.	279.	167.
TEMP - DEG C	-1.0	14.2	13.7	13.6	12.7	12.2	11.8	11.1	10.7	8.9	6.8	12.9
RH - %	-1.0	68.3	77.3	81.5	86.7	88.2	93.6	94.3	94.3	94.3	94.3	84.8
SO2 - PPM	-1.000	.015	.008	.003	.003	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
O3 - PPM	-1.000	.003	.001	≤ .001	≤ .001	≤ .001	≤ .001	≤ .001	≤ .001	≤ .001	≤ .001	.008
NOX - PPM	-1.000	.034	.040	.053	.066	.075	.087	.084	.099	.062	.038	.024
TOTAL OXIDIZED N	-1.000	.033	.039	.053	.065	.075	.086	.082	.098	.061	.038	.024
HNO3 - PPM	-1.000	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	-1.00	.37	.33	.36	.38	.41	.44	.58	.79	.64	.58	.46
PAN - PPM	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	.001	.001	.001

DAILY AVERAGE

IRAD - LANGLEY/M	.272
WIND SPEED - MPH	4.99
WIND DIR - DEG	161.
TEMP - DEG C	15.3
RH - %	70.4
SO2 - PPM	.005
O3 - PPM	.018
NOX - PPM	.032
TOTAL OXIDIZED N	.031
HNO3 - PPM	≤ .002
BSCAT - 1/M	.33

BEVERLY AIRPORT, MA.

AUGUST 22, 1978

	9	10	11	12	13	14	15	16	17	18	19	20
IRAD - LANGLEY/M	.410	.579	.715	.760	.812	.806	.741	.618	.473	.277	.125	.026
WIND SPEED - MPH	4.27	7.60	6.93	4.90	4.76	6.86	6.88	7.50	8.60	8.06	5.20	3.07
WIND DIR - DEG	135.	38.	62.	147.	118.	141.	175.	176.	155.	153.	161.	167.
TEMP - DEG C	16.1	18.2	20.0	21.7	22.2	23.0	22.8	22.2	21.8	21.1	19.9	17.1
RH - %	75.6	61.9	58.0	45.5	40.5	42.1	43.2	42.8	39.4	38.4	39.7	51.4
SO2 - PPM	≤ .002	.004	.007	.013	.019	.010	.009	.003	.036	.022	.009	.004
O3 - PPM	.016	.036	.049	.055	.055	.061	.064	.068	.044	.039	.027	.015
NOX - PPM	.021	.008	.003	.004	.003	.007	.009	.012	.027	.019	.022	.026
TOTAL OXIDIZED N	.020	.008	≤ .002	.003	≤ .002	.005	.029	.011	.027	.019	.020	.025
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	.41	.30	.24	≤ .23	≤ .23	≤ .23	.29	.28	.30	.26	≤ .23	.41
PAN - PPM	-1.000	-1.000	-1.000	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001

	21	22	23	24	1	2	3	4	5	6	7	8
IRAD - LANGLEY/M	.014	.013	.012	.011	.010	.011	.011	.011	.011	.011	.029	.210
WIND SPEED - MPH	2.46	1.90	1.43	1.13	.77	.93	1.37	1.43	1.70	1.40	1.43	2.10
WIND DIR - DEG	177.	192.	215.	235.	308.	305.	251.	244.	288.	238.	258.	280.
TEMP - DEG C	15.3	14.8	14.7	13.9	13.1	12.5	11.7	10.7	10.4	10.3	10.4	14.6
RH - %	64.7	72.6	68.6	72.1	75.6	92.7	88.9	94.4	94.3	92.4	89.8	72.7
SO2 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
O3 - PPM	.002	.004	≤ .001	≤ .001	≤ .001	≤ .001	≤ .001	.002	.008	.011	.011	.015
NOX - PPM	.041	.037	.072	.115	.100	.072	.060	.049	.033	.028	.028	.034
TOTAL OXIDIZED N	.040	.036	.070	.113	.097	.070	.059	.047	.032	.027	.026	.035
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	.41	.46	.44	.70	1.51	.83	.63	.90	.81	.77	.60	.61
PAN - PPM	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001

DAILY AVERAGE

IRAD - LANGLEY/M	.279
WIND SPEED - MPH	3.86
WIND DIR - DEG	194.
TEMP - DEG C	16.6
RH - %	64.1
SO2 - PPM	.006
O3 - PPM	.024
NOX - PPM	.035
TOTAL OXIDIZED N	.035
HNO3 - PPM	≤ .002
BSCAT - 1/M	.52

BEVERLY AIRPORT, MA.

AUGUST 23, 1978

	9	10	11	12	13	14	15	16	17	18	19	20
IRAD - LANGLEY/M	.380	.565	.676	.663	.673	.640	.628	.450	.422	-1.000	0.000	-1.000
WIND SPEED - MPH	2.67	4.71	5.37	3.57	3.93	4.67	5.23	5.30	5.50	-1.00	0.00	-1.00
WIND DIR - DEG	302.	289.	317.	248.	264.	287.	272.	287.	160.	-1.	0.	-1.
TEMP - DEG C	17.7	20.1	21.2	23.3	23.6	26.1	26.5	26.3	26.9	-1.0	0.0	-1.0
RH - %	58.3	53.6	48.2	40.0	39.5	33.0	33.6	35.7	37.0	-1.0	0.0	-1.0
SO2 - PPM	≤ .002	.004	.007	.011	.012	.013	.012	.012	.009	-1.000	≤ .002	-1.000
O3 - PPM	.030	.043	.062	.082	.098	.095	.106	.104	.101	-1.000	≤ .001	-1.000
NOX - PPM	.030	.022	.016	.010	.009	.006	.008	.005	.004	-1.000	≤ .002	-1.000
TOTAL OXIDIZED N	.029	.021	.015	.009	.007	.009	.007	.004	.002	-1.000	≤ .002	-1.000
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	-1.000	≤ .002	-1.000
BSCAT - 1/M	.52	.45	.37	.37	.46	.47	.56	.73	.98	-1.00	≤ .23	-1.00
PAN - PPM	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	-1.000	-1.000	-1.000	-1.000

	21	22	23	24	1	2	3	4	5	6	7	8
IRAD - LANGLEY/M	.015	.013	.012	.015	.013	.011	.010	.011	.012	.011	.017	.047
WIND SPEED - MPH	3.57	2.33	1.80	2.27	1.00	1.10	.37	2.30	6.27	6.53	7.00	7.83
WIND DIR - DEG	144.	231.	91.	315.	103.	260.	253.	140.	71.	49.	51.	66.
TEMP - DEG C	19.8	17.8	16.5	16.9	16.3	15.3	14.0	14.2	14.3	13.7	13.7	14.1
RH - %	47.6	53.8	59.5	61.2	63.3	66.2	73.4	74.6	72.8	68.6	68.4	68.8
SO2 - PPM	.005	.006	.006	.009	.007	.006	.005	.006	.003	≤ .002	≤ .002	≤ .002
O3 - PPM	.072	.061	.052	.034	.024	.012	.009	.016	.038	.044	.040	.033
NOX - PPM	.009	.012	.014	.025	.028	.035	.038	.027	.009	≤ .002	≤ .002	≤ .002
TOTAL OXIDIZED N	.008	.011	.013	.024	.028	.034	.030	.026	.008	≤ .002	≤ .002	≤ .002
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	1.49	1.61	1.70	1.73	1.76	1.94	2.22	2.06	1.57	.63	.29	≤ .23
PAN - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000

DAILY AVERAGE

IRAD - LANGLEY/M	.240
WIND SPEED - MPH	3.79
WIND DIR - DEG	194.
TEMP - DEG C	18.1
RH - %	52.6
SO2 - PPM	.006
O3 - PPM	.052
NOX - PPM	.014
TOTAL OXIDIZED N	.013
HNO3 - PPM	≤ .002
BSCAT - 1/M	1.00

BEVERLY AIRPORT, MA.

AUGUST 24, 1978

	9	10	11	12	13	14	15	16	17	18	19	20
IRAD - LANGLEY/M	.220	.241	.188	.095	.129	.118	.050	.055	-1.000	-1.000	-1.000	-1.000
WIND SPEED - MPH	6.31	7.30	9.10	7.17	9.13	9.60	8.87	7.03	-1.00	-1.00	-1.00	-1.00
WIND DIR - DEG	75.	111.	92.	107.	95.	80.	69.	62.	-1.	-1.	-1.	-1.
TEMP - DEG C	15.8	15.8	15.4	14.6	14.0	13.8	12.9	9.7	-1.0	-1.0	-1.0	-1.0
RH - %	67.6	67.2	64.9	66.9	68.5	67.0	72.1	89.3	-1.0	-1.0	-1.0	-1.0
SO2 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	-1.000	-1.000	-1.000	-1.000
O3 - PPM	.032	.036	.037	.036	.034	.034	.033	.030	-1.000	-1.000	-1.000	-1.000
NOX - PPM	.002	.002	≤ .002	≤ .002	.003	.003	.002	.004	-1.000	-1.000	-1.000	-1.000
TOTAL OXIDIZED N	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	.002	≤ .002	.002	-1.000	-1.000	-1.000	-1.000
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	-1.000	-1.000	-1.000	-1.000
BSCAT - 1/M	≤ .23	≤ .23	≤ .23	≤ .23	.35	≤ .23	≤ .23	≤ .23	-1.00	-1.00	-1.00	-1.00
PAN - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000

	21	22	23	24	1	2	3	4	5	6	7	8
IRAD - LANGLEY/M	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
WIND SPEED - MPH	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
WIND DIR - DEG	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.
TEMP - DEG C	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
RH - %	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
SO2 - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
O3 - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
NOX - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
TOTAL OXIDIZED N	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
HNO3 - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
BSCAT - 1/M	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
PAN - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000

DAILY AVERAGE

IRAD - LANGLEY/M	.136
WIND SPEED - MPH	8.31
WIND DIR - DEG	86.
TEMP - DEG C	13.9
RH - %	70.5
SO2 - PPM	≤ .002
O3 - PPM	.034
NOX - PPM	.002
TOTAL OXIDIZED N	≤ .002
HNO3 - PPM	≤ .002
BSCAT - 1/M	≤ .23

BEVERLY AIRPORT, MA.

AUGUST 27, 1978

	9	10	11	12	13	14	15	16	17	18	19	20
IRAD - LANGLEY/M	.367	.560	.699	.795	.803	.808	.719	.608	.460	.239	.083	.023
WIND SPEED - MPH	3.23	3.52	5.50	4.80	4.40	5.20	5.00	5.30	9.30	8.60	5.10	2.53
WIND DIR - DEG	198.	26.	189.	183.	194.	218.	160.	150.	145.	163.	151.	163.
TEMP - DEG C	15.3	16.7	17.2	17.7	18.0	19.3	18.3	18.9	17.4	16.1	14.8	13.2
RH - %	73.5	59.2	40.3	34.8	30.8	28.7	36.4	38.3	43.2	49.6	54.3	60.7
SO2 - PPM	≤ .002	≤ .002	.003	.009	.015	.019	.027	.019	.023	.013	.007	.005
O3 - PPM	.023	.031	.042	.048	.053	.055	.053	.055	.044	.044	.041	.022
NOX - PPM	-1.000	.011	.005	.006	.005	.004	.014	.013	.021	.019	.017	.029
TOTAL OXIDIZED N	-1.000	.011	.005	.006	.004	.003	.014	.012	.020	.017	.016	.028
HNO3 - PPM	-1.000	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	.54	.36	≤ .23	≤ .23	≤ .23	≤ .23	.27	.31	.30	.29	.32	.34
PAN - PPM	.001	.001	.002	.004	.004	-1.000	.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001

	21	22	23	24	1	2	3	4	5	6	7	8
IRAD - LANGLEY/M	.014	.013	.011	.012	.012	.011	.011	.011	.011	.011	.017	.020
WIND SPEED - MPH	1.50	1.87	1.43	.63	1.10	1.30	.77	3.00	2.50	1.67	1.93	2.00
WIND DIR - DEG	201.	157.	231.	261.	280.	264.	234.	308.	121.	122.	194.	165.
TEMP - DEG C	11.5	11.5	9.8	8.5	8.3	8.9	7.5	7.7	7.0	6.1	6.7	6.9
RH - %	66.4	72.3	84.7	94.4	94.4	94.4	94.4	94.4	94.4	94.4	94.4	94.4
SO2 - PPM	≤ .002	.003	.002	.002	.004	.003	.003	.003	≤ .002	≤ .002	.002	≤ .002
O3 - PPM	.017	.017	.013	.005	≤ .001	≤ .001	≤ .001	≤ .001	≤ .001	≤ .001	.002	.002
NOX - PPM	.031	.029	.034	.037	.073	.090	.102	.099	.058	.043	.030	.026
TOTAL OXIDIZED N	.029	.028	.032	.036	.070	.086	.096	.094	.055	.040	.028	.025
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	.36	.44	.64	.71	.78	.81	.81	.74	.57	.48	.44	.43
PAN - PPM	.001	.001	.002	.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001

DAILY AVERAGE

IRAD - LANGLEY/M	.263
WIND SPEED - MPH	3.42
WIND DIR - DEG	186.
TEMP - DEG C	12.6
RH - %	67.6
SO2 - PPM	.007
O3 - PPM	.024
NOX - PPM	.035
TOTAL OXIDIZED N	.033
HNO3 - PPM	≤ .002
BSCAT - 1/M	.45

BEVERLY AIRPORT, MA.

AUGUST 28, 1978

	9	10	11	12	13	14	15	16	17	18	19	20
IRAD - LANGLEY/M	.020	.041	.031	.064	.100	.065	.072	.076	.058	.030	.021	.018
WIND SPEED - MPH	2.70	2.97	3.05	6.00	8.17	8.87	8.53	10.89	10.08	11.53	11.53	12.43
WIND DIR - DEG	105.	47.	70.	140.	159.	164.	180.	173.	171.	177.	168.	172.
TEMP - DEG C	6.1	8.2	9.4	10.3	10.6	12.2	12.5	11.2	11.3	10.4	6.8	9.1
RH - %	94.4	94.4	94.3	94.3	94.4	90.1	80.1	82.7	86.7	93.5	94.4	94.3
SO2 - PPM	≤ .002	≤ .002	≤ .002	.006	.010	.014	.003	.012	.027	.004	.008	≤ .002
O3 - PPM	.002	.004	.004	.023	.030	.032	.044	.034	.027	.040	.036	.042
NOX - PPM	.026	.029	.034	.023	.021	.024	.016	.022	.032	.015	.017	.012
TOTAL OXIDIZED N	.024	.028	.032	.021	.020	.022	.015	.021	.031	.014	.016	.011
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	.44	.51	.68	.70	.67	.60	.46	.46	.51	.58	.55	.49
PAN - PPM	-1.000	-1.000	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	-1.000	-1.000	-1.000	-1.000

	21	22	23	24	1	2	3	4	5	6	7	8
IRAD - LANGLEY/M	.017	.017	.016	.016	.016	.015	.015	.015	.015	.015	.029	.073
WIND SPEED - MPH	6.10	5.37	5.37	6.03	5.17	5.30	6.43	5.33	4.27	5.95	5.20	4.00
WIND DIR - DEG	175.	186.	214.	214.	229.	231.	216.	230.	242.	228.	232.	248.
TEMP - DEG C	14.8	16.9	18.4	19.3	19.6	20.2	21.1	20.6	21.1	21.3	21.3	22.2
RH - %	94.4	94.4	94.4	94.4	94.4	94.4	94.4	94.4	94.4	94.4	94.3	94.4
SO2 - PPM	≤ .002	≤ .002	.011	.009	.004	.007	.009	.009	.010	.018	.009	.011
O3 - PPM	.040	.037	.018	.028	.043	.048	.054	.052	.045	.039	.032	.022
NOX - PPM	.013	.017	.033	.028	.020	.018	.014	.012	.013	.015	.019	.031
TOTAL OXIDIZED N	.012	.016	.032	.027	.018	.016	.013	.012	.012	.014	.018	.030
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	.86	1.36	2.17	2.63	3.34	4.79	5.70	5.65	5.46	5.56	5.36	4.87
PAN - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000

DAILY AVERAGE

IRAD - LANGLEY/M	.038
WIND SPEED - MPH	6.72
WIND DIR - DEG	182.
TEMP - DEG C	14.8
RH - %	92.8
SO2 - PPM	.007
O3 - PPM	.032
NOX - PPM	.021
TOTAL OXIDIZED N	.020
HNO3 - PPM	≤ .002
BSCAT - 1/M	2.27

BEVERLY AIRPORT, MA.

AUGUST 29, 1978

	9	10	11	12	13	14	15	16	17	18	19	20
IRAD - LANGLEY/M	.258	.463	.609	.605	.613	.765	.648	.523	.411	.191	.062	.029
WIND SPEED - MPH	4.13	4.60	5.17	6.80	7.00	8.07	8.30	5.87	11.10	7.23	6.77	4.10
WIND DIR - DEG	243.	242.	275.	256.	258.	264.	266.	275.	288.	241.	293.	276.
TEMP - DEG C	24.1	25.5	27.6	28.7	28.8	29.9	30.6	29.8	28.7	27.9	25.8	23.6
RH - %	94.4	92.3	81.1	73.1	67.1	60.9	52.3	46.9	43.3	43.9	48.6	55.0
SO2 - PPM	.011	.010	.012	.013	.013	.013	.014	.010	.008	.002	≤ .002	≤ .002
O3 - PPM	.034	.053	.075	.092	.089	.092	.088	.084	.074	.068	.065	.054
NOX - PPM	.029	.025	.017	.012	.008	.008	.007	.007	.007	.008	.009	.012
TOTAL OXIDIZED N	.028	.024	.016	.011	.008	.007	.006	.008	.006	.007	.008	.012
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	4.15	3.50	3.14	2.77	2.52	2.10	1.56	1.04	.58	.47	.68	.77
PAN - PPM	-1.000	-1.000	-1.000	-1.000	-1.000	≤0.001	≤0.001	≤0.001	.001	.001	.001	.001

	21	22	23	24	1	2	3	4	5	6	7	8
IRAD - LANGLEY/M	.016	.013	.014	.013	.012	.011	.012	.012	.012	.012	.024	.129
WIND SPEED - MPH	3.83	2.70	2.27	3.63	2.97	1.43	1.53	3.38	2.60	1.53	2.43	2.30
WIND DIR - DEG	276.	268.	267.	252.	255.	264.	257.	283.	275.	307.	224.	276.
TEMP - DEG C	21.9	20.4	19.9	19.5	17.7	17.8	16.6	16.2	16.2	14.5	14.7	15.9
RH - %	59.3	64.3	66.2	69.1	74.2	79.7	82.7	84.5	84.5	87.2	91.3	82.8
SO2 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	.002	.003	.004	.004	.005	.006	.006
O3 - PPM	.047	.040	.039	.039	.038	.037	.038	.040	.045	.041	.031	.025
NOX - PPM	.014	.016	.015	.015	.015	.016	.013	.010	.008	.009	.014	.022
TOTAL OXIDIZED N	.014	.015	.015	.015	.014	.015	.012	.011	.007	.008	.015	.021
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	.83	.86	.79	1.00	1.22	1.47	1.68	1.70	1.62	1.66	1.78	1.56
PAN - PPM	.001	.001	.001	.001	≤0.001	.001	.001	.001	.001	.001	.001	.001

DAILY AVERAGE

IRAD - LANGLEY/M	.227
WIND SPEED - MPH	4.57
WIND DIR - DEG	266.
TEMP - DEG C	22.6
RH - %	70.3
SO2 - PPM	.006
O3 - PPM	.055
NOX - PPM	.013
TOTAL OXIDIZED N	.013
HNO3 - PPM	≤ .002
BSCAT - 1/M	1.64

BEVERLY AIRPORT, MA.

AUGUST 30, 1978

	9	10	11	12	13	14	15	16	17	18	19	20
IRAD - LANGLEY/M	.293	.572	.406	.461	.468	.446	.432	.349	.360	.181	.086	.023
WIND SPEED - MPH	3.20	4.13	3.74	4.17	3.37	4.80	4.83	2.77	3.73	2.83	2.77	1.50
WIND DIR - DEG	276.	312.	188.	259.	271.	261.	258.	273.	244.	242.	236.	265.
TEMP - DEG C	19.2	21.5	21.3	21.4	21.7	21.7	21.9	21.7	22.1	20.8	19.6	16.6
RH - %	74.1	65.0	55.1	49.8	50.3	49.8	48.4	49.5	48.2	45.8	51.6	62.7
SO2 - PPM	.005	.006	.005	.004	.005	.004	.004	.003	.003	.002	.003	.003
O3 - PPM	.034	.043	.058	.057	.068	.069	.076	.075	.075	.071	.044	.017
NOX - PPM	.020	.021	.011	.008	.009	.008	.008	.008	.009	.012	.031	.046
TOTAL OXIDIZED N	.019	.020	.011	.008	.009	.009	.008	.009	.009	.012	.029	.044
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	1.28	.97	.62	.52	.57	.50	.51	.51	.51	.46	.55	.69
PAN - PPM	.001	.001	.002	.004	.004	.002	.002	.005	.004	.003	.004	.002

	21	22	23	24	1	2	3	4	5	6	7	8
IRAD - LANGLEY/M	.015	.015	.015	.013	.013	.013	.011	.012	.012	.012	.016	.023
WIND SPEED - MPH	.83	1.20	1.20	1.70	1.10	.97	1.10	1.13	1.53	1.07	.83	.87
WIND DIR - DEG	229.	246.	238.	268.	247.	265.	286.	244.	287.	291.	282.	282.
TEMP - DEG C	14.2	13.3	14.5	14.4	13.3	15.7	15.5	16.3	16.2	16.4	16.5	16.7
RH - %	74.3	80.2	78.5	79.6	82.6	84.1	87.9	89.8	88.9	90.2	91.4	88.7
SO2 - PPM	.003	.005	.003	.003	.002	.003	.003	.004	.005	.005	.005	.006
O3 - PPM	.002	≤ .001	.001	.004	.003	.007	.005	.004	.005	.003	.002	.003
NOX - PPM	.058	.086	.059	.045	.037	.032	.032	.032	.029	.030	.034	.041
TOTAL OXIDIZED N	.056	.053	.057	.042	.037	.031	.032	.031	.029	.028	.032	.040
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	.78	.90	.70	.64	.65	.71	.79	.81	.86	.93	.93	.92
PAN - PPM	.002	.001	.001	.001	.001	.002	.001	.002	.003	.001	.001	.001

DAILY AVERAGE

IRAD - LANGLEY/M	.177
WIND SPEED - MPH	2.31
WIND DIR - DEG	260.
TEMP - DEG C	18.0
RH - %	69.4
SO2 - PPM	.004
O3 - PPM	.030
NOX - PPM	.029
TOTAL OXIDIZED N	.029
HNO3 - PPM	≤ .002
BSCAT - 1/M	.72

BEVERLY AIRPORT, MA.

1977 FIELD PROGRAM AVERAGES

	9	10	11	12	13	14	15	16	17	18	19	20
IRAD - LANGLEY/M	.256	.339	.498	.514	.548	.530	.500	.401	.327	.211	.089	.033
WIND SPEED - MPH	5.19	5.62	6.05	6.34	5.93	6.35	6.60	6.65	7.58	6.93	5.15	4.50
WIND DIR - DEG	179.	170.	174.	179.	191.	197.	197.	193.	195.	201.	199.	199.
TEMP - DEG C	18.9	20.0	21.1	22.0	22.1	22.7	22.8	22.5	22.6	21.7	19.8	19.0
RH - %	80.9	75.0	68.6	63.9	62.0	59.4	59.1	59.8	59.8	61.6	62.5	71.4
SO2 - PPM	.010	.009	.010	.014	.020	.021	.033	.030	.032	.026	.026	.022
O3 - PPM	.028	.037	.048	.057	.063	.067	.069	.069	.064	.057	.044	.038
NOX - PPM	.019	.015	.012	.010	.009	.009	.010	.012	.015	.017	.020	.026
TOTAL OXIDIZED N	.018	.015	.012	.010	.006	.009	.011	.012	.014	.017	.020	.026
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	1.61	1.37	1.17	1.12	1.06	1.05	1.03	1.02	1.10	1.07	1.01	1.24

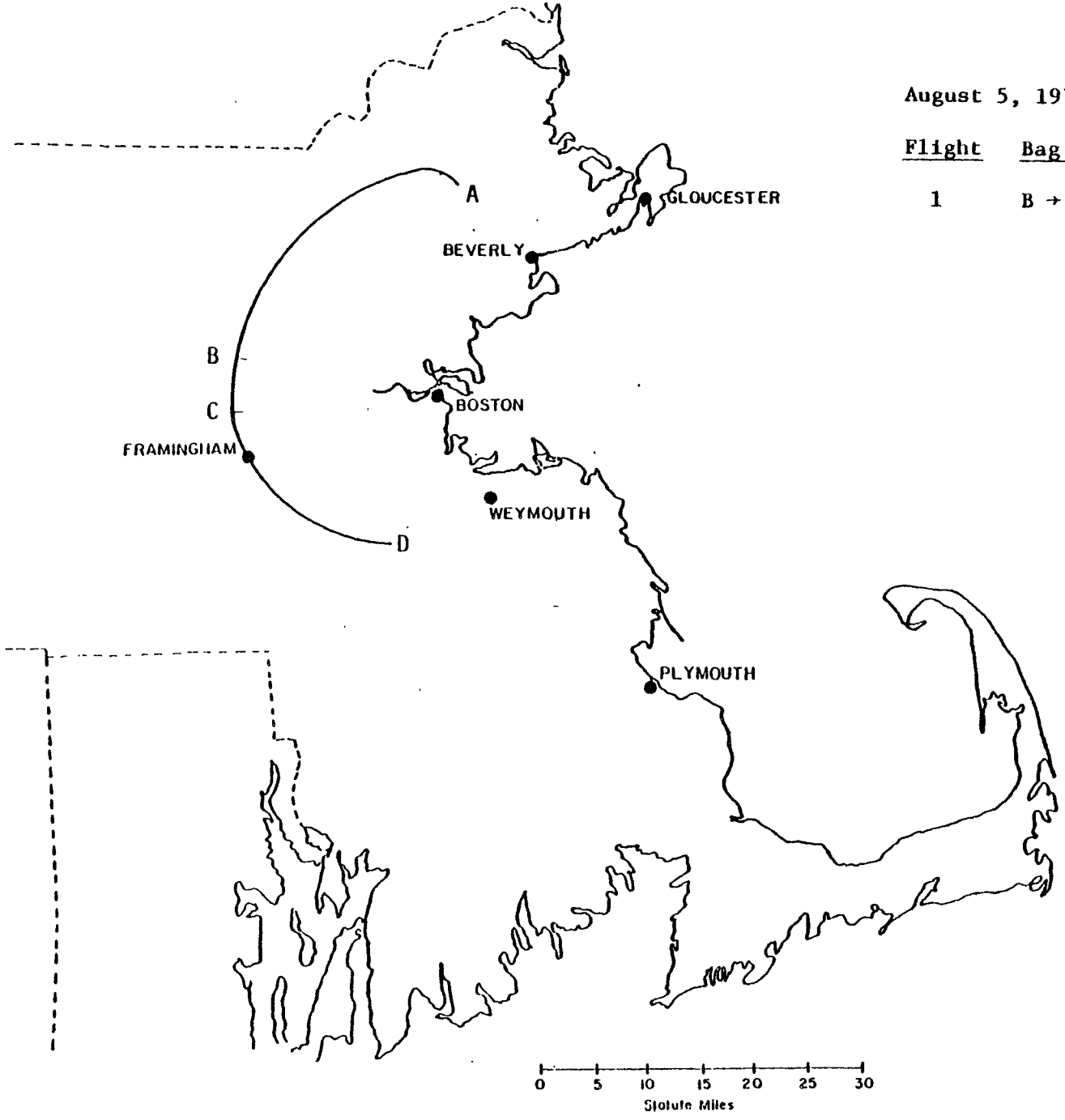
	21	22	23	24	1	2	3	4	5	6	7	8
IRAD - LANGLEY/M	.018	.016	.015	.014	.014	.013	.014	.013	.013	.014	.029	.118
WIND SPEED - MPH	3.90	3.94	3.45	3.11	3.17	2.61	2.42	3.06	3.11	3.17	3.35	3.70
WIND DIR - DEG	202.	214.	201.	233.	228.	240.	243.	219.	240.	220.	217.	209.
TEMP - DEG C	18.3	17.7	17.1	16.6	16.4	16.5	16.7	16.6	16.4	16.0	16.3	17.8
RH - %	75.9	78.0	80.5	82.5	84.2	86.1	88.4	89.4	89.3	89.8	89.2	84.9
SO2 - PPM	.016	.016	.014	.016	.015	.016	.016	.017	.016	.014	.015	.016
O3 - PPM	.031	.028	.025	.023	.022	.021	.021	.023	.026	.026	.024	.021
NOX - PPM	.032	.032	.032	.034	.033	.032	.032	.027	.021	.017	.016	.020
TOTAL OXIDIZED N	.032	.031	.032	.033	.032	.032	.032	.027	.020	.016	.016	.020
HNO3 - PPM	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002	≤ .002
BSCAT - 1/M	1.37	1.42	1.55	1.65	1.86	2.01	2.08	2.18	2.27	2.38	2.23	1.95

GRAND AVERAGE

IRAD - LANGLEY/M	.192
WIND SPEED - MPH	4.66
WIND DIR - DEG	206.
TEMP - DEG C	19.0
RH - %	75.1
SO2 - PPM	.018
O3 - PPM	.039
NOX - PPM	.021
TOTAL OXIDIZED N	.021
HNO3 - PPM	≤ .002
BSCAT - 1/M	1.53

APPENDIX B

FLIGHT MAPS FOR BOSTON PLUME STUDY

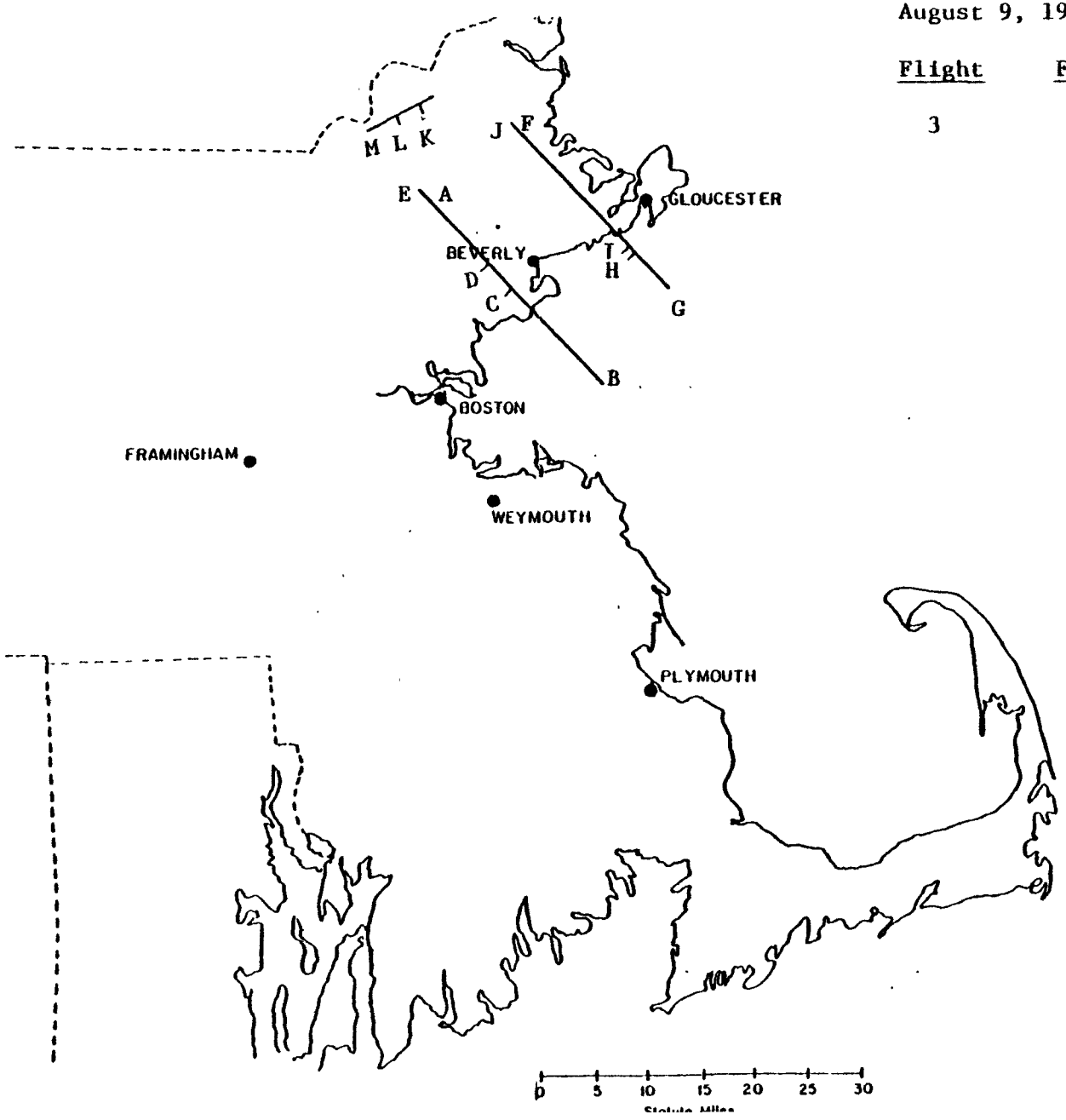


August 5, 1978

Flight	Bag 1
1	B → C

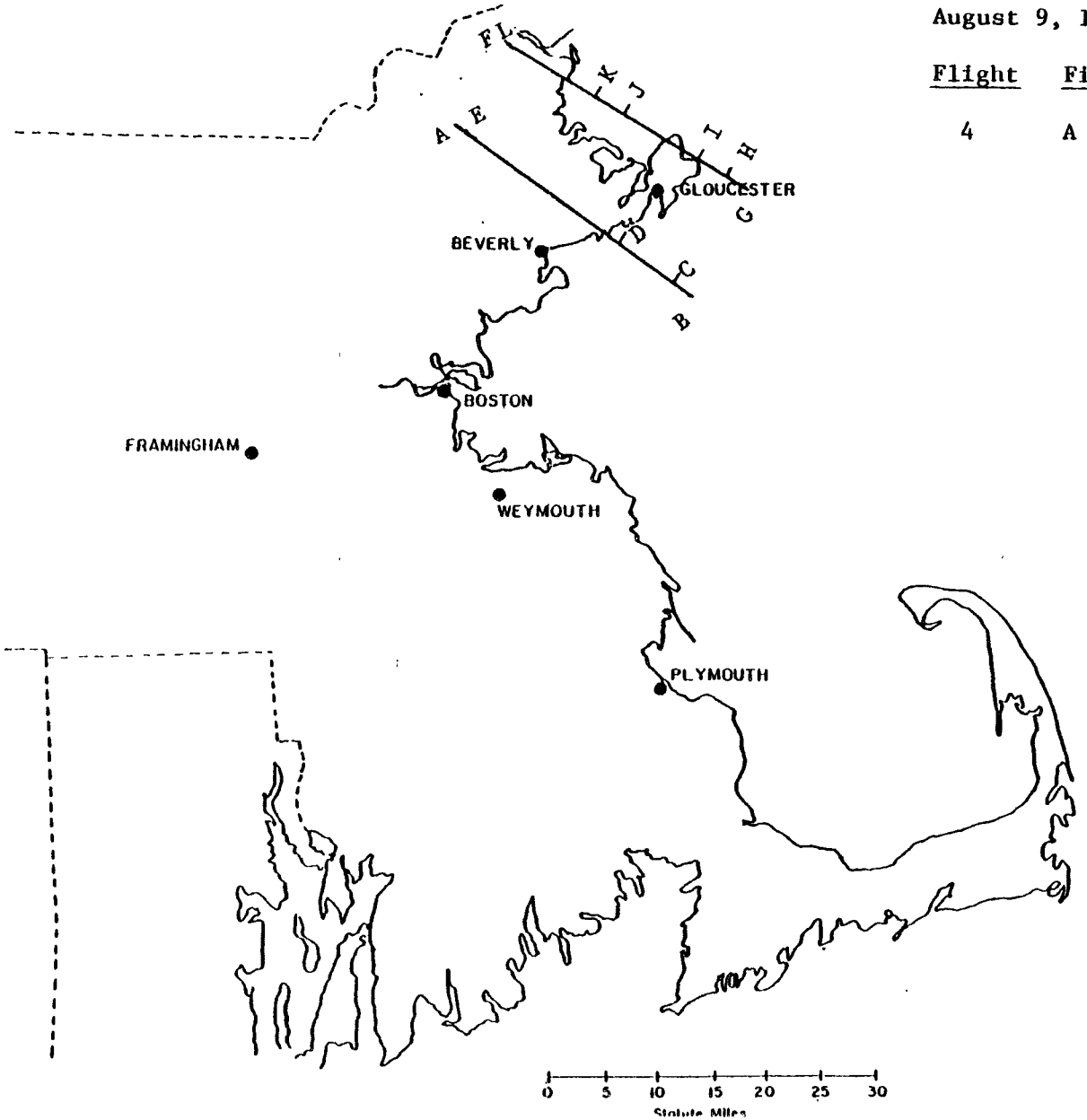
August 9, 1978

Flight	Filter	Bag 1	Bag 2	Bag 3
3	A → M	C → D	H → I	K → L



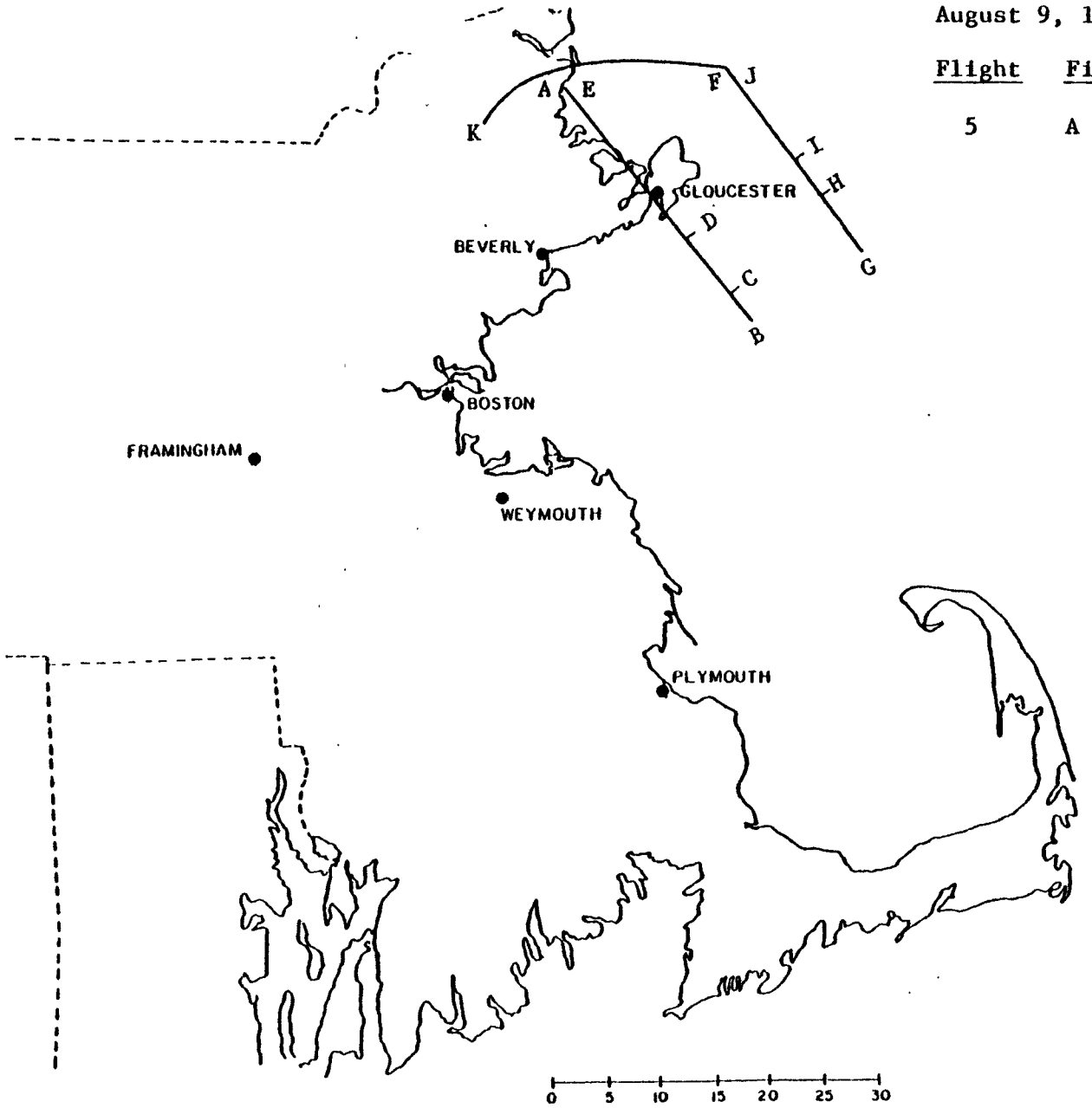
August 9, 1978

Flight	Filter	Bag 1	Bag 2	Bag 3
4	A → L	C → D	H → I	J → K



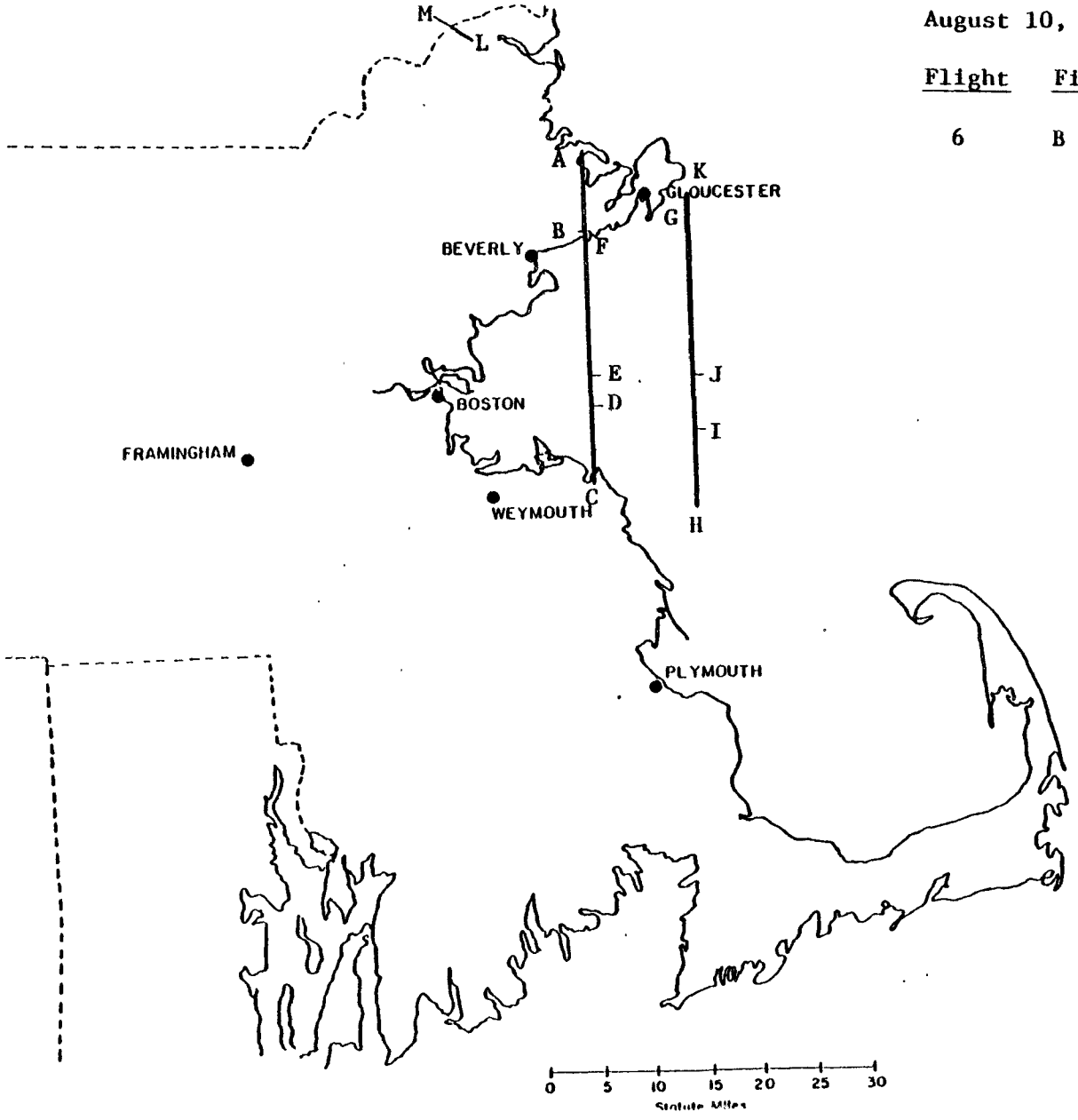
August 9, 1978

Flight	Filter	Bag 1	Bag 2
5	A → K	C → D	H → I



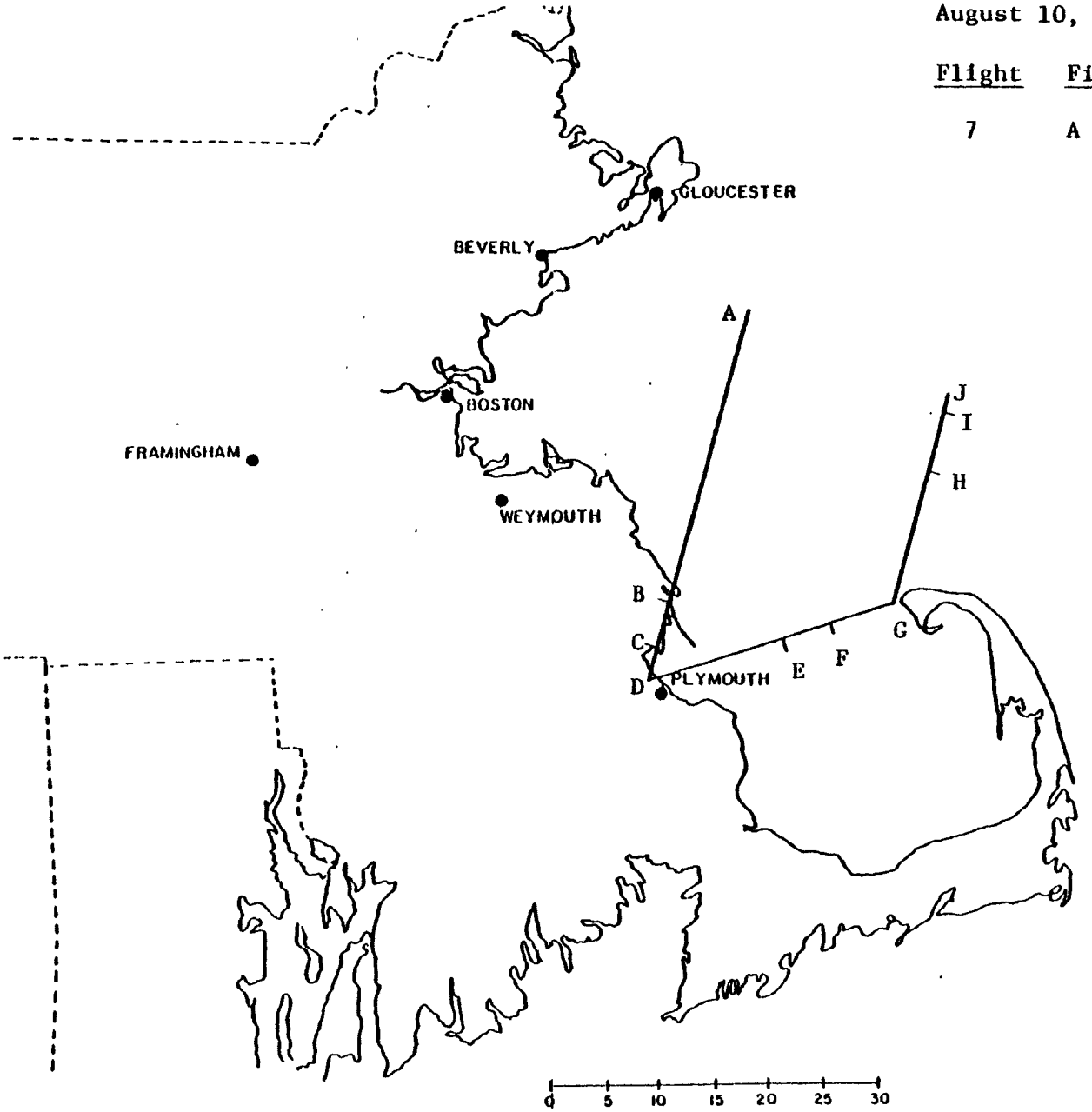
August 10, 1978

Flight	Filter	Bag 1	Bag 2	Bag 3
6	B → K	D → E	I → J	L → M



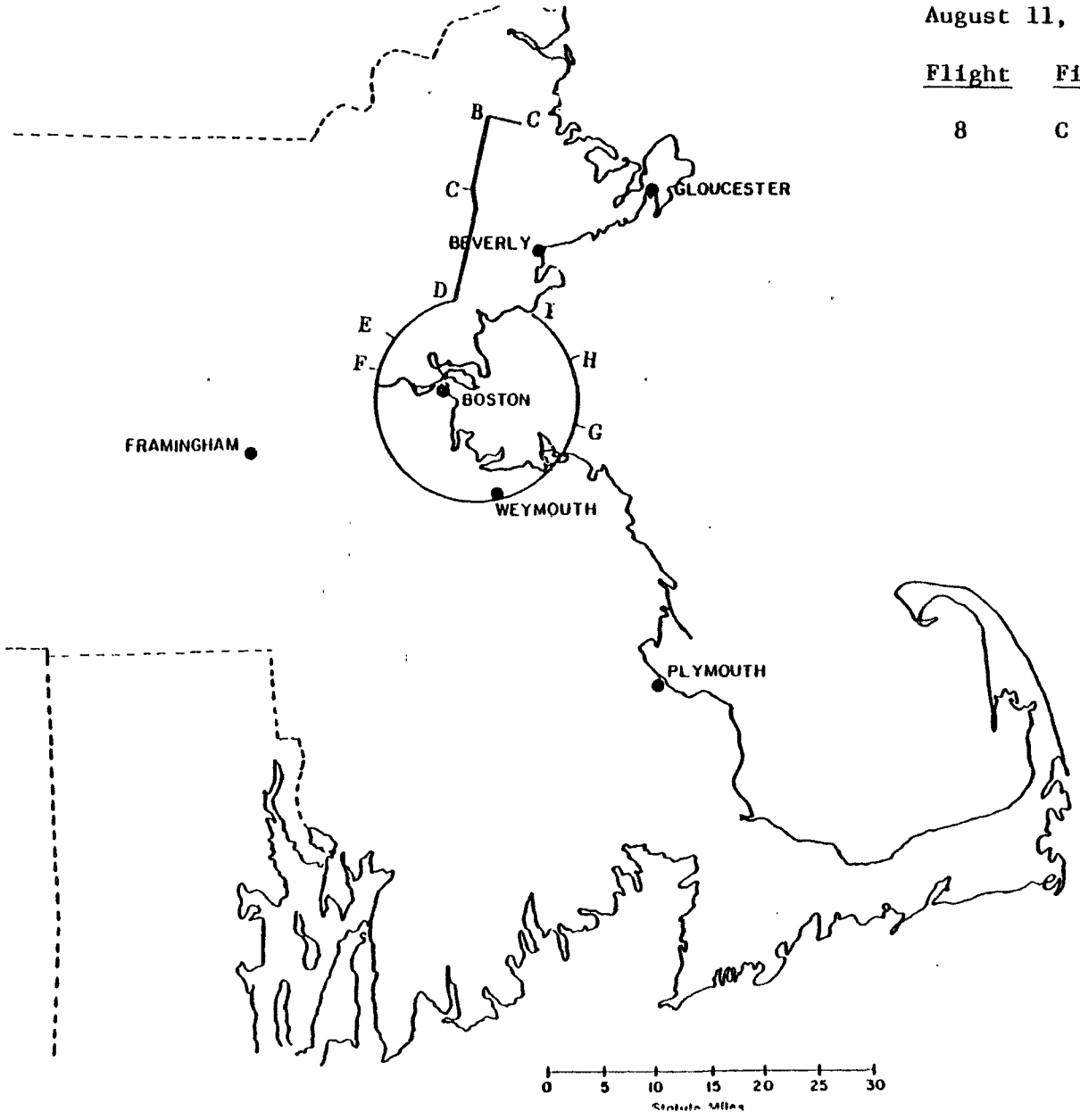
August 10, 1978

Flight	Filter	Bag 1	Bag 2	Bag 3
7	A → J	B → C	E → F	H → I



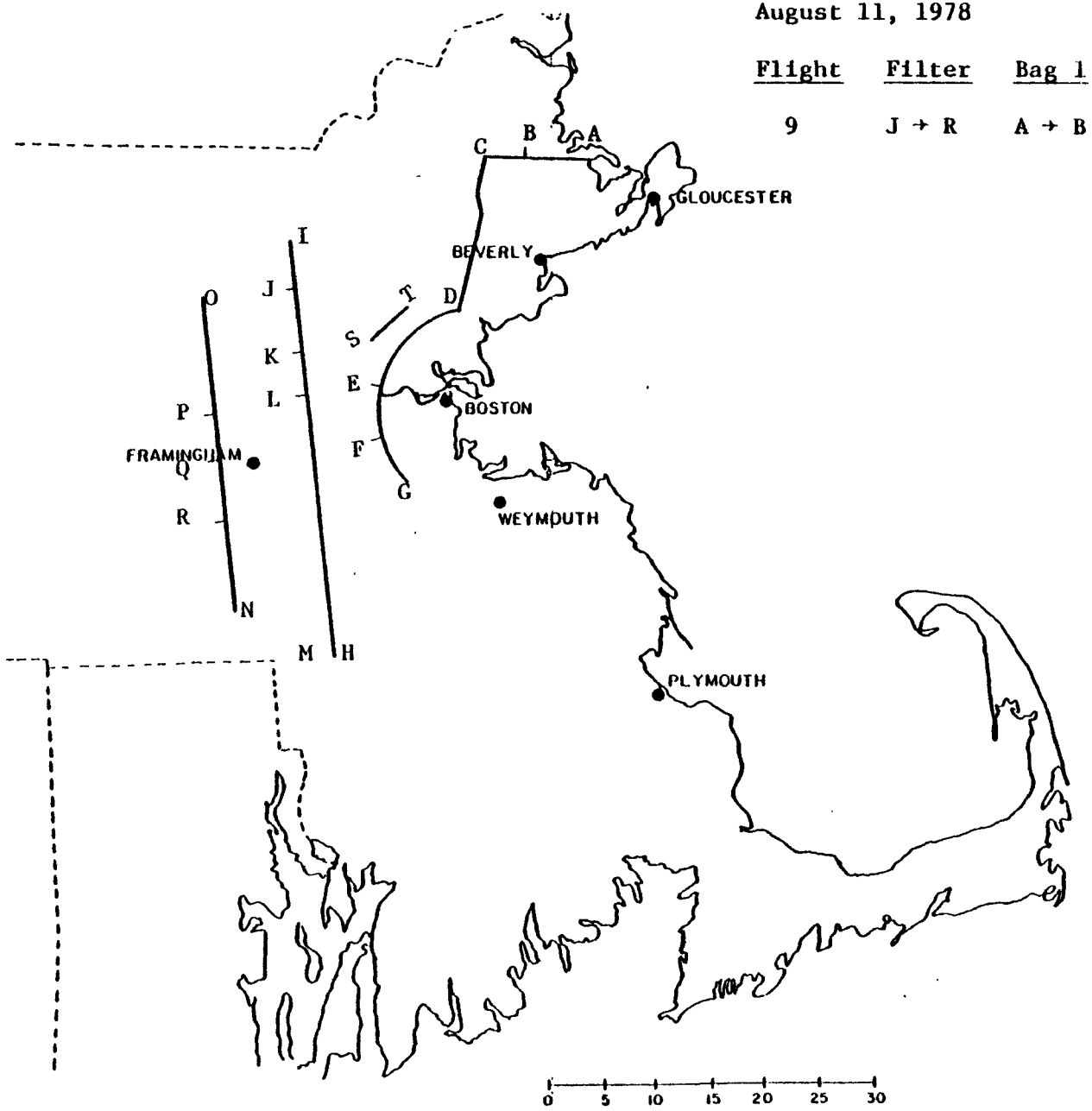
August 11, 1978

Flight	Filter	Bag 1	Bag 2	Bag 3
8	C → I	A → B	E → F	G → H



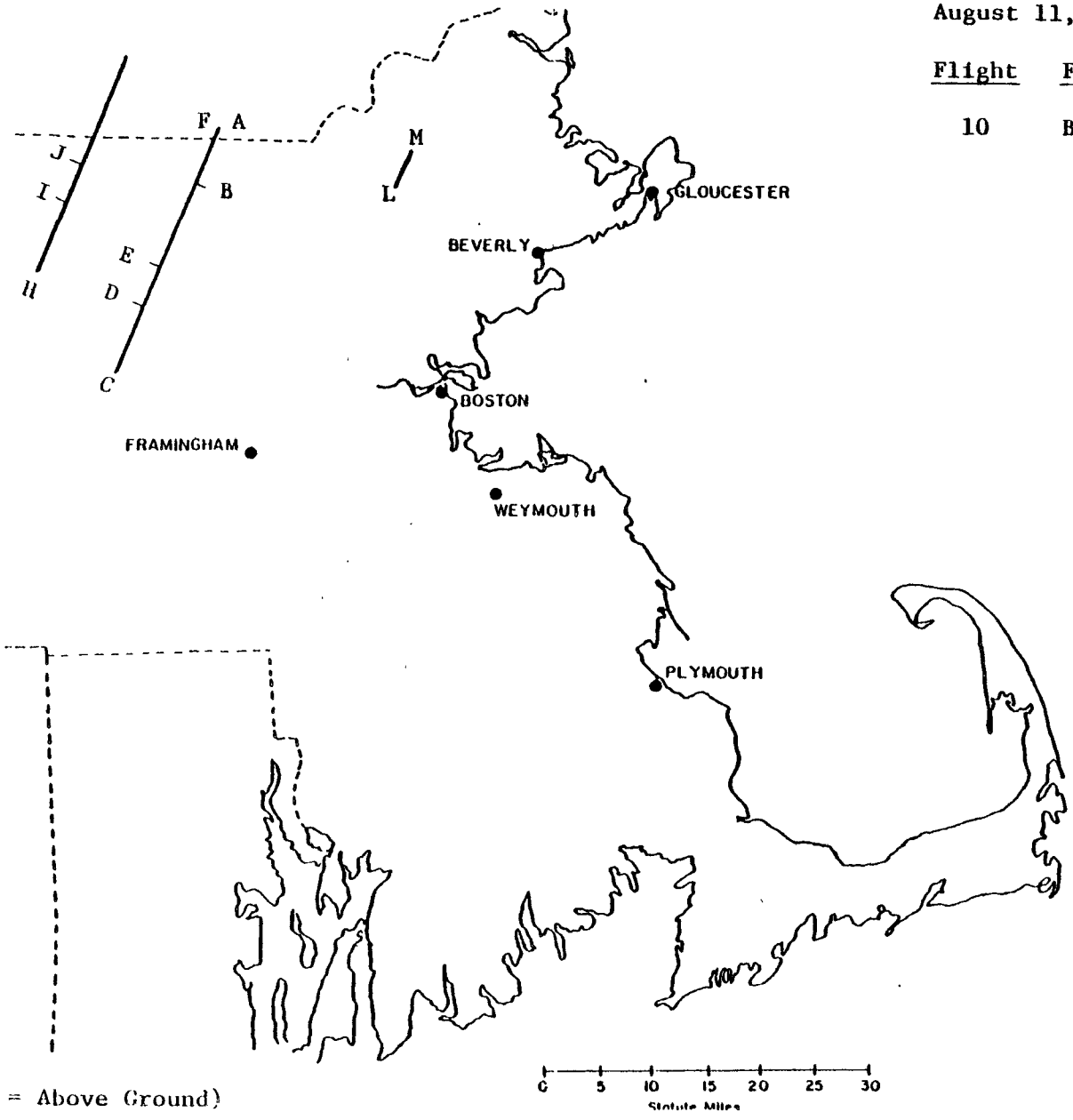
August 11, 1978

Flight	Filter	Bag 1	Bag 2	Bag 3	Bag 4	Bag 5
9	J → R	A → B	E → F	K → L	P → Q	S → T (2500'AG)*



August 11, 1978

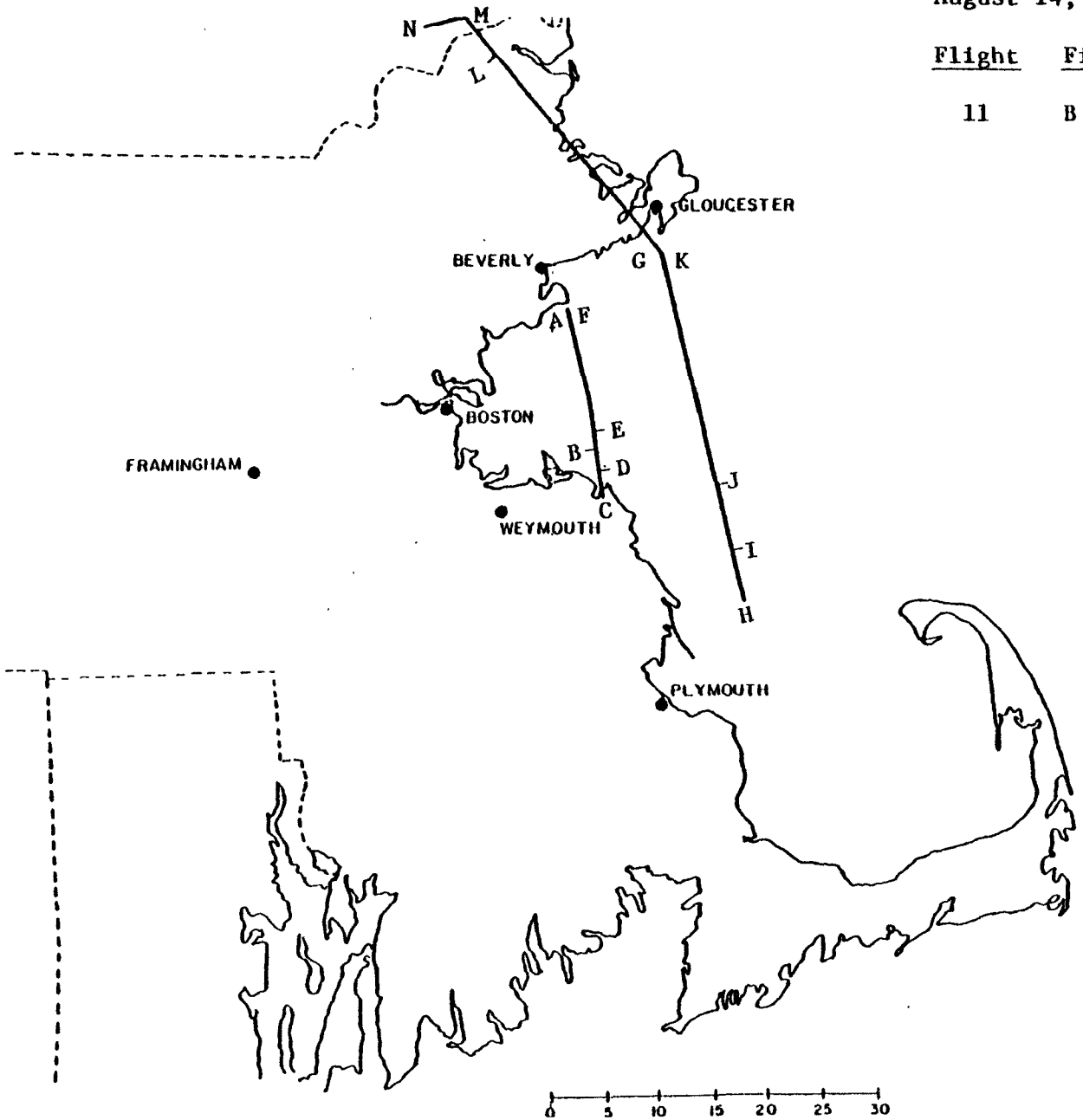
Flight	Filter	Bag 1	Bag 2	Bag 3
10	B → K	D → E	I → J	L → M (2500'AG)*



* (AG = Above Ground)

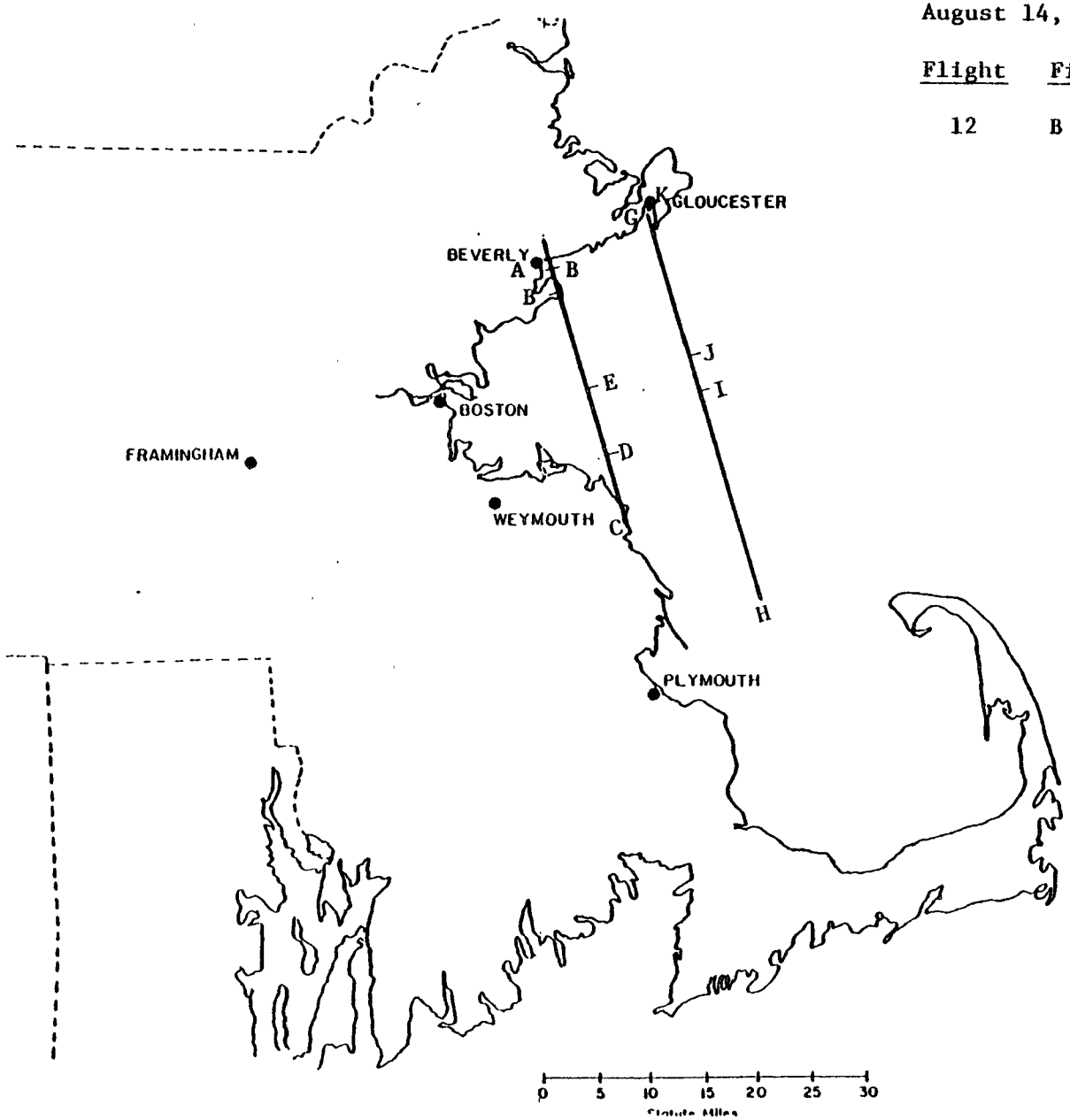
August 14, 1978

Flight	Filter	Bag 1	Bag 2	Bag 3
11	B → L	D → E	I → J	M → N



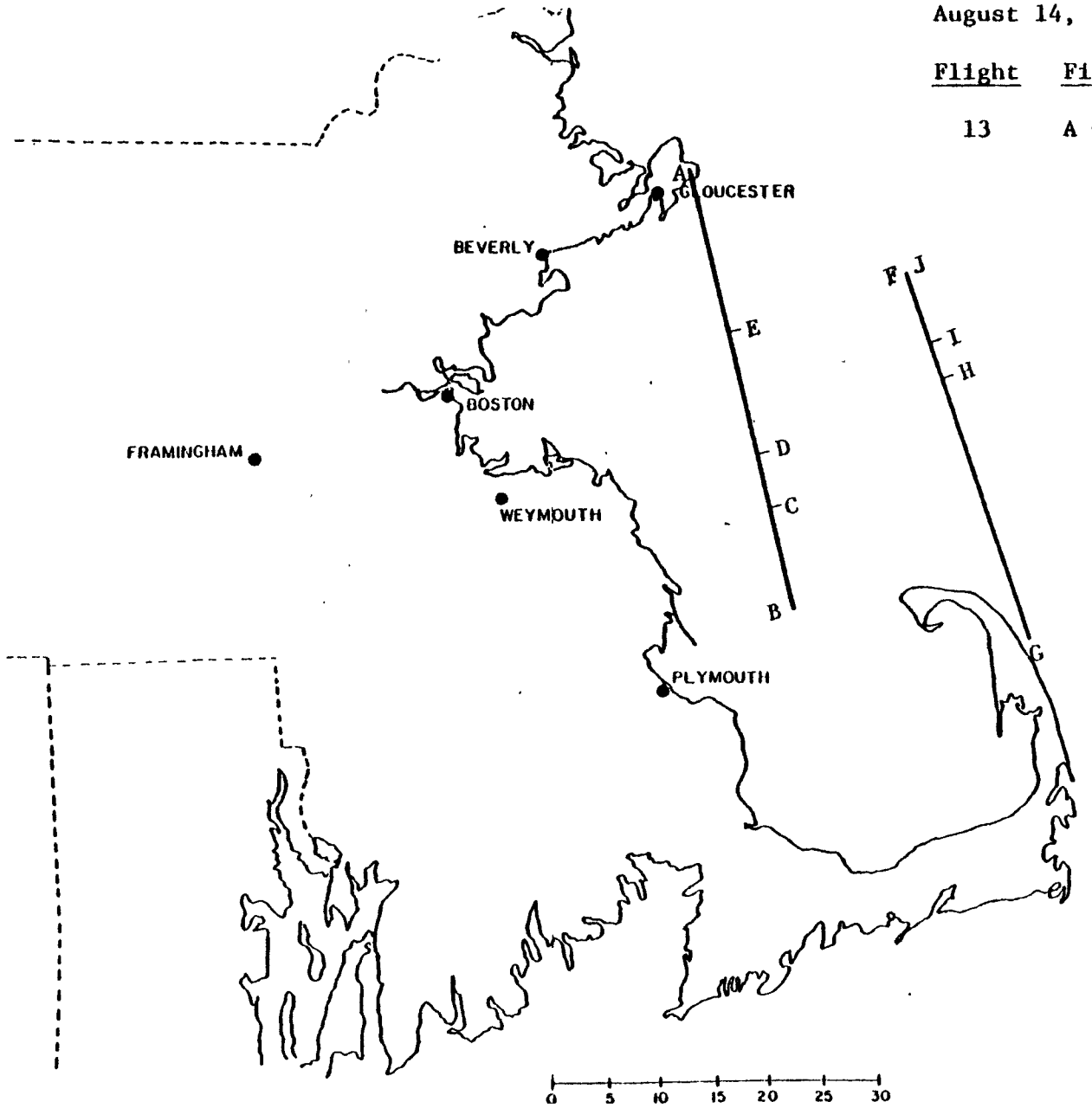
August 14, 1978

Flight	Filter	Bag 1	Bag 2
12	B → K	D → E	I → J



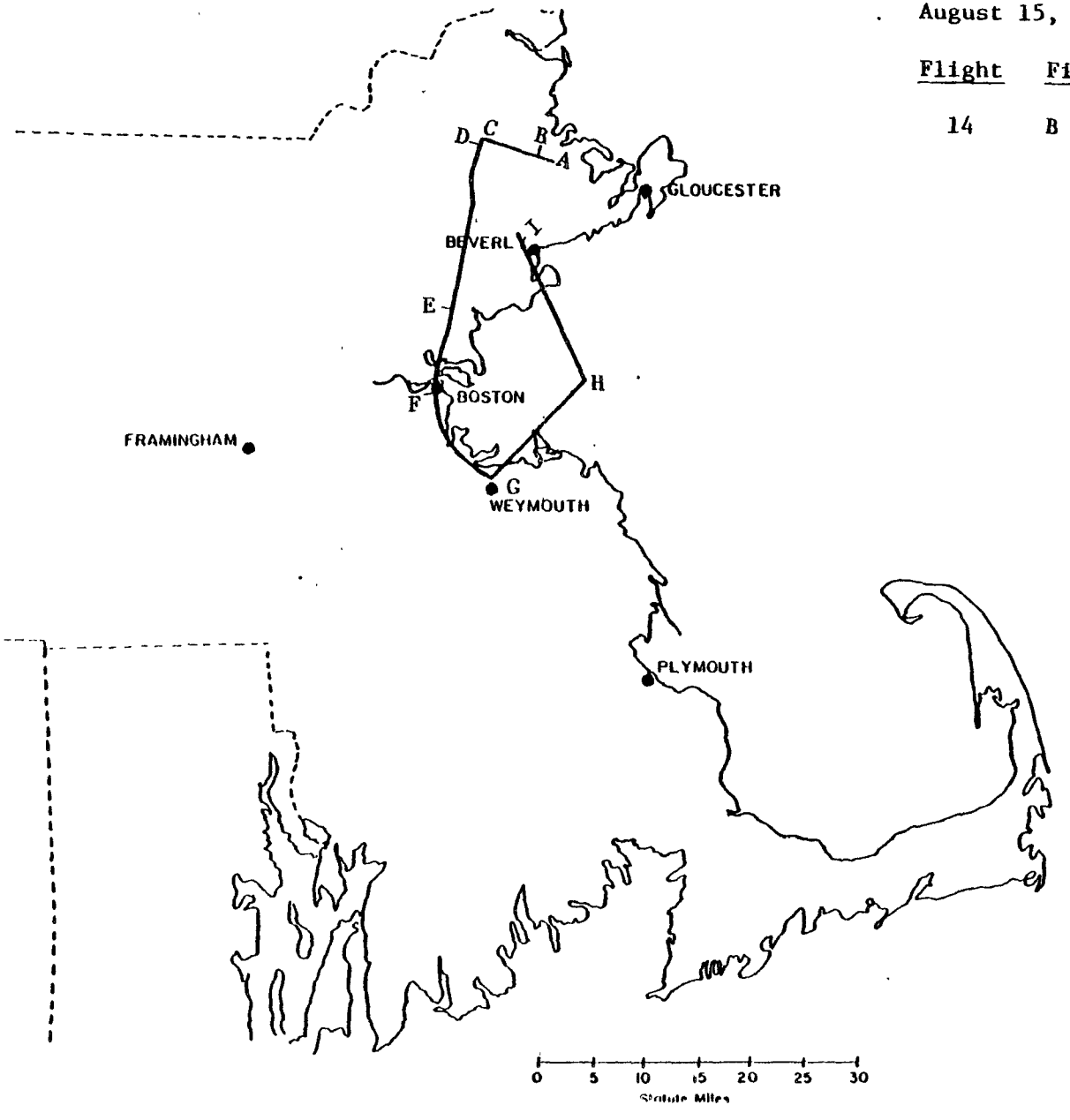
August 14, 1978

Flight	Filter	Bag 1	Bag 2
13	A → J	C → D	H → I



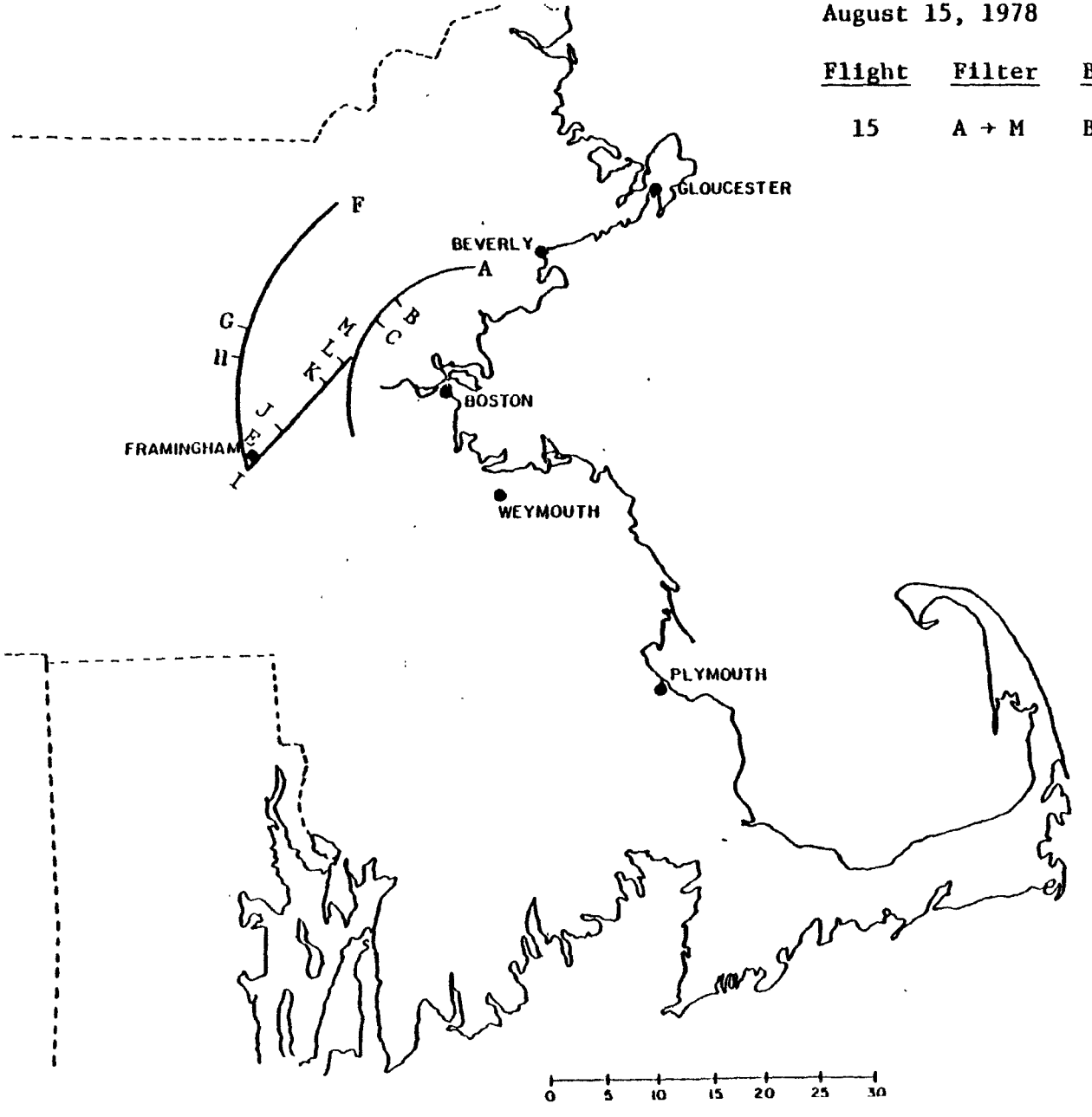
August 15, 1978

Flight	Filter	Bag 1	Bag 2
14	B → I	A → D	E → F



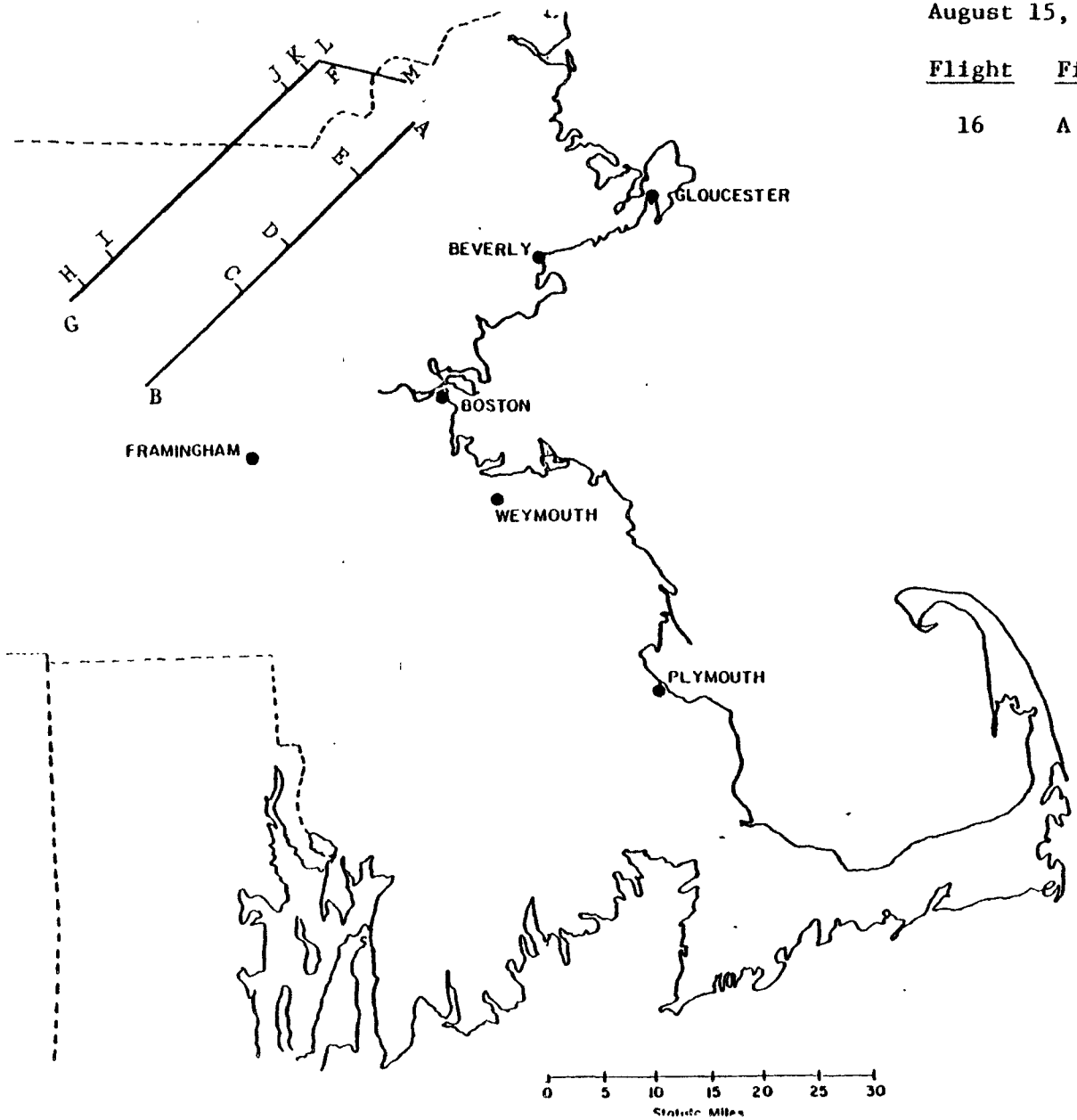
August 15, 1978

Flight	Filter	Bag 1	Bag 2	Bag 3	Bag 4
15	A → M	B → C	G → H	I → J	K → L



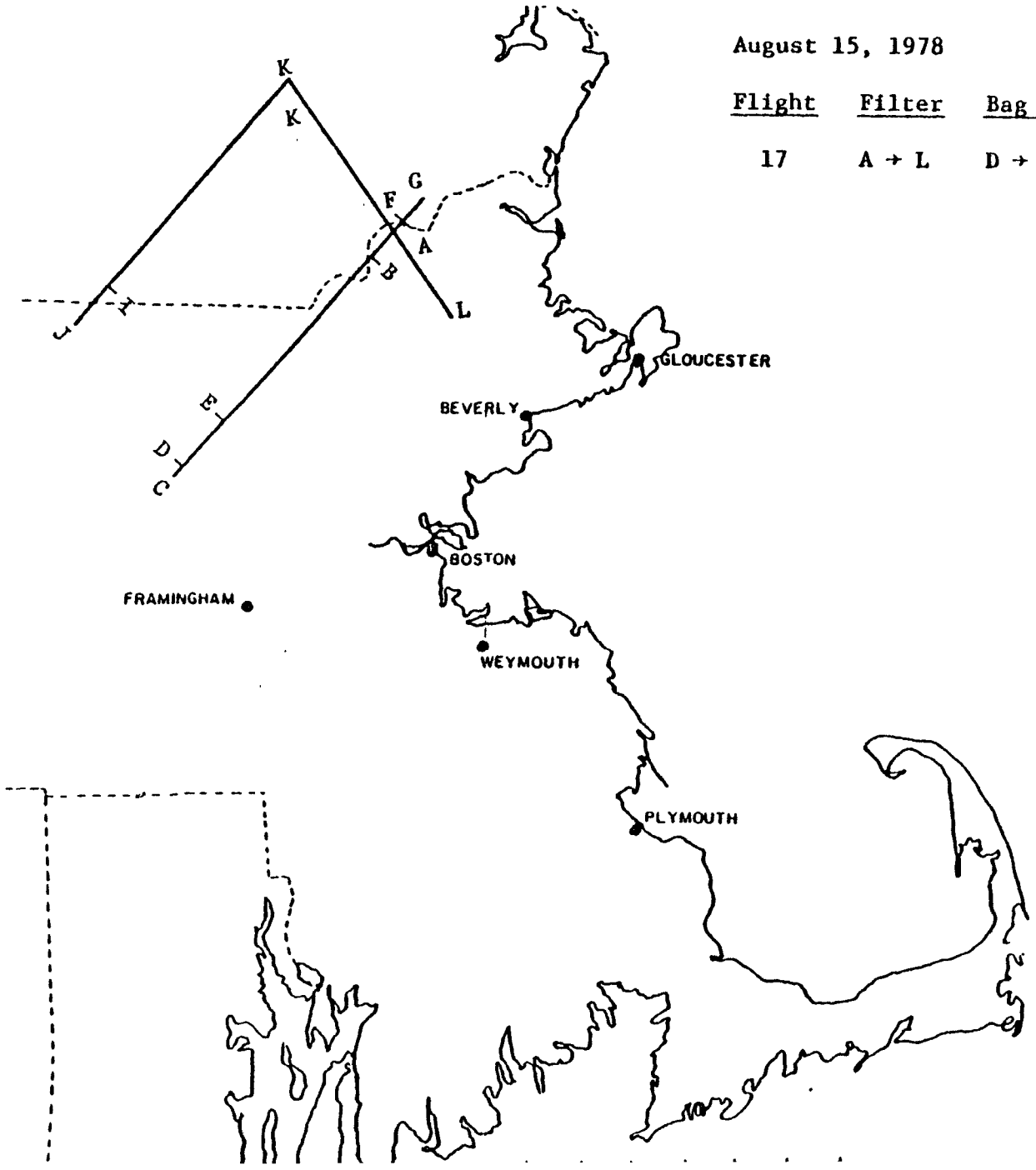
August 15, 1978

Flight	Filter	Bag 1	Bag 2	Bag 3
16	A → M	C → D	H → I	J → K



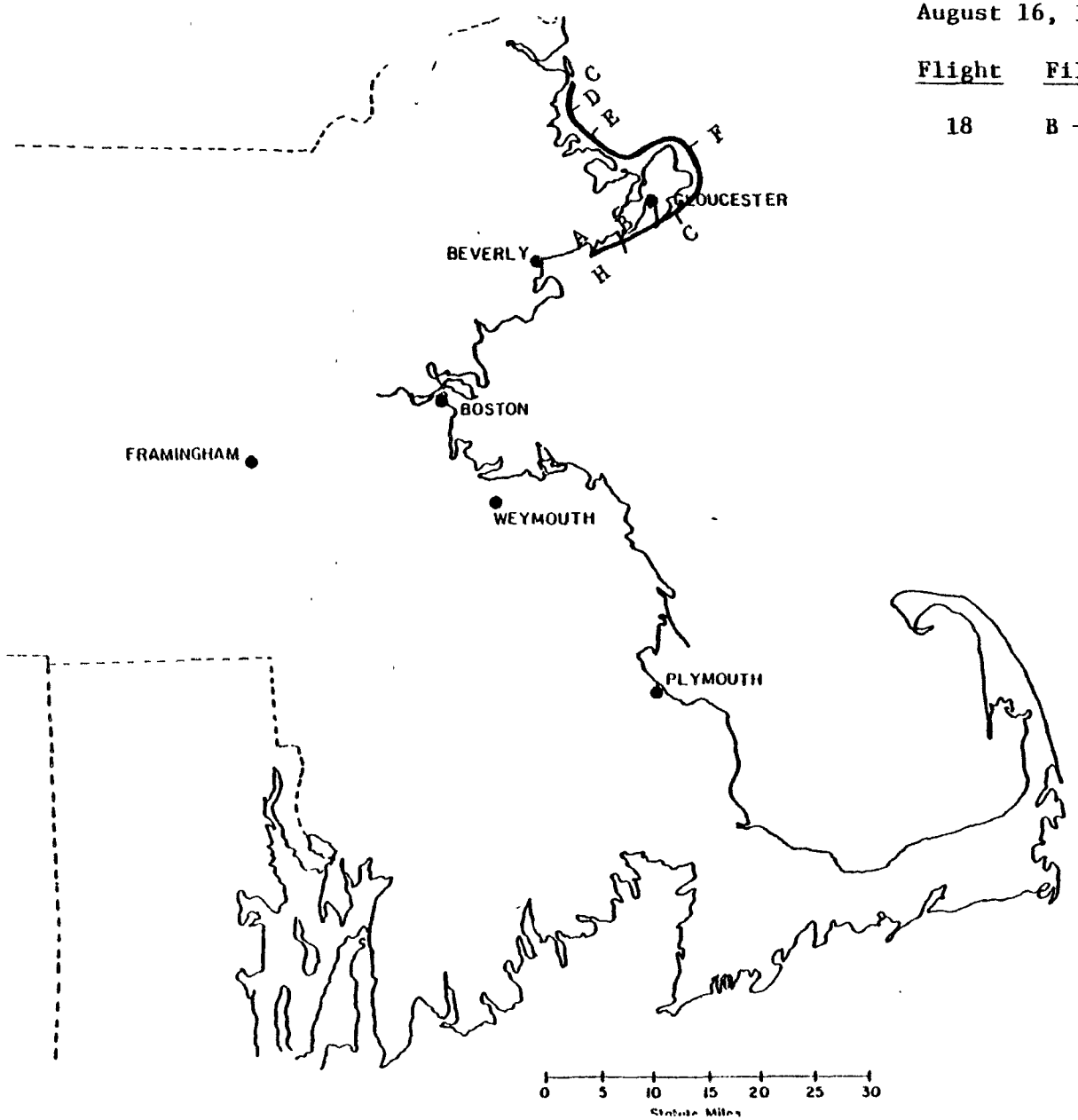
August 15, 1978

Flight	Filter	Bag 1	Bag 2	Bag 3
17	A → L	D → E	F → G	I → J



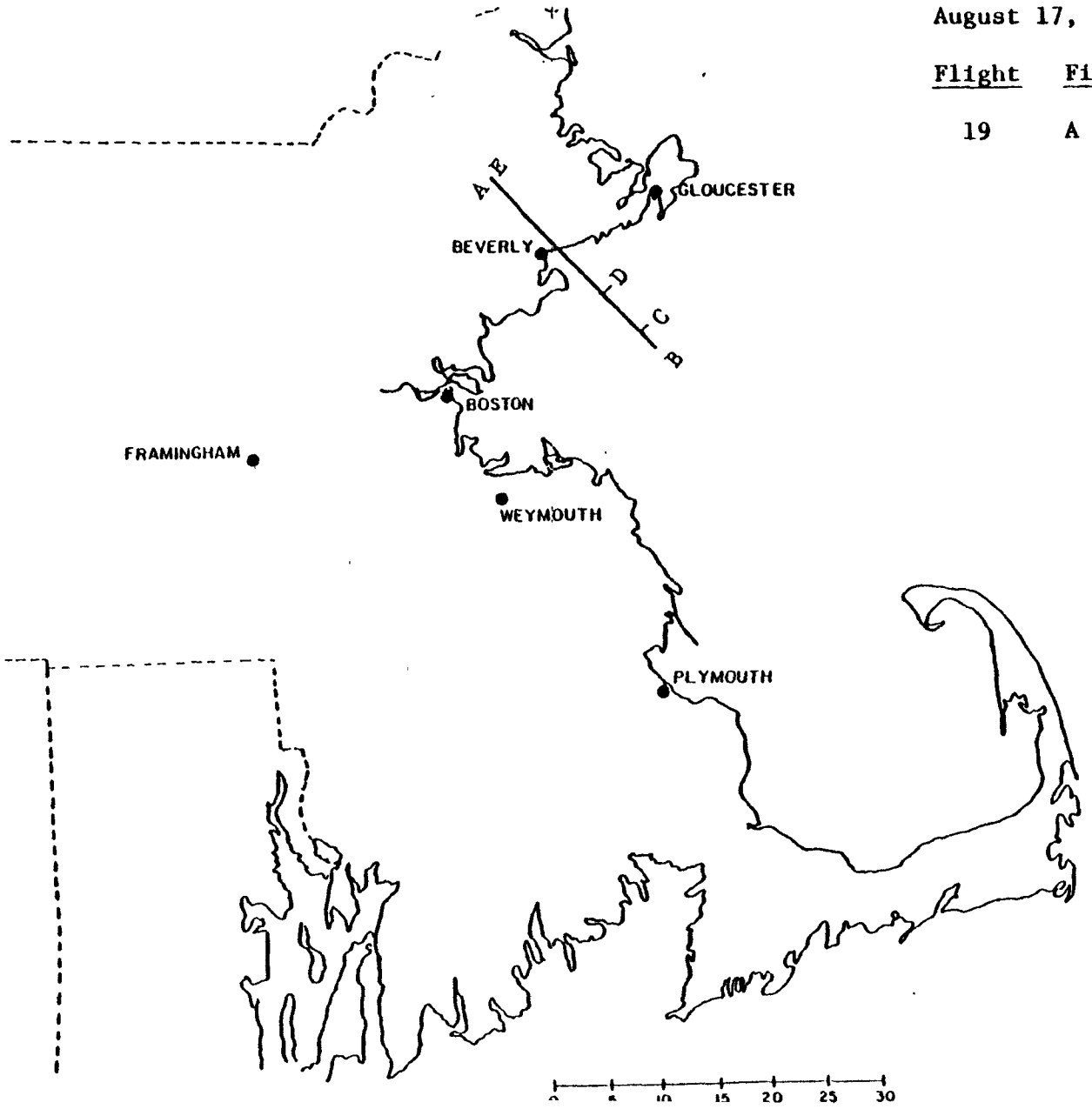
August 16, 1978

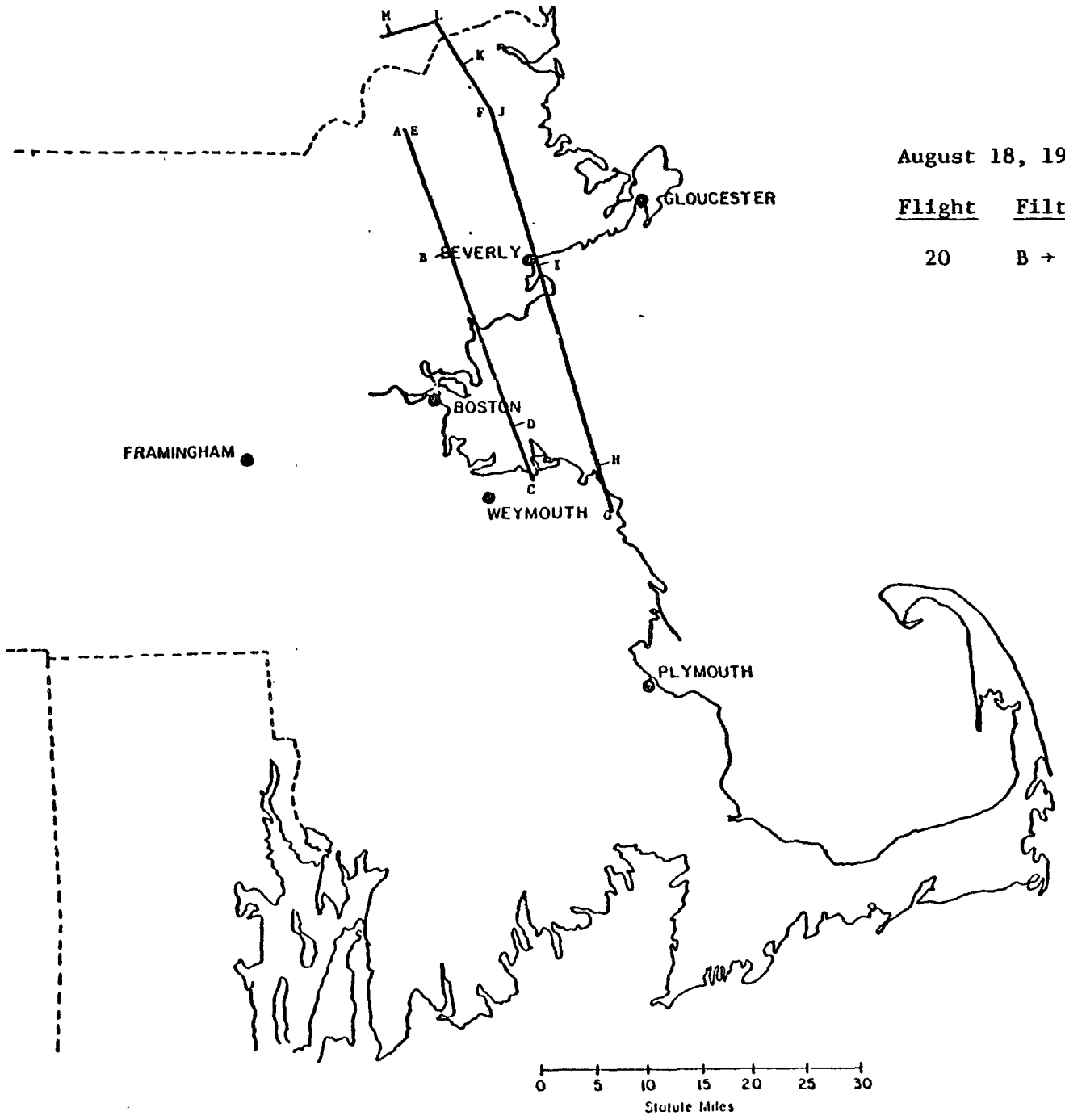
Flight	Filter	Bag 1	Bag 2
18	B → H	D → E	F → G



August 17, 1978

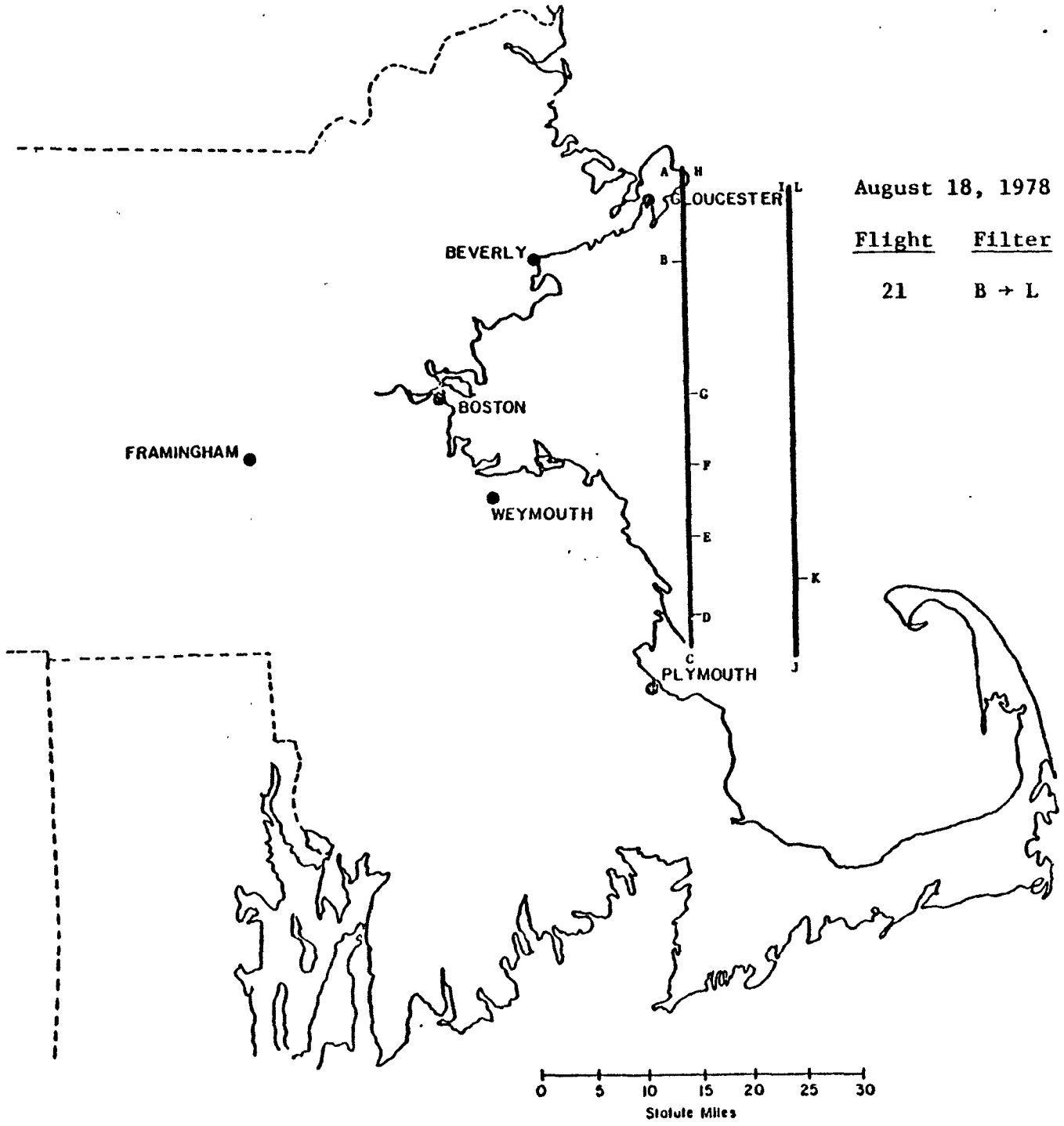
Flight	Filter	Bag 1
19	A → E	C → D





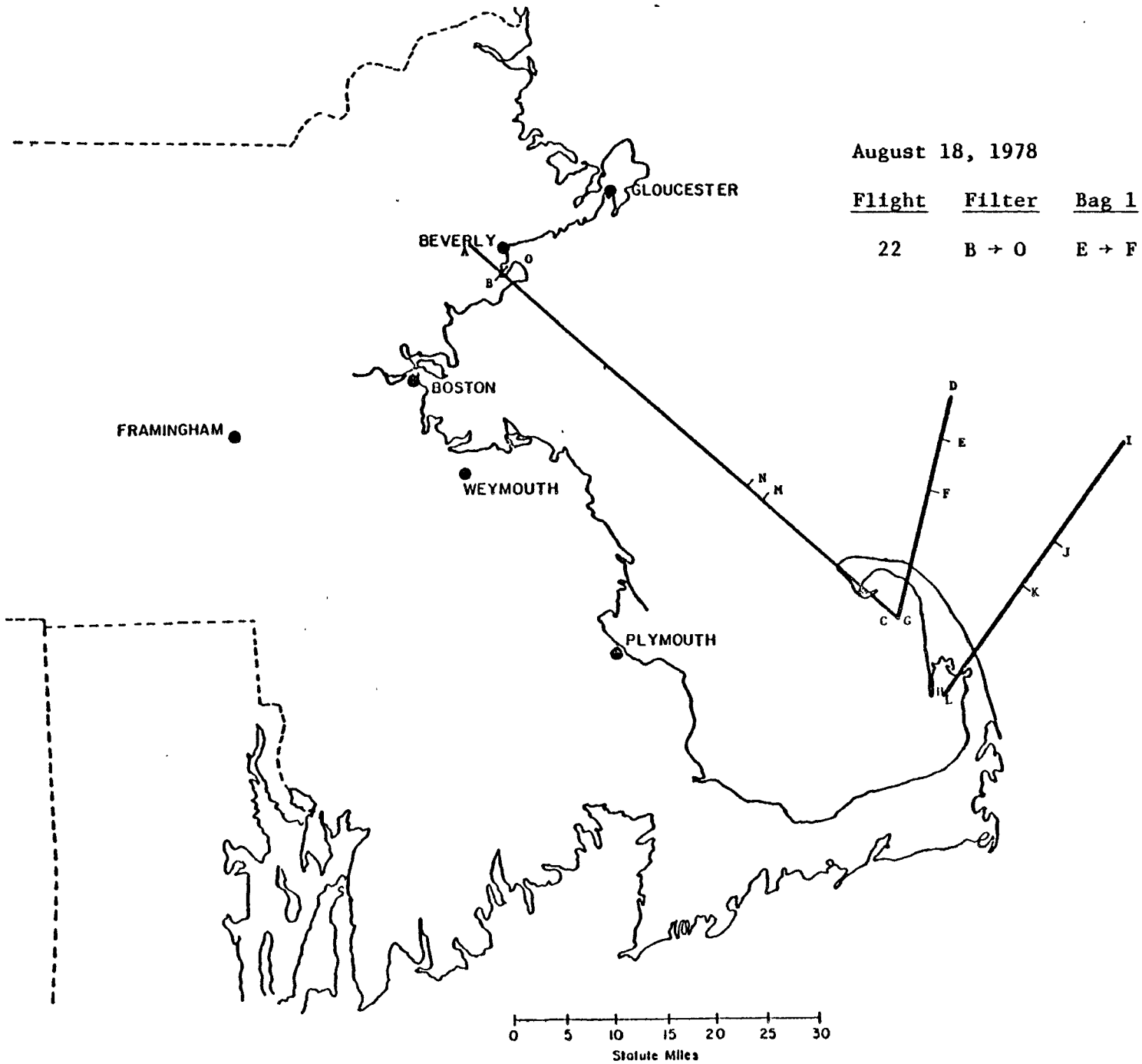
August 18, 1978

Flight	Filter	Bag 1	Bag 2	Bag 3
20	B → K	C → D	G → H	I



August 18, 1978

Flight	Filter	Bag 1	Bag 2	Bag 3
21	B → L	D → E	F → G	J → K

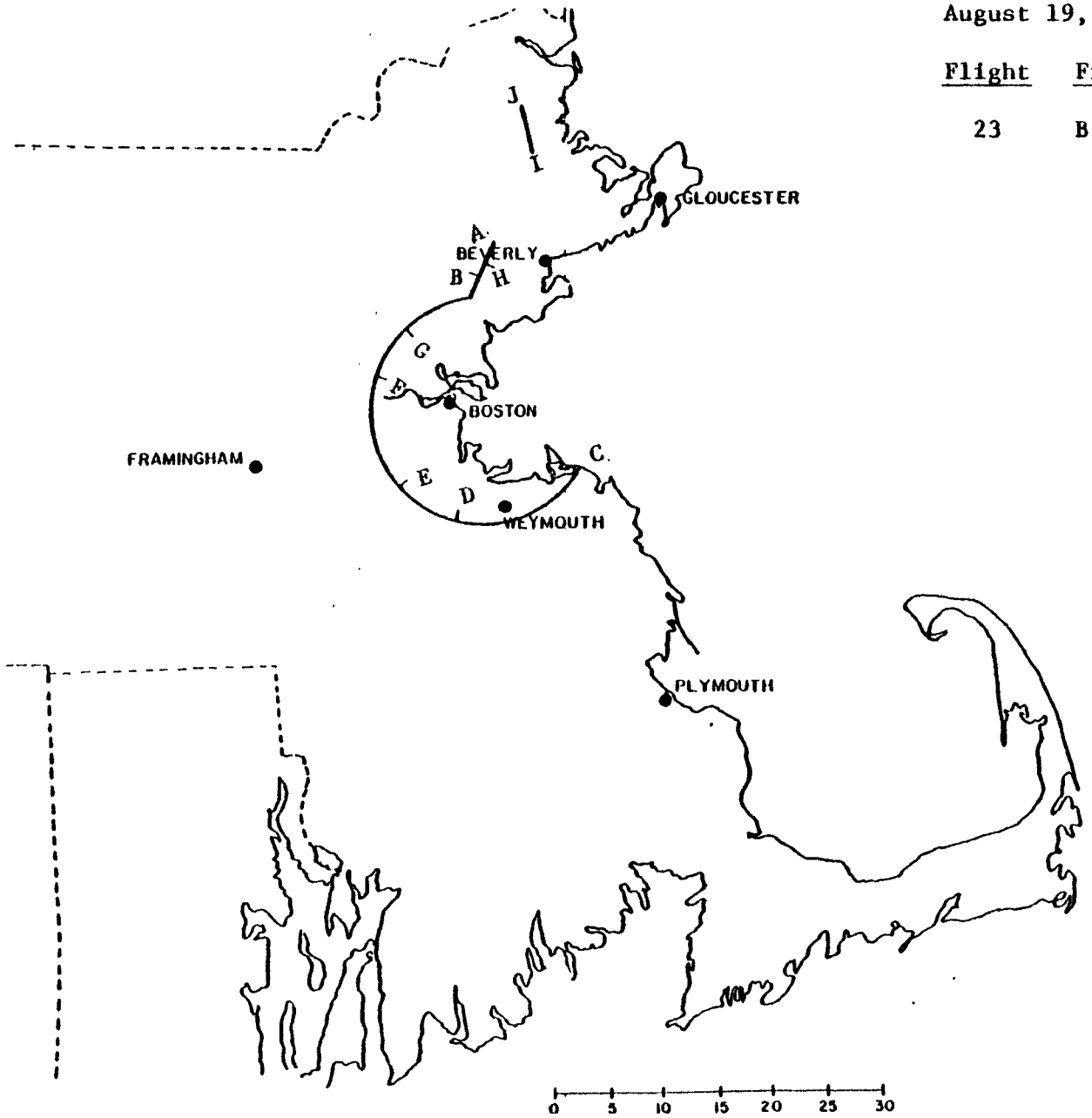


August 18, 1978

Flight	Filter	Bag 1	Bag 2	Bag 3
22	B → O	E → F	J → K	M → N

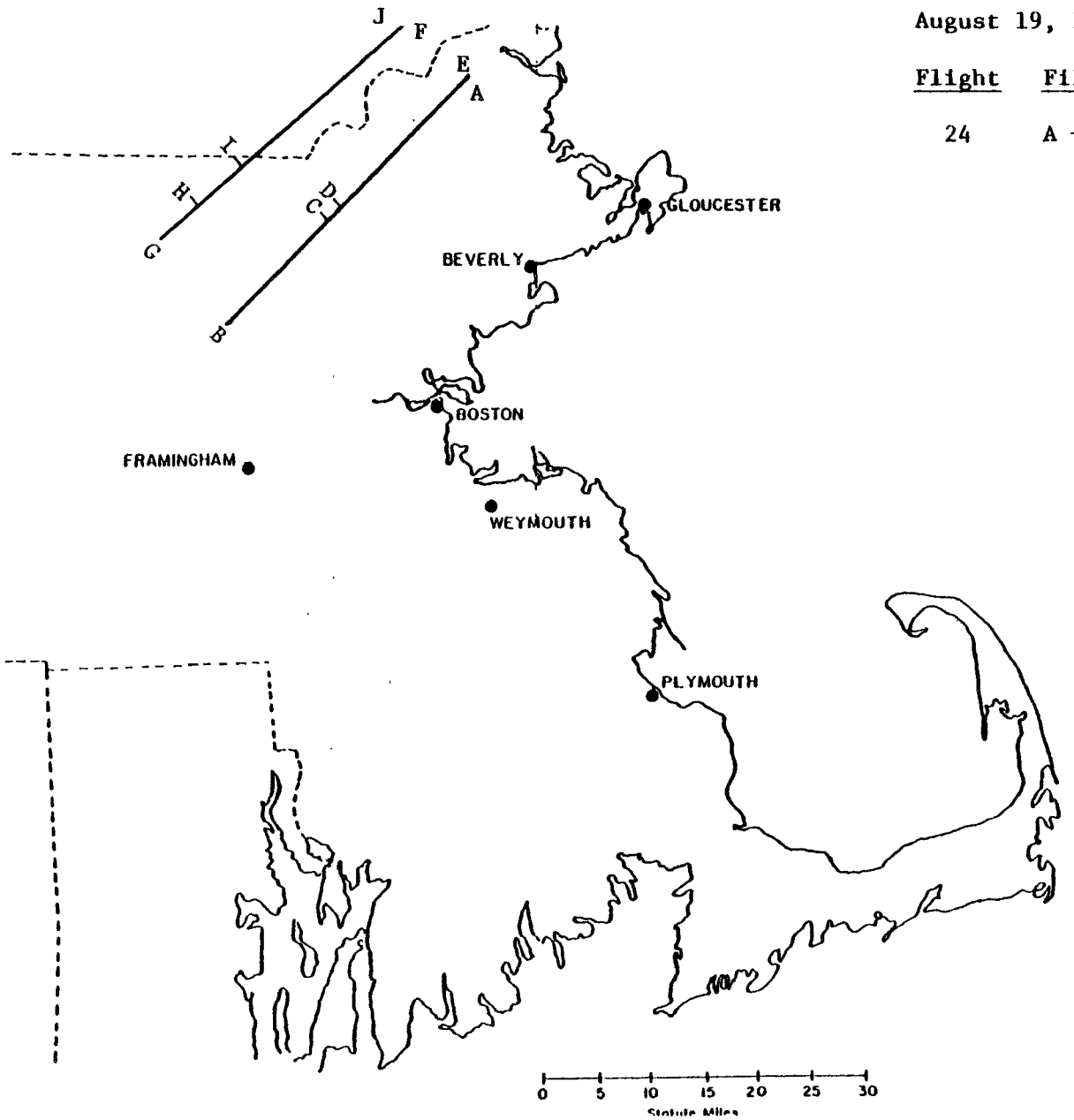
August 19, 1978

Flight	Filter	Bag 1	Bag 2	Bag 3
23	B → H	D → E	F → G	I → J



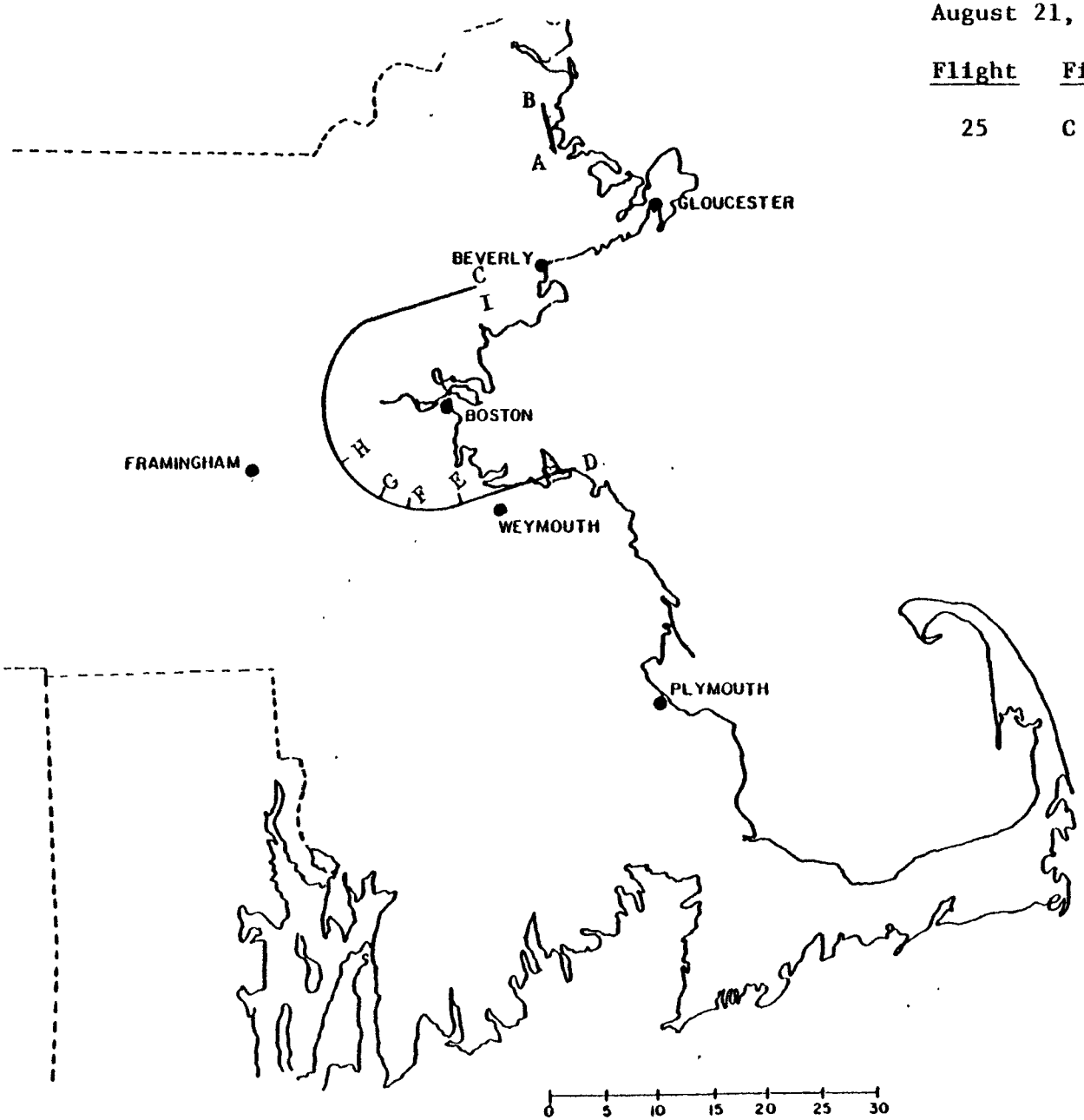
August 19, 1978

Flight	Filter	Bag 1	Bag 2
24	A → J	C → D	H → I



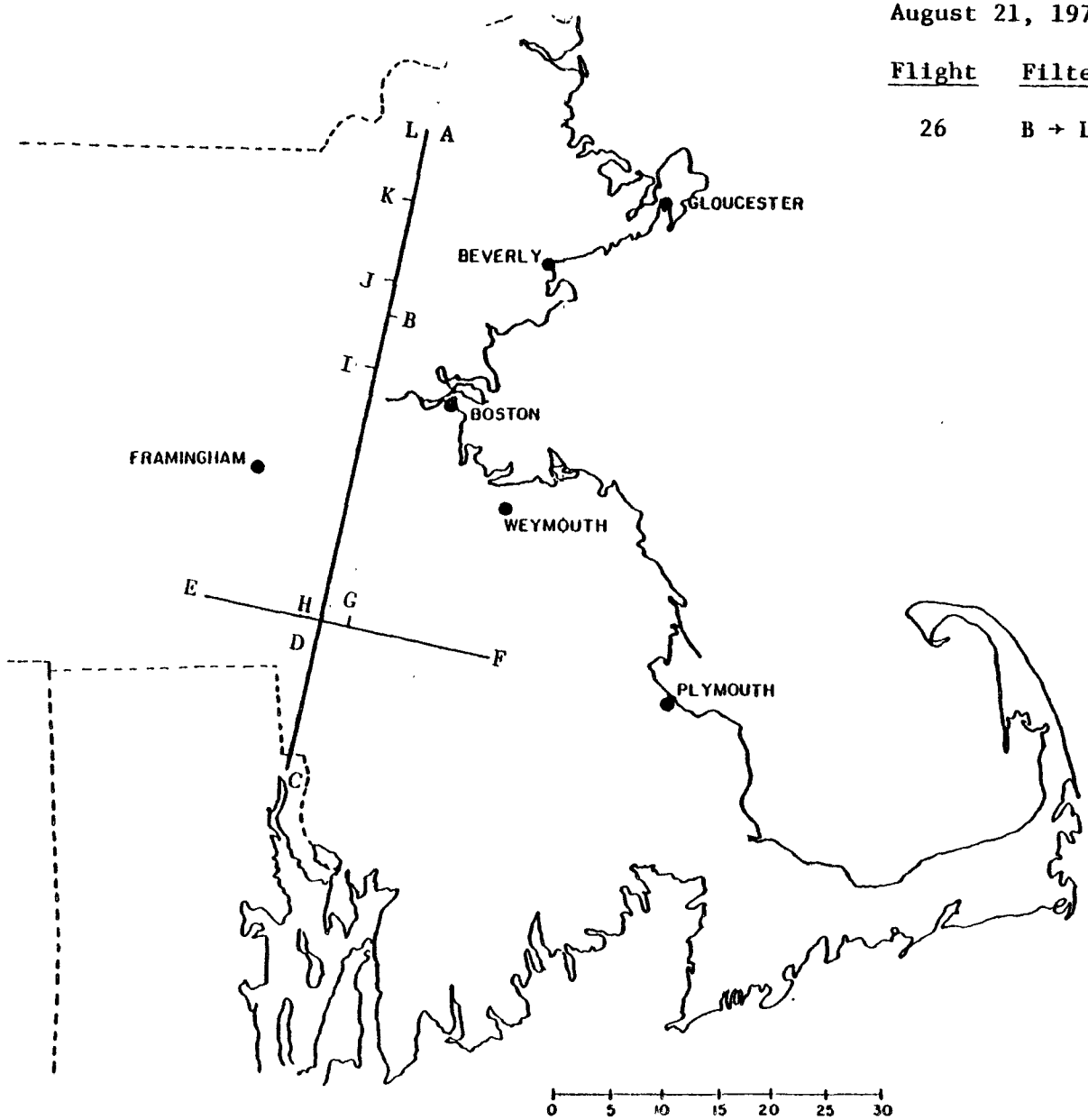
August 21, 1978

Flight	Filter	Bag 1	Bag 2	Bag 3
25	C → I	A → B	E → F	G → H



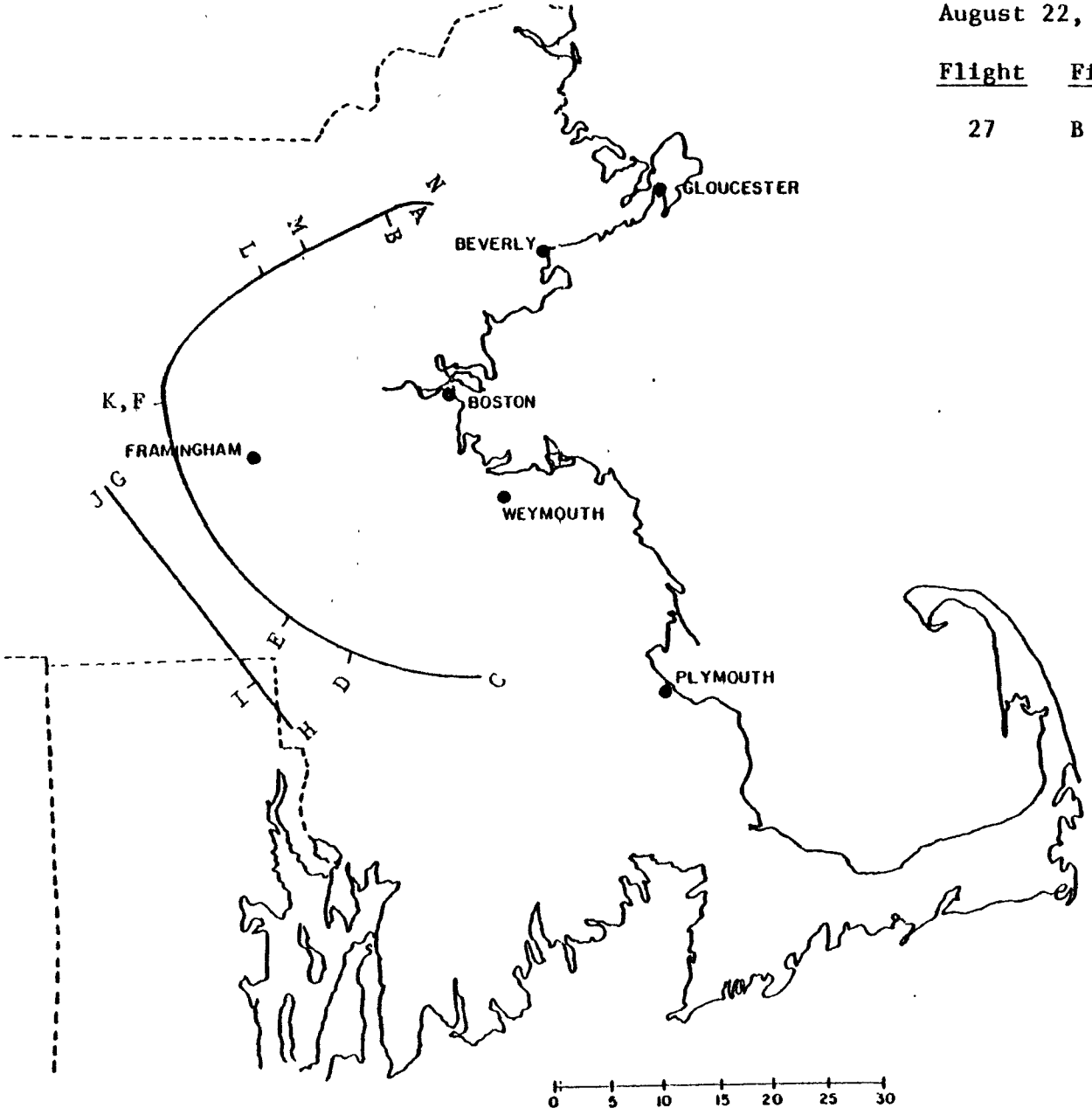
August 21, 1978

Flight	Filter	Bag 1	Bag 2	Bag 3	Bag 4
26	B → L	--	G → H	--	I → J



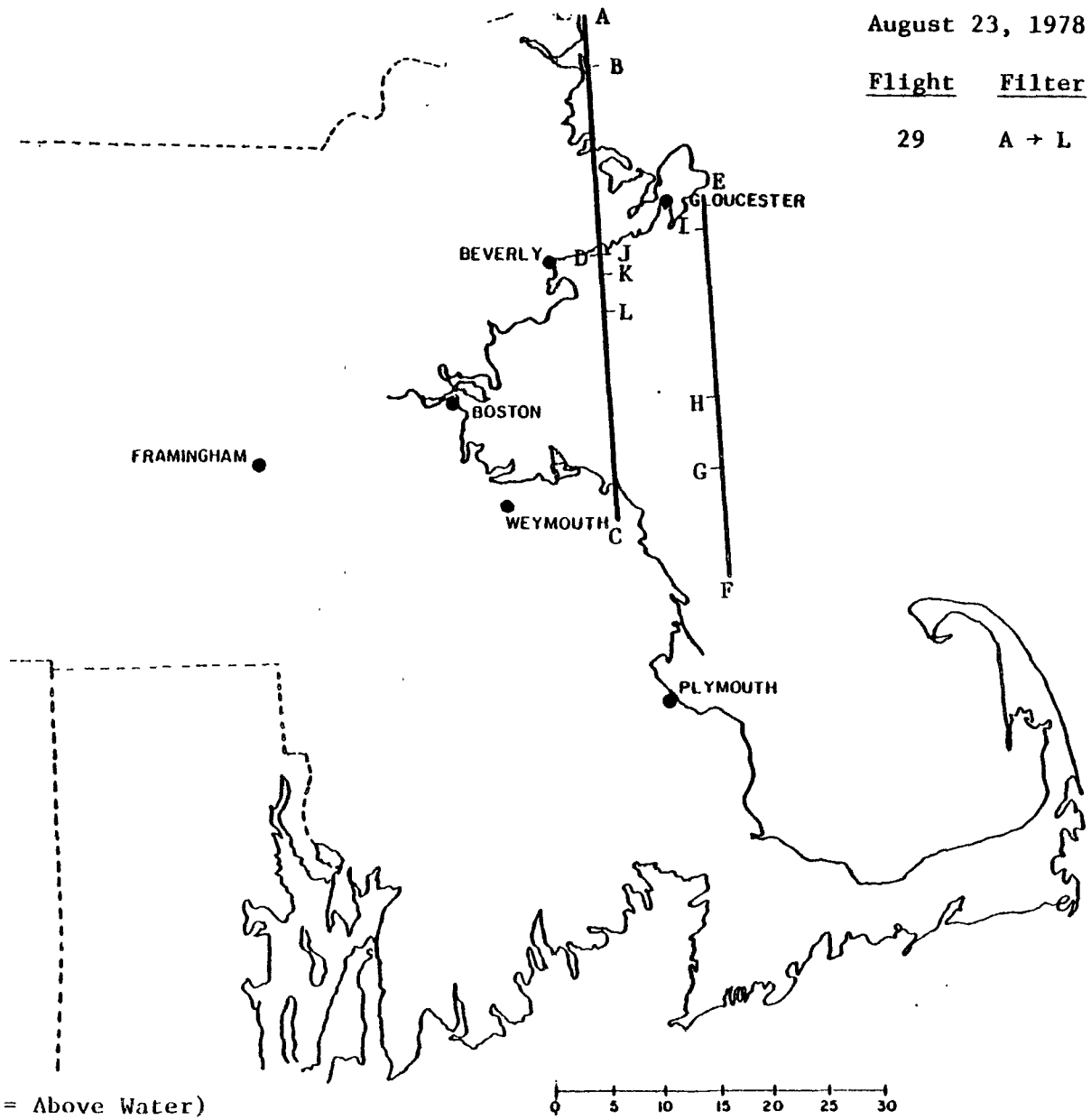
August 22, 1978

Flight	Filter	Bag 1	Bag 2	Bag 3
27	B → J	D → E	H → I	L → M



August 23, 1978

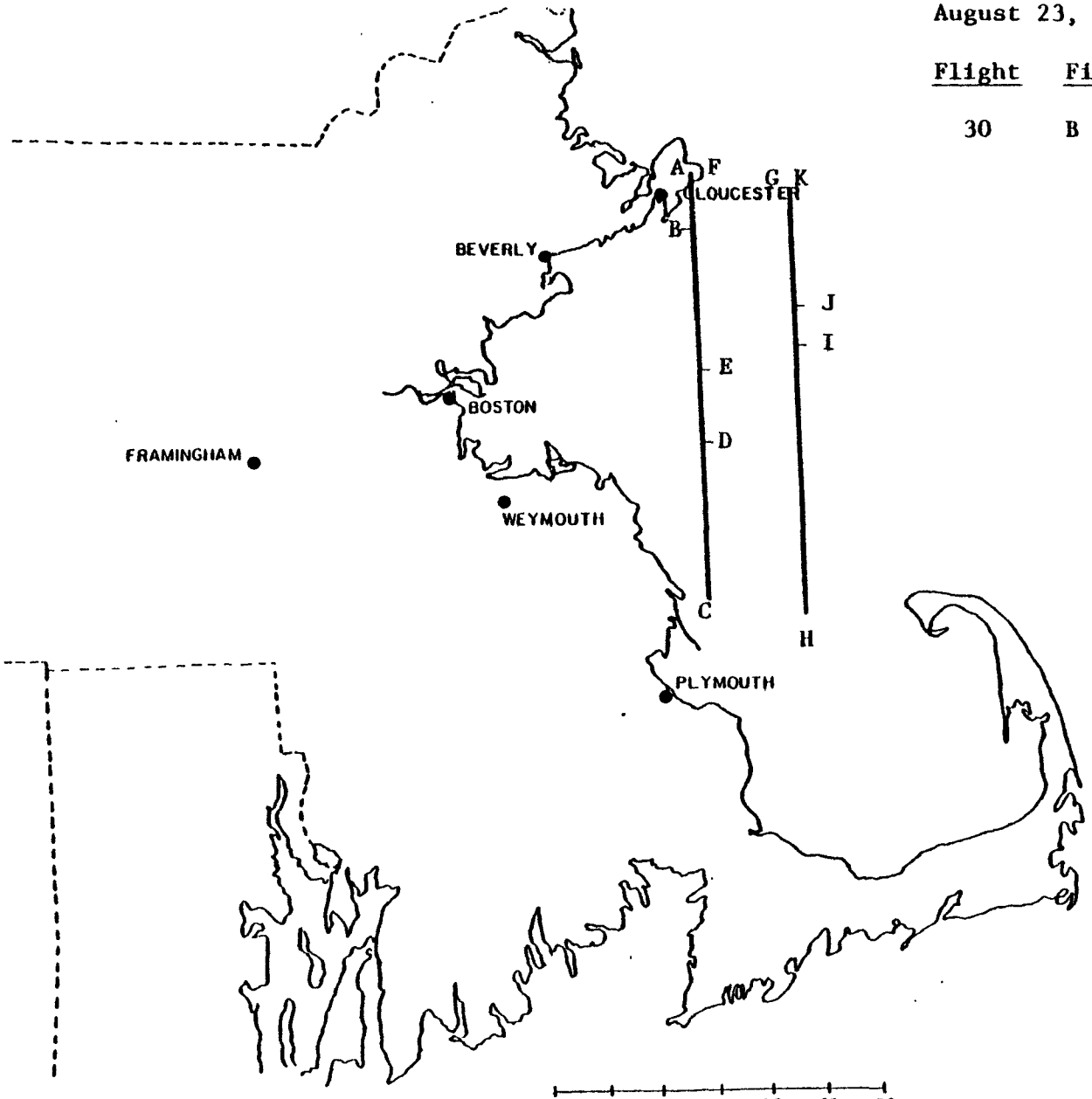
Flight	Filter	Bag 1	Bag 2	Bag 3	Bag 4	Bag 5
29	A → L	A → B	--	--	G → H* (150'AW)	K → L (100'AW)



* (AW = Above Water)

August 23, 1978

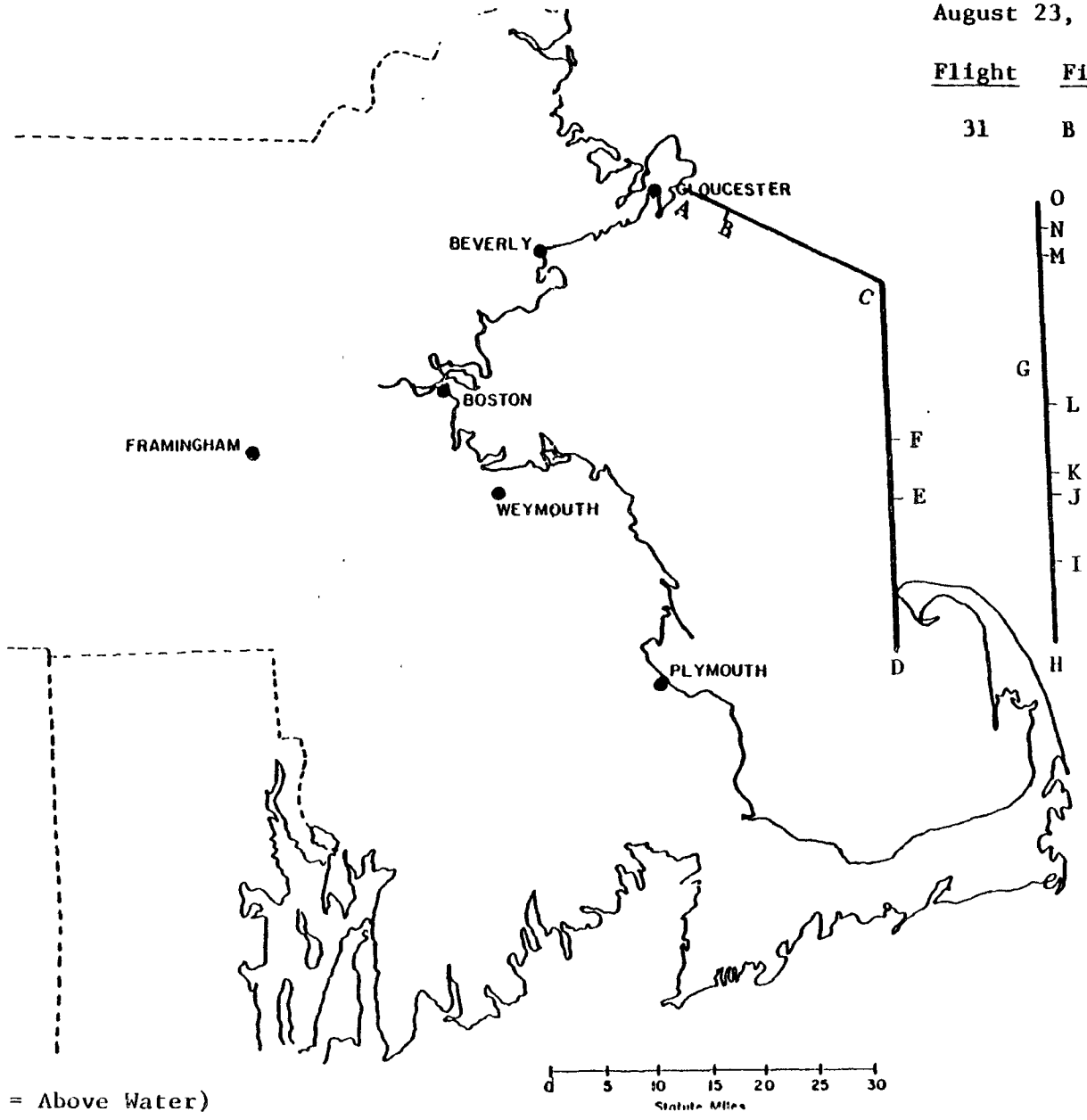
Flight	Filter	Bag 1	Bag 2
30	B → K	D → E (150'AW)*	I → J (50'AW)



* (AW = Above Water)

August 23, 1978

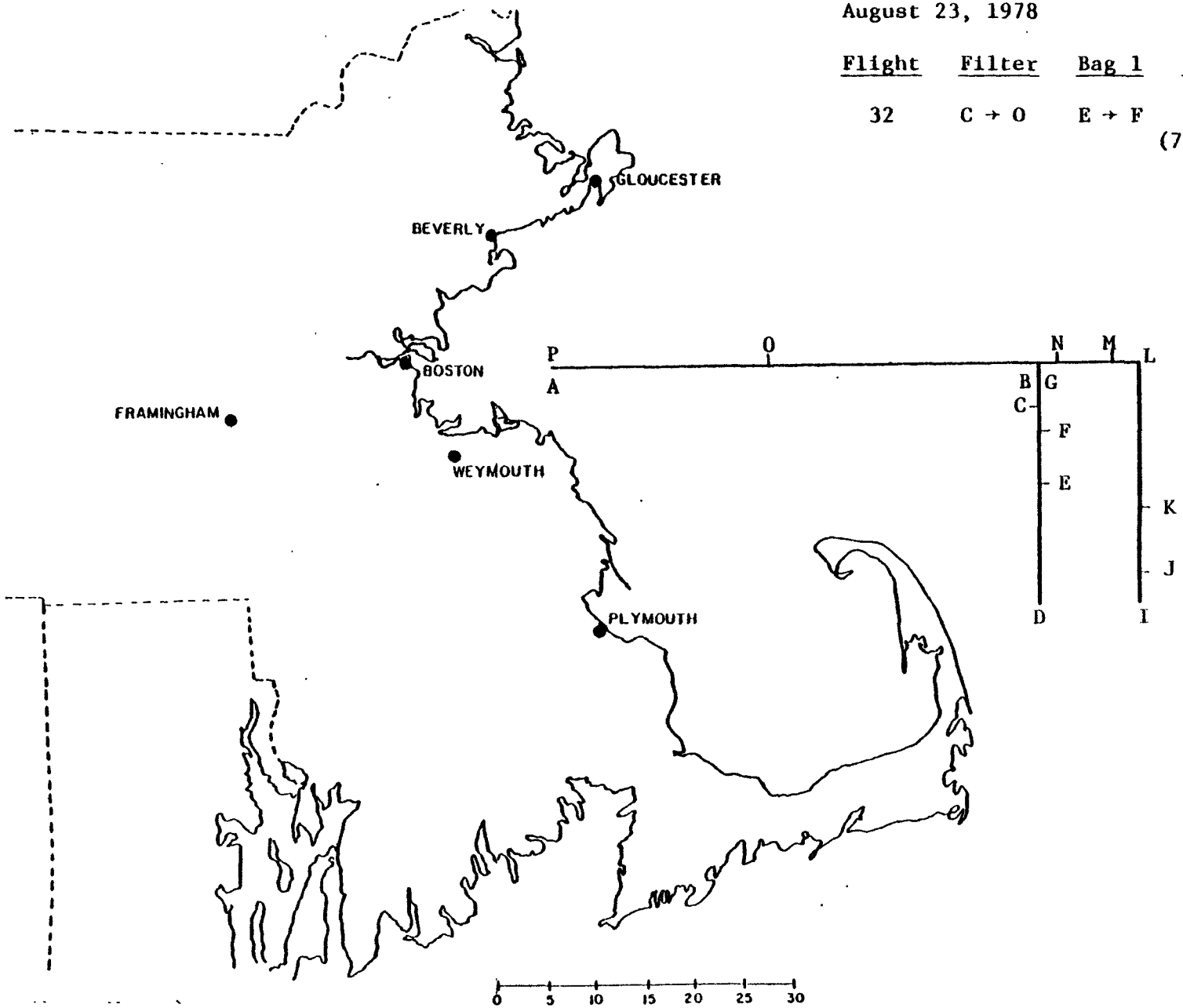
Flight	Filter	Bag 1	Bag 2	Bag 3	Bag 4
31	B → O	E → F (350'AW)	I → J (400'AW)	K → L (400'AW)	M → N *



* (AW = Above Water)

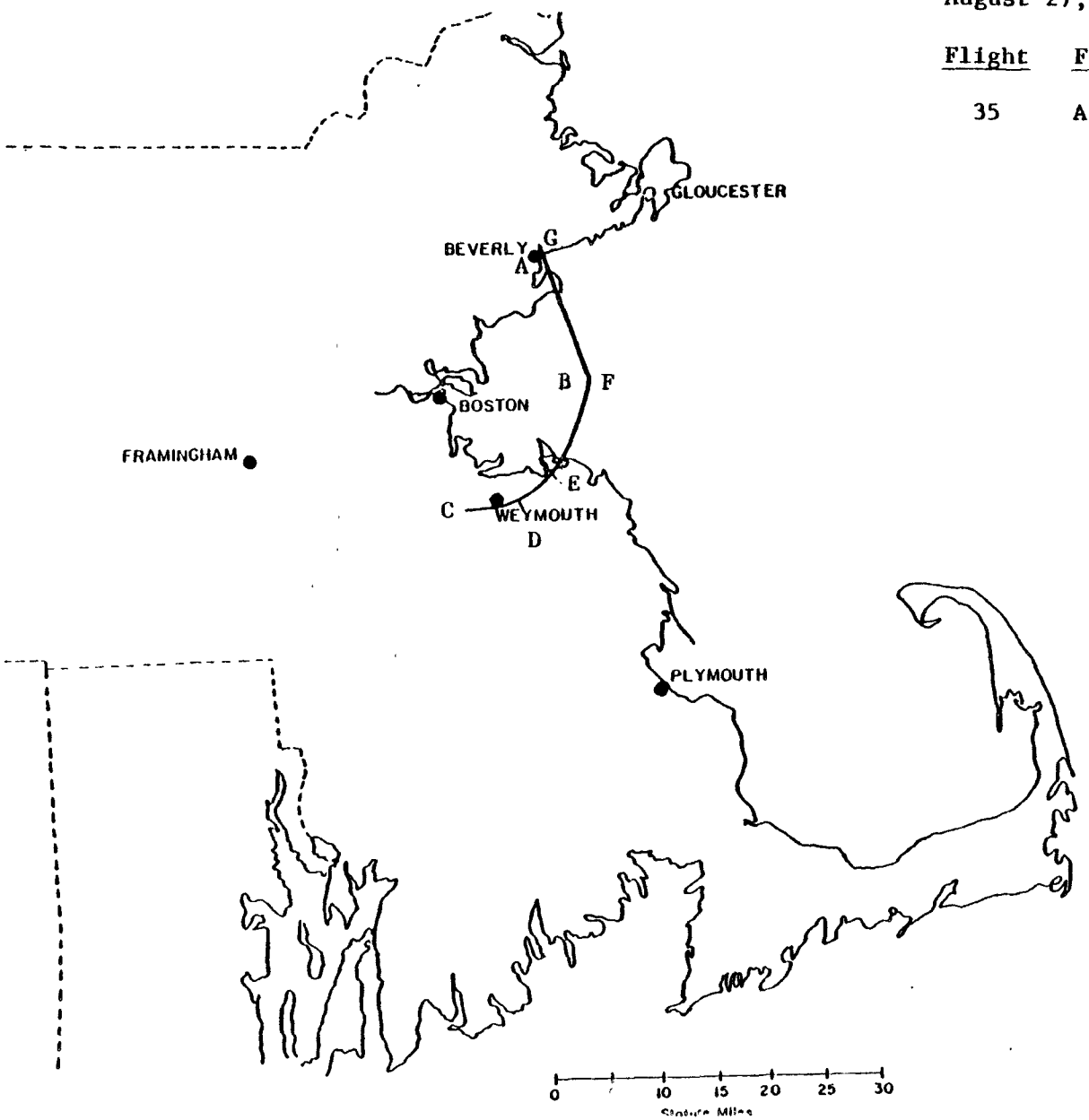
August 23, 1978

Flight	Filter	Bag 1	Bag 2	Bag 3
32	C → O	E → F	J → K (700'AW)*	M → N (600'AW)



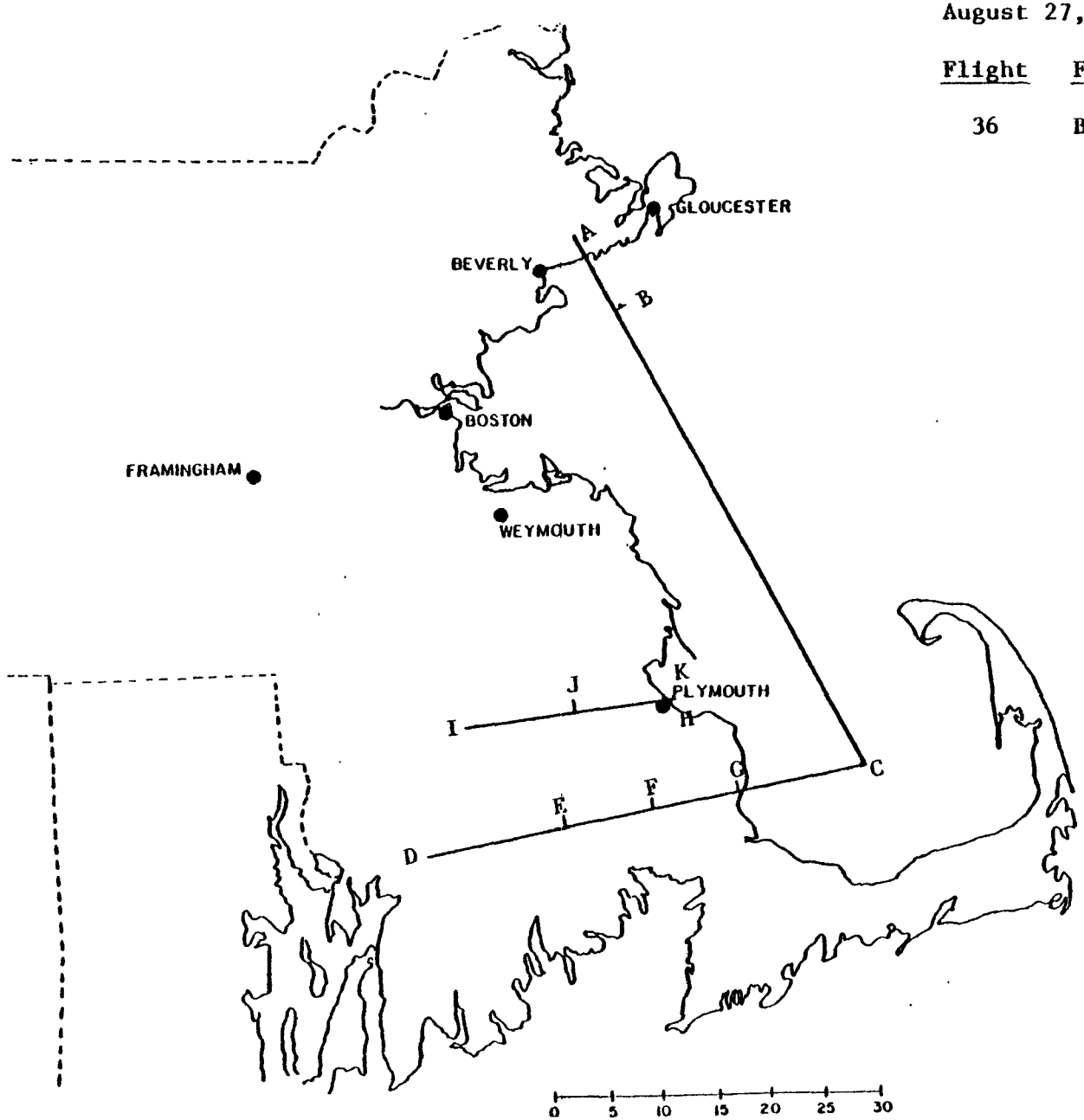
August 27, 1978

Flight	Filter	Bag 1
35	A → G	D → E



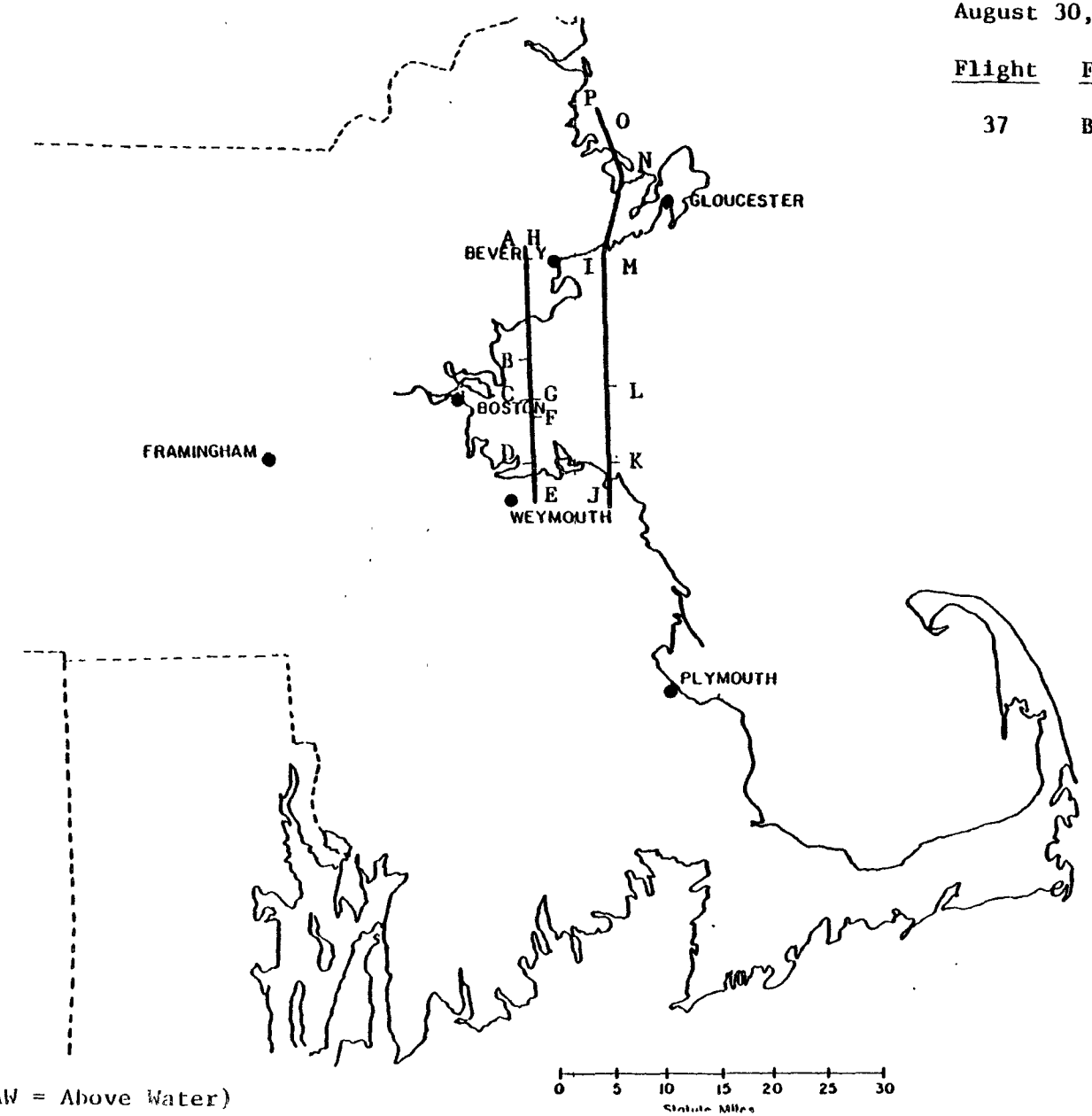
August 27, 1978

Flight	Filter	Bag 1	Bag 2
36	B → K	E → F	J → K



August 30, 1978

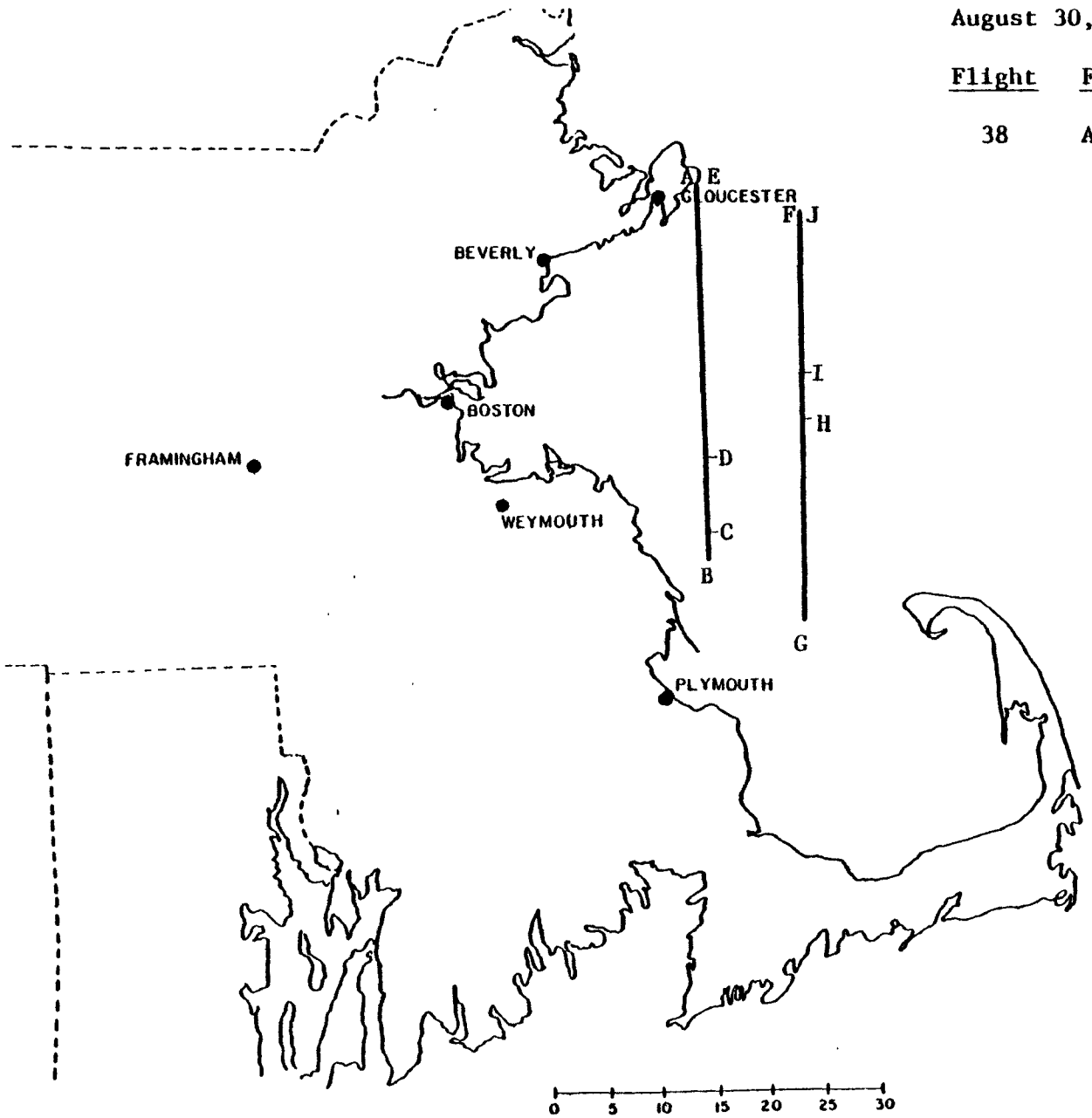
Flight	Filter	Bag 1	Bag 2	Bag 3	Bag 4
37	B → P	C → D	F → G	K → L (100'AW)*	N → O (3000'AW)



* (AW = Above Water)

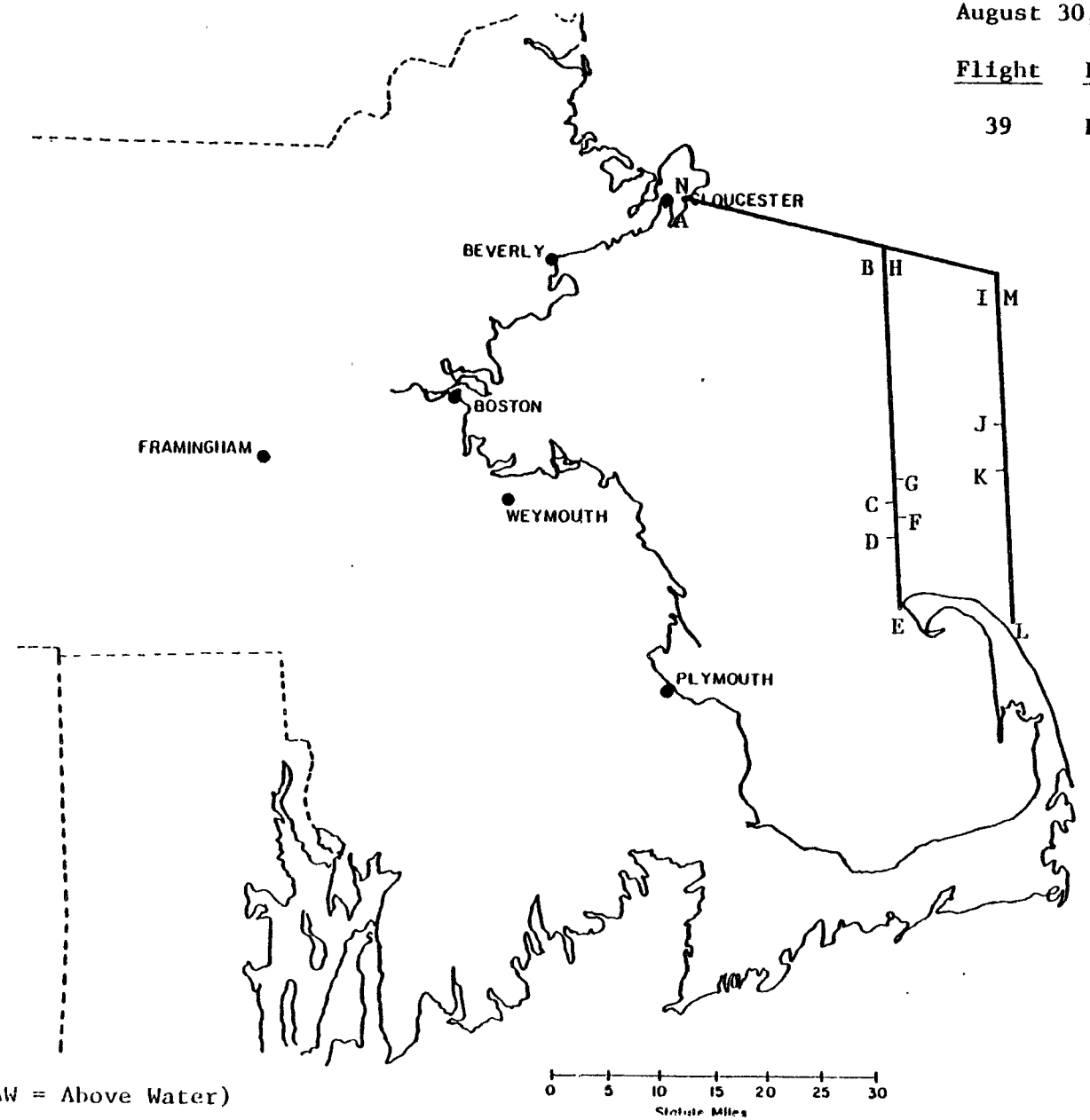
August 30, 1978

Flight	Filter	Bag 1	Bag 2
38	A → J	C → D (450'AW)*	H → I (200'AW)



August 30, 1978

Flight	Filter	Bag 1	Bag 2	Bag 3
39	E → N	C → D (500'AW)*	F → G (500'AW)	J → K (175'AW)



* (AW = Above Water)

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1.	2.
3. RECIPIENT'S A	
5. REPORT DATE	
6. PERFORMING ORGANIZATION CO	
8. PERFORMING ORGANIZATION REPORT NO.	
10. PROGRAM ELEMENT NO. CDWA1A/01 - 2355 (FY-83)	
11. CONTRACT/GRANT NO. 68-02-2957	
13. TYPE OF REPORT AND PERIOD COVERED Final Project Report, 1978	
14. SPONSORING AGENCY CODE	

E
TIDES REACTIONS WITHIN URBAN PLUMES
FR THE OCEAN

R. Koetz, G. W. Keigley,
ald F. Ward
GS

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EPA/600/09