Overview of the Oxidation and Scavenging Characteristics of April Rains (OSCAR) Experiment

**R. C. Easter
M. T. Dana
J. M. Thorp
K. M. Business
J. M. Hales**

**G. S. Raynor
C. M. Benkovitz
R. L. Tanner
J. D. Shannon**

April 1984

**Prepared for
the U.S. Environmental Protection Agency
under a Related Services Agreement
with the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830**

**Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute**

Although the research described in this article has been funded wholly or in part by the United States Environmental Protection Agency (EPA), it has not been subjected to EPA review and therefore does not necessarily reflect the views of EPA and no official endorsement should be inferred.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America
Available from
National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

NTIS Price Codes
Microfiche A01

Printed Copy	
Pages	Price Codes
001-025	A02
026-050	A03
051-075	A04
076-100	A05
101-125	A06
126-150	A07
151-175	A08
176-200	A09
201-225	A010
226-250	A011
251-275	A012
276-300	A013

OVERVIEW OF THE OXIDATION AND
SCAVENGING CHARACTERISTICS OF
APRIL RAINS (OSCAR) EXPERIMENT

Prepared jointly by

R.C. Easter, M.T. Dana, J.M. Thorp
K.M. Busness, J.M. Hales
Pacific Northwest Laboratory

G.S. Raynor, C.M. Benkovitz, R.L. Tanner
Brookhaven National Laboratory

J.D. Shannon
Argonne National Laboratory

April 1984

Prepared for the U.S. Environmental
Protection Agency under a Related
Services Agreement with the U.S.
Department of Energy under
Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

ABSTRACT

The OSCAR (Oxidation and Scavenging Characteristics of April Rains) field experiment was conducted in April, 1981, as part of the MAP3S/RAINE program. The OSCAR study was designed to provide detailed characterizations of the physicochemical and dynamical features of selected cyclonic storm systems as they traversed the eastern U.S. Major experiment components included sequential precipitation chemistry measurements, aircraft measurements both in cloud and in clear air in storm inflow regions, surface-level air chemistry measurements, and supporting meteorological measurements. The precipitation chemistry network consisted of an intermediate-density network with 37 sampling sites covering the region from southern Ontario to Tennessee and from Illinois to New Hampshire, and a high-density network with 47 sampling sites located in a 100 by 100 km area in northeast Indiana. A total of four storm events were studied during the experiment. The report describes the design and operational aspects for the high-density and intermediate-density components of the experiment, and the composition of the integrated OSCAR data set which has been developed. A synoptic meteorological description of the four storm events studied during OSCAR is also provided.

ACKNOWLEDGEMENTS

The OSCAR experiment was a highly cooperative project. Technical contributions were made by numerous individuals from many organizations, and funding was provided by several sponsors. The majority of financial support for OSCAR was provided by the Environmental Protection Agency, with a significant contribution by the Department of Energy. Additional support was provided by the Coordinating Research Council (H_2O_2 field measurements), Electric Power Research Institute (post-analyses of OSCAR data), the Ontario Ministry of Environment, and Environment Canada (operation of Canadian intermediate-density network sites).

Numerous individual efforts deserve to be acknowledged. Besides those persons appearing as co-authors to this report, the following ANL, BNL, and PNL personnel made significant contributions to OSCAR:

ANL: S.A. Johnson, C.M. Sheih, R.L. Coulter, I.Y. Lee, D.L. Sisterson, D.L. Cook, R.L. Hart, T.J. Martin, G.A. Zerbe, F.T. DePaul, F.C. Kulhanek, and D. Wagner

BNL: Robert M. Brown, Peter H. Daum, Seymour Fink, Walter E. Jahnig, Martin J. Leach, Daniel F. Leahy, and John P. McNeil

PNL: Elaine Chapman, Don Glover, Richard Lee, Jane Rothert, Bryan Scott

Several special measurement capabilities were provided at the surface air chemistry site by: Susanne Hering, UCLA (size classified sulfate aerosol), Gregory Kok, NCAR (hydrogen peroxide), and M.W. Holdren and C.W. Spicer, Battelle Columbus (peroxyacetyl nitrate). The many individuals who operated the intermediate-density network sites provided essential contributions, and many of these people are noted in Appendix A. We would also like to thank the personnel of the Fort Wayne NWS and FAA stations for their cooperation in assisting the high-density network operations, and the many citizens of the Fort Wayne area who allowed high-density network sites on their private property. Finally, Jack Shannon of ANL must be given credit for the OSCAR acronym.

TABLE OF CONTENTS

	<u>Page</u>
1 <u>INTRODUCTION</u>	1-1
REFERENCES	1-4
2 <u>HIGH-DENSITY EXPERIMENT DESCRIPTION</u>	2-1
RATIONALE AND EXPERIMENT DESIGN	2-1
HIGH-DENSITY PRECIPITATION CHEMISTRY NETWORK	2-7
Network Organization	2-7
Sampler Design	2-10
Field Sampling Procedure	2-16
AIRCRAFT MEASUREMENTS	2-19
BNL Islander Aircraft	2-20
PNL DC-3 Aircraft	2-22
PNL Cessna 411 Aircraft	2-25
SURFACE AIR CHEMISTRY	2-26
REFERENCES	2-29
3 <u>INTERMEDIATE-DENSITY EXPERIMENT DESCRIPTION</u>	3-1
RATIONALE	3-1
INTERMEDIATE-DENSITY PRECIPITATION CHEMISTRY NETWORK	3-1
Network Organization	3-2
Sampler Design	3-2
Field Sampling Procedure	3-5
AIRCRAFT OPERATIONS	3-7
SURFACE AIR CHEMISTRY	3-9
FORECAST CENTER OPERATION	3-10

TABLE OF CONTENTS

	<u>Page</u>
4 <u>OSCAR EVENT DESCRIPTIONS</u>	4-1
EVENT 1, APRIL 8-9, 1981	4-1
EVENT 2, APRIL 11-14, 1981	4-4
EVENT 3, APRIL 16-18, 1981	4-8
EVENT 4, APRIL 21-24, 1981	4-10
5 <u>CENTRAL DATA COORDINATION</u>	5-1
RATIONALE	5-1
METEOROLOGICAL DATA	5-1
PRECIPITATION AND PRECIPITATION CHEMISTRY DATA	5-2
OSCAR High-Density Network	5-2
OSCAR Intermediate-Density Network	5-3
U.S. and Canadian Precipitation Data	5-3
AIR QUALITY DATA	5-4
High-Density Experiment Surface Air Chemistry Site	5-4
BNL Site	5-4
Other U.S. and Canadian Data	5-4
AIRCRAFT DATA	5-5
APPENDIX A INTERMEDIATE-DENSITY PRECIPITATION CHEMISTRY NETWORK DESCRIPTIONS	
APPENDIX B METEOROLOGICAL BULLETINS AVAILABLE FROM THE BNL-SUITLAND LINK	
APPENDIX C NAMER-WINDTEMP DATA	

TABLES

	<u>Page</u>
2-1 High-Density Precipitation Chemistry Site Positions	2-9
2-2 Characteristics of the High-Density Network Automatic Sequential Bulk Collector	2-11
2-3 BNL Islander Measurement Systems	2-21
2-4 PNL DC-3 Measurement Systems	2-23
2-5 PNL Cessna 411 Research Instruments	2-26
2-6 OSCAR Surface Air Chemistry Site Measurements	2-28
3-1 Locations and Types of Stations in the Intermediate-Density Network	3-3
3-2 BNL Aircraft Flights During OSCAR	3-8

FIGURES

	<u>Page</u>
1-1 OSCAR Intermediate-Density Sampling Station Locations and High-Density Network Position	1-3
2-1 Schematic of Idealized Two-Dimensional Storm Cross-Section Used in Applying the Hales Model to a Warm Frontal Storm	2-3
2-2 Schematic Vertical Cross-Section of a Typical Warm Front Showing Planned Aircraft Sampling Positions	2-4
2-3 Organization of the OSCAR High-Density Precipitation Chemistry Network	2-8
2-4 Top View of Interior of a High-Density Network Automatic Sequential Sampler	2-12
2-5 Front View of High-Density Network Automatic Sequential Sampler	2-13
2-6 Laboratory Tests of the High-Density Network Automatic Sequential Sampler	2-15
2-7 A Typical High-Density OSCAR Network Station	2-17
3-1 Locations of the OSCAR Intermediate-Density Precipitation Chemistry Network Sampling Sites	3-4
3-2 A Typical OSCAR Intermediate-Density Station	3-6
4-1 Frontal Positions Associated with Storm of April 8-10	4-2
4-2 Frontal Positions Associated with Storm of April 14	4-5
4-3 Frontal Positions Associated with Storm of April 23-24	4-11

SECTION 1

INTRODUCTION

The Oxidation and Scavenging Characteristics of April Rains (OSCAR) experiment, conducted during April, 1981, was a cooperative field investigation of wet removal by cyclonic storms. The experiment was primarily supported by the U.S. Environmental Protection Agency, with significant contributions from the U.S. Department of Energy, as a part of the MAP3S/RAINE (Multistate Atmospheric Power Production Pollution Study/Regional Acidity of Industrial Emissions) program.^{1,2} The overall objective of the MAP3S/RAINE program was to define the relationships between emissions of air pollutants, their deposition, and the chemical quality of precipitation. The OSCAR experiment was an attempt, using existing measurement capabilities and existing knowledge of wet removal, to expand our understanding of the above relationships in cyclonic storms through a field measurements project.

The experiment was designed and directed cooperatively by scientists from the three national laboratories predominantly involved in MAP3S/RAINE [Argonne (ANL), Brookhaven (BNL) and Pacific Northwest (PNL)]. Additional institutional participants in OSCAR included Ontario Ministry of Environment, Environment Canada, the National Center for Atmospheric Research, the Coordinating Research Council, and the Electric Power Research Institute. Working-level contributions to OSCAR were made by a variety of laboratories and research organizations. These included precipitation-chemistry network operations as well as special-purpose measurements.

In broad terms the primary design requirement for OSCAR was to characterize, in as much detail as possible, the physicochemical and dynamical features of selected cyclonic, or "frontal" storm systems as they traversed the eastern portion of the North American continent. The formal objectives of the study are stated as follows:

1. To assess spatial and temporal variability of precipitation chemistry in cyclonic storm systems, and to test the adequacy of existing networks to characterize this variability.

2. To provide a comprehensive, high-resolution data base for diagnostic, regional deposition model development.
3. To develop increased understanding of the transport, dynamical, and physicochemical mechanisms that combine to make up the composite wet-removal process, and to identify source areas responsible for deposition at receptor sites.

The OSCAR field experiment was designed to maximize progress towards the above goals, as constrained by practical and financial limitations of the project. The foundation of the experiment was two complementary, sequentially operated, precipitation chemistry networks. Spatial and temporal resolution were primary factors determining the networks. A nested high-density, intermediate-density network design was chosen to allow both regional coverage over the MAP3S/RAINE geographical region, and intensive measurements over a limited area to resolve wet-removal mechanisms in cyclonic storms. The networks are depicted schematically in Figure 1-1. The intermediate-density network consisted of 37 stations in the eastern U.S. and Canada. The high-density network consisted of 47 stations in a 110 by 110 km area in northeast Indiana/-northwest Ohio.

Additional components of the experiment involved the collection of surface air chemistry data, aircraft air chemistry and cloud chemistry data, and meteorological data in support of the two networks. The April operational period for OSCAR was chosen so that most precipitation would be rain rather than snow, but storm systems would still be more cyclonic than convective in nature.

The purposes of this report are to describe the OSCAR experimental design, the experimental operations and the data set resulting from the experiment. Analyses of the experimental results will be presented in subsequent reports. The organization of this report is as follows. Sections 2 and 3 describe the design and operational aspects of the experiment for the high-density and intermediate-density components, respectively. Section 4 presents a meteorological description of the four storm events studied during OSCAR and a brief discussion of data capture for each event. Section 5 is a

Figure 1-1. OSCAR intermediate-density sampling station locations and high-density network position.

detailed description of the OSCAR data set. This data set, which is archived at BNL, is an important product of the experiment and is available to other investigators.

REFERENCES

1. "MAP3S/RAINE Program Design-Basis Document," U.S. EPA/U.S. DOE Report, PNL-3434 (1980).
2. "MAP3S/RAINE Biennial Progress Report for the Period FY1980 - FY1981," U.S. EPA/U.S. DOE Report, PNL-4096 (1981).

SECTION 2

HIGH-DENSITY EXPERIMENT DESCRIPTION

RATIONALE AND EXPERIMENT DESIGN

The high-density network experiment was oriented largely towards the objective of increasing understanding of physicochemical wet removal mechanisms. Specifically, the experiment was designed to provide information on the contributions of aerosol scavenging, non-reactive gas scavenging, and reactive gas scavenging to sulfate and nitrate deposition. The resulting experimental plan involved closely coordinated aircraft and surface measurements centered on a relatively compact high-density precipitation chemistry network.

The experiment design involved two main measurement strategies. The first strategy was linked to two diagnostic wet-removal models: the one-dimensional steady-state model of Scott,¹ and the two-dimensional steady-state model of Hales.² The primary consideration in this design was to obtain input data required by the models, so that the models could be utilized to analyze the data in terms of the above experiment objective. The second measurement strategy involved performing Lagrangian type measurements with aircraft to directly measure in-cloud aqueous conversion.

The two diagnostic scavenging models are effectively mass balance models, and the models' primary data requirements are pollutant inflows to and outflows from the systems being analyzed. Scott's one-dimensional model is a mass-balance model for an entire storm or precipitation system, and was originally applied to idealized 'typical' storms using seasonally and regionally averaged input data. The models spatial domain consists of the storm volume and the region outside the storm, and horizontal uniformity is assumed within the storm volume. Data required by the model are pollutant inflow rates to the storm (concentrations and air velocity), pollutant wet deposition and precipitation rates (event averaged), and some storm characteristics such as storm height and freezing level. With these data the

model can predict removal efficiencies for the various pollutants and an effective first-order aqueous conversion rate for SO_2 .

Hales' model is formulated as a one-dimensional time dependent model, but can be applied in a two-dimensional steady state mode if the precipitation system is quasi-steady state. For example, Fig. 2-1 shows how the model has been applied to an idealized warm frontal cross-section. Two advantages of this model over Scott's model are that it includes a more flexible and complete treatment of precipitation chemistry, and it can be used for analyses of temporal behavior^{*} of the precipitation chemistry (sequential rather than event data). The models input requirements are similar to Scott's, except that sequential rather than event data are utilized.

This mass balance approach involved four main experiment components: the precipitation chemistry network, the research aircraft, the surface air chemistry site, and meteorological measurements. The precipitation chemistry network provided data on the outflow of pollutants via wet deposition from the storms. The network was designed to have fine enough spacing to resolve larger-scale mesoscale features within frontal storms, and have good temporal resolution at the beginning of the storm. The aircraft performed measurements of gaseous and aerosol pollutants feeding the storms. Three research aircraft were available. Their deployment, in an idealized warm frontal situation is shown in Figure 2-2. The BNL Islander was to sample in the warm air mass, while the PNL DC-3 and Cessna would sample in the cold air mass ahead of the warm front. After performing clear air sampling, the DC-3 would then move incloud along an air trajectory and sample using the Lagrangian measurement strategy. Warm frontal events were to be sampled in preference to cold frontal situations because the expected convective activity associated with cold fronts would make interpretation more difficult and would preclude incloud aircraft operations. The surface air chemistry facility provided a ground-level complement to the aircraft measurements, documenting temporal

^{*}In applying the model, one assumes that the storm system is quasi-steady state. However, the storm system will be moving relative to the ground. This temporal behavior in precipitation chemistry at a surface site is equated to spatial behavior in the steady-state framework of the storm.

Figure 2-1. Schematic of idealized two-dimensional storm cross-section used in applying the Hales model to a warm frontal storm. Arrows depict airflows relative to front movement, and shading depicts liquid water cloud region.

Aircraft Positions: (I) BNL Islander; (D) PNL DC-3; (C) PNL Cessna

Figure 2-2. Schematic vertical cross-section of a typical warm front showing planned aircraft sampling positions (adapted from Godske et al.)⁴

changes in pollutant concentrations at a stationary point and allowing some measurements which could not be performed on the aircraft. Meteorological measurements included the use of a NWS weather radar at Fort Wayne airport, which provided a qualitative description of the storm structure and aided in aircraft positioning for sampling, and a rawinsonde unit also operated at the Fort Wayne airport.

The concept behind the Lagrangian measurement strategy was to follow a parcel of low level air in a Lagrangian sense as it moves from a clear air region in the vicinity of the frontal system into a cloud region. Aerosol and trace gas measurements are made in the parcel while in clear air, and cloud water samples are collected in the parcel while in cloud. By comparing the composition of the aerosol to the composition of the cloud-water (e.g., the ratio of concentrations of sulfate and hydrogen ion in aerosol vs. cloud water), estimates of the contribution of aqueous-phase SO_2 conversion to the cloud-water sulfate concentration can be made. This type of argument has been used before with regional data.^{1,3} If the residence time of the air parcel in cloud is known, then an effective first-order conversion rate can also be estimated.

Although conceptually simple, the actual measurements involved can be rather difficult. Following a parcel in a Lagrangian sense involves estimating its horizontal and vertical velocity components. The horizontal wind velocity was available from the aircraft navigation system. Rather than attempting to measure vertical velocity, the strategy was to locate the vertical position of the parcel based upon the conservation of equivalent potential temperature. The parcel measurements actually could be made either by a single aircraft, or with two aircraft, one horizontally downwind of the other but at the same equivalent potential temperature level.

The parcel model concept is not limited to a specific type of frontal system. As noted earlier, however, warm frontal situations were expected to be more amenable to the experiment than cold frontal situations, because of the possibility of intense convection associated with cold fronts both curtailing aircraft measurements and destroying the identity of parcels

through mixing. As shown in Figure 2-2, the parcel measurements could be made in either the warm or cold air mass associated with the warm front. Operating in the cold air mass ahead of the front offers two advantages. First, the cold air mass was expected to be more stable and thus have a larger vertical gradient of equivalent potential temperature than the warm air mass, allowing greater accuracy in locating the correct vertical position of a parcel. Second, for the location and season chosen, cloudiness and instability showers were common behind the warm front, making clear air sampling difficult.

The location chosen for the high-density network was northeast Indiana - northwest Ohio, roughly centered on Fort Wayne. This selection was based upon several criteria.

- An area with relatively high pollutant loadings and wet-deposition but relatively low local SO_x and NO_x sources (especially large point sources) was desired. Neither the interpretive models nor the measurements (e.g., precipitation chemistry and many of the aircraft measurements) were designed to resolve features with horizontal spatial scales of much less than 20 km. Thus we could not expect to explain any observed effects resulting from compact, point-source plumes.
- Weather radar was desirable for directing aircraft sampling and providing information on storm structure. A standard NWS radar at Fort Wayne was available to the experiment.
- The flat terrain of the Fort Wayne area was preferable to the hilly or mountainous terrain at other locations meeting the first two criteria, both for ground operations logistics and for low level aircraft operations.
- The in-cloud aircraft sampling (IFR) requires a large degree of cooperation from FAA authorities, and is more feasible in locations having light or moderate aircraft traffic.

HIGH-DENSITY PRECIPITATION CHEMISTRY NETWORK

This precipitation chemistry network was the foundation of the high-density experiment. The network organization, sampler design, and sampling protocol are described below.

Network Organization

The high-density precipitation network consisted of 47 sites covering a roughly square region in northeast Indiana-northwest Ohio (see Figure 1-1). The layout of the network is shown in Figure 2-3. Individual sampler locations are listed in Table 2-1. The extent of the network was roughly 110 km in both the north-south and east-west directions. This resulted in a typical spacing of 15 to 20 km between sampling sites. The number of sites in the network was dictated by the resources available to the network. The spacing of the network was chosen to cover as large an area as possible while still meeting the criteria of providing sufficiently dense coverage to allow an area integration of precipitation and wet deposition amounts and to resolve the mesoscale sub-structure of the frontal systems (i.e., rainbands). The coverage was not designed to resolve smaller-scale cellular structure, and the experiment plan called for studying warm frontal situations in preference to cold frontal situations so that convective structure would be less pronounced.

Figure 2-3. Organization of the OSCAR high-density precipitation chemistry network. Numbers indicate sampling site locations. Site 62 coincided with the surface air chemistry site. The weather radar and rawinsonde were located at FWA (Fort Wayne Airport).

Table 2-1
High-Density Precipitation Chemistry Site Positions

<u>Site No.</u>	<u>Latitude</u>	<u>Longitude</u>	<u>Site No.</u>	<u>Latitude</u>	<u>Longitude</u>
11	41.591	85.603	45	41.129	84.862
12	41.639	85.378	46	41.175	84.646
13	41.638	85.199	51	40.995	85.659
14	41.575	85.038	52	41.001	85.423
15	41.561	84.849	53	41.032	85.293
16	41.588	84.720	54	40.966	84.966
21	41.377	85.624	55	40.986	84.817
22	41.430	85.403	56	41.058	84.710
23	41.439	85.194	57	40.929	84.561
24	41.443	85.059	58	41.015	84.391
25	41.394	84.892	61	40.806	85.679
26	41.409	84.701	62	40.844	85.464
27	41.435	84.482	63	40.914	85.231
31	41.276	85.582	64	40.798	85.153
32	41.331	85.464	65	40.791	84.966
33	41.305	85.178	66	40.860	84.756
34	41.306	85.069	67	40.810	84.521
35	41.251	84.859	71	40.663	85.693
36	41.309	84.564	72	40.665	85.466
37	41.338	84.431	73	40.665	85.303
41	41.175	85.645	74	40.668	85.092
42	41.136	85.489	75	40.665	84.858
43	41.143	85.152	76	40.644	84.628
44	41.198	85.019			

The area of the network is predominantly rural farm country with the exception of Fort Wayne (population 180,000). As noted earlier, the area was chosen for its lack of local sources, especially large SO₂ point sources. Most of the sites were either adjacent to private residences, in yards, or in farming fields. Most of the samplers placed by residences were on grass. Many of the fields were bare during the experimental period, and samplers placed in fields had a larger potential for contamination by resuspension.

All sites were equipped with an automatic sequential bulk collector (see below) and a weighing rain gauge. Site 62 was also an intermediate-density network site (number 00), and a manual sequential collector (see Section 3) was operated simultaneously here. Site 62 was also the surface air chemistry site.

Sampler Design

Since the objectives of the high-density experiment required that sequential rain collections be made throughout the main part of a frontal rain event at about 50 locations, an inexpensive collector was developed that would not need attendance by ground sampling personnel. The basic structure of the sampler is a tube with bottles attached in series along the tube. The entrances to the bottles are stepped vertically so that the second bottle is above the first, and so on. As rainwater enters the tube, the bottles ("stages") are filled sequentially. In order to minimize mixing of new rainwater with previously collected samples and subsequent exchange between the stages, the bottles must be sealed from the flow along the tube once they are filled. This is accomplished with hollow floating balls, which just fit the entrances to the bottles and become firmly attached by their buoyancy as the water level reaches the top.

The collecting characteristics of the sampler--the amount of rainfall collected per stage and the total rainfall capacity of the collector--depend on the number and volume capacity of the stages and the rainfall collection (funnel) area. Very fine resolution of the time or rainfall during the event to be sampled requires a large collection area or small stages (but large enough to provide a usable sample) or a large number of stages, but total capacity may be limited. Conversely, the need for sequential collection of an entire event, however much rain falls, requires large capacity stages (and thus loss in time resolution), many stages, or small collection area. Obviously there are practical limits to be considered: for portability, the size and number of stages is restricted, and the practical funnel area is limited generally to the range 50-1000 cm².

For the purposes of the OSCAR high-density network experiment, fine resolution of rainfall at the beginning of the event was the primary

requirement of the collector. Considerations leading to this choice were that rapidly and efficiently scavenged species would be best studied in the early part of the event, and that concentrations in the later part of an event can be complicated by scavenging which occurs in the early part of an event. The configuration arrived at to meet these needs, within the practical and physical restrictions noted above, is described in Table 2-2 and shown in Figures 2-4 and 2-5. All of the collection funnels, stage bottles, connecting tubing, and float-valve balls used in the collectors were polyethylene or polystyrene.

Table 2-2

Characteristics of the High-Density Network Automatic Sequential Bulk Collector

Number of stages	9
Funnel collection area	1000 cm ²
Stage volumes - stages 1-8	67 cm ³
stage 9	1130 cm ³
Rainfall per stage - stages 1-8	0.07 cm
stage 9	1.13 cm
Total rainfall capacity	1.67 cm

Testing of the prototype and final design models confirmed, from visual inspection, that the stage balls firmly seat and that the stages fill sequentially. The major concern was that there be a minimum of exchange between stages so that the chemistry of the collected samples adequately represented that of the water entering the stages. A series of tests were conducted in which simulated rain containing a known amount of tracer (in this case, sodium nitrite) was administered to the collector. The mass of tracer recovered from the stages could be compared to that applied. Very low concentrations ($<1 \mu\text{mole/l}$) were used at first, and it was found that the mass

Figure 2-4. Top view of interior of a high-density network automatic sequential sampler. Collection funnel is attached to fitting on lower left.

Figure 2-5. Front view of high-density network automatic sequential sampler, removed from container.

recovered was a small fraction of that applied, implying loss to the tubing and/or bottle walls. A larger concentration, about 10 umoles/l, was subsequently used; this level is generally low for the species of primary interest to the experiment, and it was felt that a large fractional recovery at this magnitude would be acceptable. Figure 2-6 shows the results of three of these tests.

It is apparent that a time lag or "stage lag" occurs; this is to be expected since the water entering must mix with and push through that in the tube ahead of the stage. In addition, the timing of delivery of the tracer to the stages is not precise: at the flow (corresponding to a rainfall rate of 7-9 mm hr⁻¹) used here, the uncertainty in stage-delivered mass was $\pm 20\%$. The degree of the lag should vary with rainfall rate, and for the case of a slowly increasing concentration as in Figure 2-6b, the lag appears more abrupt. However, the sequential rain chemistry of most events is more like that shown in Figure 2-6c, where an initial high concentration tapers off rapidly, and less abrupt changes occur later. The recovery and relative concentrations were considered good in this case, especially in view of the uncertainty in delivered mass. In all three tests shown, the recovered mass was greater than 94% of that administered.

The overall result of the testing was that the collector tends to smooth sharp variations in rain concentration, and that there is a lag in timing, which varies with rainfall rate--lower rates meaning longer lag and greater smoothing. In areas away from strong pollution sources, natural variations in concentration are usually not severe, however, and the greatest changes occur in a decreasing trend, when initially high-concentration low-rate rains give way to low-concentration high-rate rain. In this case, any collector error identified would be minimized, since the time lag would decrease as the rain rate increases. The opposite trend (high-rate low-concentration moving to low-rate high-concentration) is probably rare, since the high-rate rain would tend to deplete the pollution, and the following low-rate rain would not have a sufficient source of pollutants to raise its concentration. In the absence of nearby pollution sources, air mass changes (bringing in more polluted air) are

Figure 2-6. Laboratory tests of the high-density network automatic sequential sampler. For each of the three tests, the solid line shows the concentration of sodium nitrite administered to the sampler, and the dashed line shows the concentration obtained in each stage of the sampler. Concentrations are relative to the maximum input concentrations. Test A: 10 $\mu\text{mol/l}$ peak input concentration, 6.9 mm/hr simulated precipitation rate, 95% mass recovery. Test B: 10 $\mu\text{mol/l}$ peak input concentration, 9.1 mm/hr simulated precipitation rate, 94% mass recovery. Test C: 7 $\mu\text{mol/l}$ peak input concentration, 6.9 mm/hr simulated precipitation rate, 100% mass recovery.

not apt to be as sudden as during the time from one collector stage to the next.

The field configuration is shown in Figure 2-7. The box housing the stages is a slightly-modified commercially-available tool box. The collection funnel arrangement is very simple, but effective. Very few funnels or collectors were lost to winds or other natural conditions, and fractional data capture was high as the results later in this report indicate.

Field Sampling Procedure

Approximately 100 OSCAR Automatic Sequential Bulk Collectors (ASBC) were fabricated, numbered, and outfitted with all internal components contained in the metal boxes prior to the field session. The bottles, balls, fittings and tubing were rinsed with and soaked in distilled, deionized (DD) water, and the soak water of randomly-selected samplers was analyzed for the chemical constituents of interest to OSCAR. Concentration levels of all these species were found to be insignificantly low compared to those reasonably expected in rain samples. The ends of the sampler stage assemblies were sealed with polyethylene bags and packed for shipment within their metal boxes. Extra components, including extra bottles enough for two additional experiments, were cleaned in the same manner and shipped in polyethylene bags. The components external to the boxes - funnels, 1 m polyethylene delivery tubes and connectors (see Figure 2-7) - were cleaned with low inorganic laboratory soap and copious DD water rinses, and DD water soaks were analyzed to assure cleanliness. These components were sealed in individual bags for shipment separate from the metal boxes.

Since the network consisted of 47 sites, which were outfitted with ASBC support stakes and weighing rain gauges prior to the field series, the pre-cleaned and packaged collectors were enough for two complete, laboratory quality-control experiments. After two experiments, the used collector sample-exposed surfaces (funnels, tubes, and fittings) were rinsed with DD water at the network field headquarters. New, precleaned bottles and balls were installed and the collectors resealed for eventual deployment.

Figure 2-7. A typical OSCAR high-density network station showing weighing rain gauge and automatic sequential sampler with collection funnel and support stake.

Under normal experiment conditions, seven personnel were responsible for deploying and retrieving the collectors at six to seven sites each. When the forecast center and field experiment directors gave the order to deploy, each person proceeded to his or her designated area and deployed collectors as follows. Optimally, the samplers were deployed shortly before a precipitation event so that dryfall would be minimized. Samplers could not be deployed after dark, however, so for the first two events, when the rain began shortly after midnight (event 1) and in the early morning (event 2), the samplers were exposed 10 to 16 hours before precipitation began. At each site, a funnel was unwrapped and attached to the support stand, the collector box was opened and attached to the delivery tube and its support rod. The vent line was assured to be open. The rain gauge was started (clock wound), inked, and the time noted on the chart. Sampler deployment time and collector number was recorded. At the end of the rain event, at the field directors' order, the process was reversed, except for the following additional procedures. The collector manifold was drained through the stopcock at the top of stage 1, and for the first two experiments, an attempt was made to collect the manifold water in a separate bottle for analysis. It was found, however, that this could not be accomplished without contamination of the obtained sample, so for the remaining runs, this manifold water was discarded. An attempt was always made, however, to drain the manifold in the field, to minimize exchange of water between the stages during the often rough ride back to the field headquarters. The rain gauge chart was time marked and removed.

After all the sealed collectors were returned to the field headquarters, the stage bottles were carefully removed, starting with stage 8 or the last small stage with water collected. Any interstage water was discarded. The stage 9 sample (if any) was aliquoted to a new, clean small bottle. Each bottle was marked with the run number and sample ID (which includes stage number). The now debottled manifolds were placed in bags and kept in their own metal boxes prior to rinsing for the next run, as were the large stage 9 bottles. All samples were then refrigerated prior to preparation for shipment to the PNL laboratory. Selected samples were aliquoted for field pH

measurement and for treatment with tetrachloromercurate for dissolved SO_2 measurements (which were done at the field laboratory within a few days).

Samples to be analyzed at the PNL Precipitation Chemistry Laboratory in Richland, Washington were packed in insulated shipping containers and sent air freight within a few days of each experiment. The shipments were monitored closely and care was taken to minimize transit time between the field laboratory refrigerator and the PNL laboratory refrigerator. This time period averaged about two days. Because of the season, it was felt that insignificant effects due to warming of the samplers were experienced. After being received at PNL, samples were analyzed for $\text{SO}_4^{=}$, NO_2^- , NO_3^- , Cl^- , $\text{PO}_4^{=}$, NH_4^+ , Na^+ , K^+ , Ca^{++} , Mg^{++} , pH and conductivity, using the MAP3S Precipitation Network methods.⁵ Because of the large number of samples obtained during the experiment, there were delays of up to several months before some samples were analyzed. Multiple analyses of selected samples indicated that the delays did not significantly degrade the results.

AIRCRAFT MEASUREMENTS

Three research aircraft were utilized during the OSCAR experiment: the BNL Brittan Norman Islander, the PNL Douglas DC-3, and the PNL Cessna 411. All three aircraft were equipped for measurements of trace gas and aerosol concentrations in clear-air environments. The DC-3 was also equipped for in-cloud measurements and cloud water sampling. During the OSCAR experiment, the two PNL aircraft were based in Fort Wayne and the BNL Islander was based at Brookhaven. The experiment design gave priority to the high-density experiment for aircraft usage. The aircraft would be flown in support of the intermediate density network after the storm passed the high-density network (if feasible), or if it appeared that a storm might miss the high-density network but the intermediate density network would be activated. As events transpired, the PNL aircraft were only utilized for the high-density experiment. The BNL Islander flew missions during storm events 1 and 4 for the high-density experiment, and also flew several missions in support of the intermediate-density experiment. The measurement capabilities of each of the three aircraft are described below.

BNL Islander Aircraft

The Brittan Norman Islander is a twin engine, high wing, STOL type airplane. It has been outfitted with navigational, meteorological, air sampling and measuring instrumentation suitable for studies in meteorology, atmospheric chemistry and air pollution. It is fully equipped for instrument flight except in icing conditions. The unpressurized cabin accommodates two pilots and two scientific observers. The Islander has a typical range of 700 miles (zero wind) and a ceiling of 12000 feet.

Three separate sampling probes are installed on the outside fuselage (starboard) forward of the engines; these probes can be opened from inside the aircraft cabin during flight. The two top probes are designed for isokinetic sampling, one supplying the high-volume filter pack sampler and one supplying the particle size discrimination unit. The bottom intake is composed of three smaller diameter tubes and supplies air samples to instruments inside the airplane.

During the OSCAR experiment, the Islander was utilized in support of both the high-density and intermediate-density experiments to character airborne concentrations of gas and particulate pollutants. The instrumentation on the Islander utilized during the experiment are shown in Table 2-3. A more detailed description of the Islander and its instrumentation is available in Leahy.⁶

Table 2-3

BNL Islander Measurement Systems

Navigational

VOR (2), DME, Air Speed	Metrodata M-8 unit
Indicated Air Speed	Rosemount 831 CP
Compass Heading	Humphrey Gyro Compass DGOY-0122-1
Pressure Altitude	CIC Model 7000
Radar Altitude	Bonzer MK-10 Radar Altimeter
Ground Speed, Drift Angle	Singer SK1000 Doppler Radar
Wind Speed and Direction	(computed from airspeed, headings, groundspeed, drift angle)

Meteorological

Temperature, Ambient	Yellow Springs 705 Thermistor
Temperature, Surface	Precision Radiation Thermometer
Dew Point	EG&G Model 137-3C Hygrometer
Turbulence	MRI 1120 Universal Turbulence Indicator System
Total Solar Radiation	Eppler Pyranometer Model 8-48
UV Radiation	Eppler UV Radiometer Model 14168
Relative Humidity	Weather Measure Model HM111

Trace Gas and Aerosol

NO-NO ₂ -NO _x	Teco 14D Chemiluminescent Analyzer
SO ₂	Meloy 160-2 Flame Photometric Detector
Ozone	AID Model 560
Light Scattering	MRI Integrating Nephelometer
Condensation Nuclei	General Electric CNC-2
SO ₂ , HNO ₃ , aerosol sulfate, nitrate ammonium, and strong acid	High Volume Filter Pack

The filter pack used during the experiment consisted of a treated quartz filter for aerosol sulfate, nitrate, ammonium, and strong acid (Leahy and Daum),⁷ followed by a pair of NaCl-impregnated cellulose filters for nitric acid (Forrest et al.)⁸ and a pair of Na₂CO₃ impregnated cellulose filters for SO₂ (Forrest et al.).⁹ This filter pack configuration was also used on the other aircraft and at the surface air chemistry site.

Signals from the real time instrumentation are connected to a Metrodata 640 digital recorder and recorded at a rate of either 10 to 160 channels per second. Four dual-pen chart recorders provide real-time display of selected parameters.

PNL DC-3 Aircraft

The Douglas DC-3 aircraft is a heavy, twin-engine, low-wing aircraft. The unpressurized cabin accommodates two pilots, a crew of four scientific personnel, and an extensive array of research instrumentation. The aircraft is equipped with several inlet and outlet probes. The inlet probe for most of the gas and particle instrumentation is designed to reduce airstream velocities to near-isokinetic values appropriate for input to the instruments. The inlet probes for three high-volume air samplers are located on the upper left side of the aircraft and are equipped with manually operated cover mechanisms. The high-volume air sampling system, which allows simultaneous filter collection from each of the three probes, is driven by a 2.5 hp 28VDC blower, minimizing filter sample collection time. Turbine flowmeters continuously monitor flow rates and provide analog signals for recording by the onboard data acquisition system.

The basic sampling schemes for the DC-3 during the OSCAR field study included clear-air flights prior to storm frontal passage to characterize the initial air mass, and subsequent in-cloud sampling to collect cloud water. Several types of equipment were carried onboard to fulfill the necessary sampling configurations, which can be categorized into three subsets. One group provided environmental data (temperature, dewpoint, ...), required in all situations. A second set of instruments consisting of trace gas and particle monitoring systems were employed during clear-air sampling. A third group consisting of cloud water and precipitation characterizing devices made up the in-cloud sampling ensemble.

The DC-3 measurement systems are listed in Table 2-4. A more detailed description of the DC-3 and its instrumentation is available in Busness et al.¹⁰ The NO_x instrument, developed at PNL, can achieve sub-ppb

Table 2-4

PNL DC-3 Measurement Systems

Navigational and Environmental

Ambient Air Temperature	Rosemount Temperature System Model 102U2U Sensor
Dewpoint Temperature	Model 510BF Linear Bridge
Absolute Pressure	EG&G Cambridge Dewpoint Hygrometer
Airspeed, Groundspeed, Wind Velocity and Direction	Metrodata M8 Pressure Transducer
Latitude and Longitude	GNS-500A VLF/Omega Navigation System
Air Turbulence Intensity	MRI Universal Indicated Turbulence System

Trace Gas and Aerosol

SO ₂	Meloy SA 260 Sulfur Analyzer
O ₃	Monitor Labs Model 8410E Ozone Analyzer
NO/NO _x	PNL NO/NO _x Analyzer
Light Scattering Coefficient	MRI 1562 Integrating Nephelometer
Particle Size Distribution	Royco Model 220 Optical Particle Counter
SO ₂ , HNO ₃ , NH ₃ ; aerosol sulfate, nitrate, ammonium, strong acid, trace metals	High Volume Filter Samples
Size Classified Aerosol Sulfate	Low Pressure Impactor and Flash Vaporization/Flame Photometric Analysis (UCLA)(11)
Aerosol Sulfate, Nitrate, Ammonium, and Acidic Sulfate	Attenuated Total Internal Reflection Impactor (ANL)(12)

In-Cloud

Cloud Liquid Water Content	Johnson & Williams Liquid Water Content Indicator
Cloud Droplet Size Distribution	Particle Data Systems Size Droplet Spectrometer
Cloud Water Collection	Cloud Water Samplers (Warm and Supercooled)
Precipitation Characterization	MEE Foil Impactor

sensitivities.¹⁰ The SO₂ monitor is a Meloy Model 260 flame-photometric device, modified to function with a gas inlet system that provides a constant-pressure sampling environment, independent of altitude below about ten thousand feet. This configuration eliminates variations in the Meloy response as a result of altitude change.

Three filter combinations were used: BNL type filter packs, single zeffluor (a poly-tetrafluorethylene polymer, pure teflon), and zeffluor backed by an oxalic acid treated IPC filter. The BNL filter packs provided concentrations of SO₂, nitric acid, and aerosol sulfate, nitrate, ammonium, and strong acid. The zeffluor filters were to be analyzed by either aqueous extraction for major anions and cations, or by x-ray fluorescence for trace metals. The oxalic acid backup filters were for gaseous ammonia, but yielded no usable results. An ATR impactor developed at ANL¹² provided additional data on aerosol chemical composition. The low-pressure impactor (UCLA¹¹) provided size distribution data for sulfate aerosol (an identical impactor was operated at the SAC site).

In-cloud measurement systems include those listed in Table 2-4. Two cloud water sampler configurations were employed, depending upon the temperatures encountered. For above freezing situations, a set of three warm cloud collectors of the ASRC design⁽¹³⁾ was utilized. These samplers collect cloud droplets and deliver the sample to collection bottles inside the aircraft. For sub-freezing conditions, supercooled cloud water collectors were employed. These were simply nylon rods that, when exposed to the airstream, collect cloud droplets as ice. After sufficient sample has been obtained (as determined visually), the rods are retracted and stored in sterile plastic bags. After the flight, the now melted sample is decanted to a smaller storage bottle. Both types of collectors are mounted at the forward top of the fuselage and are deployed inflight to avoid contamination prior to the actual sampling period. Cloud water samples were handled and analyzed in the same manner as precipitation samples. No measurements of interstitial (i.e., unscavenged) gases or aerosol were performed during in-cloud sampling.

Data from the various instruments were recorded on nine-track magnetic tape by a computer-controlled data acquisition system. This system also includes a digital interface to the VLF navigation unit to permit recording of aircraft position and a real-time display to provide operator-selected display of acquired parameters. Multi-channel chart recorders served as redundant backup recorders and provided additional real-time trends of selected parameters. Particle data were recorded on magnetic tape via a companion data system that acquired data from an optical particle counter (Royco) during clear air sampling or size distributions from a cloud droplet spectrometer while sampling in cloud.

PNL Cessna 411 Aircraft

The Cessna-411 is a low-wing, twin-engine airplane which can carry a crew of three persons and a research equipment load of roughly 500 lb. with a corresponding airborne time limit of about five hours. Normal speed is 100 to 160 knots, giving an effective range of approximately 700 miles. Service ceiling for the aircraft is 22,000 ft.

The aircraft is equipped with sampling probes for gas and particle measuring instruments and for high-volume filter collection. A high-volume air sampler, driven by a Staplex blower and incorporating a reliable quick disconnect clamp-type receptacle, allows for filter collection on pre-loaded filter modules. Air flow is monitored by a flowmeter and counter and is recorded on magnetic tape by an onboard data acquisition system.

For the OSCAR experiment, the Cessna-411 aircraft flew only clear air missions to characterize the relevant air mass prior to storm passage. Standard meteorological parameters, temperature, dewpoint, and altitude were logged along with gaseous species of ozone and SO_2 and light scattering coefficient via nephelometer. A listing of instruments and parameters is included in Table 2-5. The filter configuration used on the Cessna was a zefluor prefilter backed by NaCl and Na_2CO_3 impregnated filters, and provided concentrations of SO_2 and nitric acid, and aerosol sulfate, nitrate, ammonium, and strong acid.

Table 2-5

PNL CESSNA 411 Research Instruments

<u>Parameter</u>	<u>Instrument</u>
Ambient Air Temperature	Rosemount Temperature System Model 102U2U Platinum Resistance Sensor
Dewpoint Temperature	Model 510BF Linear Bridge
Absolute Pressure	EG&G Cambridge Dewpoint Hygrometer
Airspeed, Groundspeed, Wind Velocity and Direction	Metrodata M8 Pressure Transducer
Latitude and Longitude	GNS-500A VLF/Omega Navigation System
SO ₂	Meloy SA285 Sulfur Analyzer
O ₃	Bendix Model 8002 Ozone Analyzer
Light Scattering Coefficient	MRI 1560 Integrating Nephelometer
Filter Sample Collection	High Volume Air Sampler

Data acquired onboard the Cessna-411 were logged onto a nine-track magnetic tape using a Particle Data Systems DAS-32 acquisition unit. This unit provides a variable sampling rate while logging 16 simultaneous channels. A digital interface permits recording of VLF Omega navigation parameters on the DAS-32 magnetic tape.

SURFACE AIR CHEMISTRY

A surface air chemistry (SAC) measurement facility was located at site 62 of the high-density network (see Figure 2-3) in a position expected to allow monitoring of airborne precursors of pollutants depositing across the sampling array. A location in the southwestern portion of the network was chosen so that, during storm events, the site would not be downwind of the Fort Wayne area. The SAC facility provided a ground-level complement to aircraft measurements and documented temporal changes in air quality continuously at a stationary point. Furthermore, the surface facility included some measurements which could not be performed on the aircraft (e.g. the PAN and H₂O₂ measurements).

The SAC site was situated adjacent to a grassy field in a rural setting, near the U.S. Army Corps of Engineers offices at the Huntington Dam reservoir. Local sources of contamination were minimal, consisting mainly of infrequent automobile traffic and possibly agricultural sources of ammonia. Site 62 also coincided with site 00 of the intermediate-density network, and thus both types of sequential rain samplers were operated at this location. The measurements obtained at the SAC site are shown in Table 2-5. Two additional measurements were ammonia (no data recovery due to equipment problems), and H_2O_2 in air and precipitation (data discarded due to later discovered interferences in the analysis method). Measurements at the SAC site were performed before, during, and after each high-density network storm event when possible.

Table 2-6

OSCAR Surface Air Chemistry Site Measurements

<u>Species</u>	<u>Technique</u>
Aerosol sulfate, nitrate, ammonium, strong acid, gaseous nitric acid, sulfur dioxide	Filter pack - treated quartz front filter, NaCl impregnated cellulose back filter, Na ₂ CO ₃ impregnated cellulose back filter (BNL) ^{6,7,8}
Aerosol nitrate, nitric acid	Denuder - difference apparatus (BNL) ¹⁴
Sulfur dioxide	Commercial flame photometric detector, continuous (BNL)
Aerosol sulfate	Sensitivity enhanced flame photometric detector with gaseous sulfur denuder, continuous (BNL) ¹⁵
NO/NO _x /NO _x + HNO ₃	Sensitivity-enhanced ozone chemiluminescence, sequential instrument (BNL) ¹⁶
Ozone	Ethylene chemiluminescence, commercial instrument (BNL)
Aerosol sulfate, nitrate, ammonium, and acidic sulfate in 0.3-1 and 1-3 μ m diameter ranges	Modified Lundgren impactor with Fourier transform infrared spectroscopy analysis (ANL) ¹⁷
Aerosol size distribution	TSI Electric Aerosol Analyzer and Climet Optical Particle Counter (ANL)
Size classified aerosol sulfate (8 classes covering .04 to 8 μ m diameter)	Low pressure impactor and flash vaporization/flame photometric analysis (UCLA) ¹¹
Peroxyacetyl nitrate	Automated electron capture gas chromatography (BCL)
Light scattering	MRI integrating nephelometer (BNL)
Dew Point	Commercial dewpoint hygrometer (BNL)

REFERENCES

1. Scott, B.C. Predictions of In-Cloud Conversion Rates of SO_2 to SO_4 Based Upon a Simple Kinetic and Kinematic Storm Model. Atmos. Environ., Vol. 16, 1982, pp. 1735-1752.
2. Hales, J.M. Mechanistic Analysis of Precipitation Scavenging Using a One-Dimensional, Time-Variant Model. Atmos. Environ., Vol. 16, 1982, pp. 1775-1783.
3. Newman, L. General Considerations on How Rainwater Must Obtain Sulfate, Nitrate, and Acid. Presented before the Division of Environmental Chemistry, American Chemical Society, Honolulu, Hawaii, April 1979.
4. Godske, C.L., Bergeron, T. Bjerkness, J. and Bundgaard, R.C. Dynamic Meteorology and Weather Forecasting. American Meteorological Society, Boston, 1957.
5. The MAP3S/RAINE Precipitation Chemistry Network: Quality Control. PNL Report no. PNL-3612 to U.S. EPA, October, 1980, 72 pp.
6. Leahy, D.F. The Brookhaven National Laboratory Atmospheric Sciences Aircraft, BNL Informal Report BNL-28102, Upton, NY, July 1980.
7. Daum, P.H. and Leahy, D.F. The Brookhaven National Laboratory Filter Pack System for Collection and Determination of Air Pollutants. BNL Informal Report BNL-31381, May 1982.
8. Forrest, T., Tanner, R.L., Spandau, D., D'Ottavio, T., and Newman, L. Determination of Total Inorganic Nitrate Utilizing Collection of Nitric Acid on NaCl-Impregnated Filters. Atmos. Environ., Vol. 14, 1980, pp. 137-144.
9. Forrest, T., Garber, R., and Newman, L. Formation of Sulfate, Ammonium, and Nitrate in an Oil-Fired Power Plant Plume. Atmos. Environ., Vol. 13, 1979, pp. 1287-1297.
10. Busness, K.M., Alkezweeny, A.J., Easter, R.C., Hales, J.M., and Lee, R.N. Composite Design of an Advanced Airborne Monitoring System. Presented at the APCA Conference on In-Situ Air Quality Monitoring From Moving Platforms, San Diego, January 1982.
11. Hering, S.V., Friedlander, S.K., Collins, J.C., and Richards, L.W. Design and Evaluation of a New Low Pressure Impactor. Envir. Sci. Technol., Vol. 13, 1979, pp. 184-188.
12. Johnson, S.A., Kumar, R., and Cunningham, P.T. Airborne Detection of Acidic Sulfate Aerosol Using an ATR-Impactor. Accepted for publication in Aerosol Science and Technology.

13. Winters, W., Hogan, A., Mohnen, V., and Barnard, S. ASRC Airborne Cloud Water Collection System, ASRC-SUNYA Publication No. 728, State University of New York, Albany, New York, 1979.
14. D'Ottavio, T., Garber, R., Tanner, R.L., and Newman, L. Determination of Ambient Aerosol Sulfur Using a Continuous Flame Photometric Detection System II. The Measurement of Low-Level Sulfur Concentrations Under Varying Atmospheric Conditions. Atmos. Environ., Vol. 15, 1981, pp. 197-203.
15. Forrest, T., Spandau, D.J., Tanner, R.L., and Newman, L. Determination of Atmospheric Nitrate and Nitric Acid Employing a Diffusion Denuder With a Filter Pack. Atmos. Environ., Vol. 16, 1982, pp. 1473-1485.
16. Tanner, R.L., Daum, P.H., and Kelly, T.J. New Instrumentation for Airborne Acid Rain Research. Intern. J. Environ. Anal. Chem., Vol. 13, 1983, pp. 323-335.
17. Sheih, C.M., Johnson, S.A., and DePaul F.T. A Case Study of Aerosol Size Distribution and Chemistry During Passages of a Cold and a Warm Front. Accepted for publication in Atmos. Environ.

SECTION 3

INTERMEDIATE-DENSITY EXPERIMENT DESCRIPTION

RATIONALE

The Intermediate-Density Experiment was planned to supplement the High-Density Experiment in meeting the objectives of the OSCAR program and was designed to be intermediate in spatial extent between the MAP3S network and the High-Density network.

The Intermediate-Density network was planned to sample up to four April rain events sequentially, with fine temporal and moderate spatial resolution. The aim was to achieve from 100 to 200 km spacing over most of the northeastern United States so that the probability of several precipitation events occurring over much of the network would be high. The MAP3S stations formed the core of the network and were requested to sample sequentially during each event, using equipment designed and provided by BNL. They were also requested to establish from one to three satellite or remote stations, each to be operated during precipitation events by its own personnel or by other institutions under the direction of the MAP3S station operator. The general locations of satellite stations were selected to give the most uniform coverage possible. The exact locations were left to the MAP3S station operators.

The experimental plan included aircraft and ground-level measurements of atmospheric chemistry, acquisition of air pollution monitoring data from established stations in the region, and operation of a forecast center at BNL.

INTERMEDIATE-DENSITY PRECIPITATION CHEMISTRY NETWORK

This precipitation chemistry network was the foundation of the Intermediate-Density experiment. It consisted of 37 stations in the U.S. and Canada. The network organization, sampler design, and sampling protocol are described below.

Network Organization

The Intermediate-Density sampling network, as finally established was very similar to the preliminary plans. All nine MAP3S stations took part in the experiment, but inadequate funds made it impossible to operate as many MAP3S satellite stations as planned. However, a number of other researchers fortunately volunteered to participate in the experiment. Thus, the number of sites originally planned was reached or even slightly exceeded although the final spacing was not quite so uniform as desired. Thirty-seven stations in 17 states and provinces took part in the experiment, nine MAP3S stations,^{*} nine satellite stations operated by MAP3S station personnel, eight stations supervised by MAP3S station operators but operated by other institutions or individuals under sub-contract, and eleven stations operated by individuals or institutions not included in the MAP3S network. All but two sites used the equipment provided by BNL. All except two sites were operated during all three rain events selected for sampling. One of these (Loudenville, Ohio) sampled the last two events. No rain occurred at Cape Hatteras during the first two events during which the station was operated. Each station was assigned a number based on the MAP3S station number where applicable. Station locations, types and coordinates are summarized in Table 3-1. Locations are illustrated in Figure 3-1.

Locations for stations were chosen, as far as possible, in rural or at least non-urban regions with no local pollution sources. The only exception was a station near Columbus, Ohio (06), chosen for an urban-rural site comparison with the other Ohio sites which were in rural areas. All station operators were requested to provide site descriptions of latitude and longitude, immediate surroundings (with distance and direction to any nearby obstacles) and the general area (with distance and direction to any significant pollution sources). These descriptions are given in Appendix A.

Sampler Design

Sequential sampling throughout each rain event was considered necessary, to obtain the time history of changes in precipitation constituents. Time and

^{*}At the Champaign, Lewes, and Oak Ridge MAP3S sites, the OSCAR and MAP3S samplers were not collocated.

Table 3-1

Locations and Types of Stations in the Intermediate-Density Network

Number	Type*	Latitude	Longitude	Location and Nearby City
00	O	40 50	85 28	Huntington, Ind. (Fort Wayne)
01	O	41 42	87 59	Argonne, Ill.
02	O	42 24	85 24	Hickory Corners, Mich. (Kalamazoo)
03	O	42 42	84 24	Okemos, Mich. (E. Lansing)
04**	O	42 36	80 30	Long Point, Ont.
05	O	44 14	77 06	Marysville, Ont. (Kingston)
06	O	40 01	83 03	Upper Arlington, Ohio (Columbus)
07**	O	40 36	82 19	Loudenville, Ohio (Mansfield)
10	M	44 24	73 52	Whiteface Mt., N.Y.
11	S	42 57	73 57	Charlton, N.Y. (Albany)
12	O	43 48	74 55	Big Moose, N.Y.
20	M	42 22	76 46	Connecticut Hill, N.Y. (Ithaca)
21	S	42 42	77 55	Letchworth State Park, N.Y.
22	C	43 56	71 45	Hubbard Brook, N.H.
30	M	40 47	77 57	University Park, Pa.
31	C	40 05	79 37	Scottdale, Pa.
32	C	41 45	78 32	Marvindale, Pa.
33	C	40 58	76 00	Hazleton, Pa.
40	M	38 08	78 23	Charlottesville, Va.
41	C	38 26	79 49	Green Bank, W. Va.
43	O	38 53	76 33	Edgewater, Md.
50	Mx	40 02	88 16	Champaign, Ill.
60	M	40 52	72 53	Upton, N.Y.
61	S	40 17	74 31	Hightstown, N.J.
62	S	41 21	74 40	Port Jervis, N.Y.
63	S	41 55	72 50	Granby, Conn.
70	Mx	38 47	75 09	Lewes, Del.
71	S	39 44	75 50	Kembelsville, Pa.
72	S	39 30	74 28	Smithville, N.J. (Atlantic City)
73	S	37 17	75 58	Cheriton, Va.
74	S	35 16	75 33	Cape Hatteras, N.C.
75***	S	37 32	75 49	Exmore, Va.
80	M	39 32	84 45	Oxford, Ohio
81	C	39 50	83 45	S. Charleston, Ohio
82	C	38 58	82 40	Jackson, Ohio
90	Mx	35 58	84 17	Oak Ridge, Tenn.
91	C	35 03	83 27	Franklin, N.C.
92	O	38 03	84 28	Lexington, Ky.

* O Station operated by organization not part of MAP3S network

M MAP3S station

Mx Station near, but not collocated with, MAP3S station,
operated by MAP3S personnel

S Satellite station - operated by MAP3S station personnel

C Station operated under contract with MAP3S station

** Station using sequential sampler other than the BNL design

*** Station 73 moved to station 75 location for third event

Figure 3-1. Locations of the OSCAR Intermediate-Density Precipitation Chemistry Network Sampling Sites.

financial constraints made it impossible to equip the network with automatic sequential samplers. Therefore, a manual sampling method was selected and equipment was designed and fabricated at BNL. The sampler (Figure 3-2) consists of an 45.7-cm diameter polyethylene funnel set in a collecting jar made from a cut-off 1000-ml polyethylene bottle. The jar is supported in a wooden base on which is drawn a line indicating the liquid level at which the sample jar should be changed. The wooden base was mounted on a stand or other support structure so that the funnel entrance was 1-3 m above the ground. Stands varied between stations. The type shown in Figure 3-2 was used at BNL and its satellite stations.

All except the more southern stations were also provided with a set of 9x12x4-inch polyethylene freezer containers for collecting snow if any occurred. These were not required.

Field Sampling Procedure

The funnel and jar were mounted in sampling position just before precipitation started. Two collecting-jars were provided. Operators were requested to change jars when about 100 ml which represents 0.6 mm or 0.024 inches of rain was obtained. During very heavy rainfalls, it proved impossible to change fast enough, so some larger samples were obtained. At the end of precipitation periods or during very light rainfall, smaller samples were sometimes taken. Care was taken not to contaminate the funnel and jar during use. Each jar was rinsed with deionized water before being reused. After removal of a jar from the sampler, its contents were poured into a 250-ml plastic bottle, capped and labeled. Because variable amounts were expected, operators were requested to weigh each sample in its bottle after the event. The weight of the bottles (36 g) was subtracted during computer processing of the data. The time of beginning and ending of each sample to the nearest minute was also recorded. The rainfall rate during each sample period was calculated from the weight and time data. At the end of each event, an aliquot was removed from each sample for a pH measurement. These were taken at all but one station which lacked equipment. Following these

Figure 3-2. A typical OSCAR intermediate-density station.

procedures the samples were refrigerated until shipped to PNL for complete chemical analysis.

Operators were also requested to record precipitation type and estimated intensity. Because most operators were not trained meteorologists, their qualitative descriptions may not be comparable. Therefore, intensity may be classified by users of the data from the rainfall rates.

Station operators were instructed to mount the sampler over a grassy surface far enough from obstacles so that wind-blown drops from buildings or trees could not reach the funnel, and high enough so that splash from the ground could not contaminate the apparatus. However, the downward sloping collar at the top of the funnel stem was designed to prevent water from moving down the outside of the funnel into the collecting jar.

The collection apparatus was cleaned before each event and kept sealed in a plastic bag until an event started. An initial check of the cleaned collection apparatus showed no contamination. (Five rain collection bottles and three funnels were randomly selected from those to be used and were leached for a period of fourteen days in 100 ml of distilled-deionized water. At the beginning and end of this period, the leachate was analyzed for pH, specific conductivity, NH_4^+ , NO_3^- , NO_2^- , $\text{SO}_4^{=}$, Cl^- , and Na^+ . The analyzed anion and cation concentrations of the leachate never exceeded the minimum detection limits of the analytical procedures used for this precipitation chemistry experiment).

AIRCRAFT OPERATIONS

Although the high-density experiment was given priority for aircraft utilization, aircraft measurements of pollutant concentrations were also desirable over the intermediate-density network region. As it turned out, the two PNL aircraft were flown in support of the High-Density experiment only. The BNL aircraft was used to support both the High-Density and Intermediate-Density networks and was involved in the OSCAR experiments on April 8, 9, 14, 22, and 23, 1981. These flights are summarized in Table 3-2.

Table 3-2

BNL Aircraft Flights During OSCAR

Date	Flight No.	Location	Start-End Time (EST)	Altitude (ft agl)
Apr 8	OSCAR 1	Marion to Portland, Ind.	1242-1259	1500
		Portland to Marion, Ind.	1308-1328	2500
		Marion to Portland, Ind.	1338-1350	4000
		Spiral down at Portland, Ind.	1357-1414	5000-1000
Apr 8	Test Flight	Findlay, Ohio to Pittsburgh, Pa.	1558-1705	2500
Apr 9	OSCAR 2	Yardley (VOR), N.J. to Colt's Neck (VOR), N.J.	1211-1227	1500
		Colt's Neck to Yardley	1233-1255	2500
		Yardley to Colt's Neck	1301-1316	4000
		Spiral down at Colt's Neck	1320-1327	6000-2000
		Colt's Neck, N.J. to Brookhaven Airport	1328-1351	2500
Apr 14	OSCAR 3	White Sulphur Springs to Charleston, W. Va.	1253-1356	3000
Apr 22	OSCAR 4	Rosewood (VOR), Ind. to Marion, Ind.	1033-1121	1500
		Marion to Rosewood, Ind.	1137-1214	2500-3500
		Rosewood, Ind. to Findlay, Ohio	1223-1244	1500
		Spiral up at Findlay, Ohio	1247-1252	1500-3500
		Spiral down at Findlay, Ohio	1252-1256	3500-1500
Apr 22	OSCAR 5	Findlay, Ohio to Clarksburg, W. Va.	1432-1608	2500-4000
Apr 23	OSCAR 6	Martinsburg, W. Va. to Westminster (VOR), Del.	1149-1211	2000-3000
		Westminster (VOR) to Phillips (VOR), Del.	1212-1229	1500
		Phillips to Westminster, Del.	1231-1252	1500
		Spiral up at Westminster, Del.	1252-1300	1400-6000
		Westminster, Del. to Harrisburg, Pa.	1301-1327	5000

The aircraft was flown to Evansville, Indiana on April 7, 1981 and sampled the atmosphere at three altitudes just south of the high-density network on April 8th. The aircraft then proceeded eastward and sampled from Findlay, Ohio to Pittsburgh, Pa. on the same date. Aircraft sampling at several altitudes then took place between the Yardley and Colt's Neck VOR's in New Jersey during the middle of the day on April 9th. Sampling ended on the 9th with a traverse from Colt's Neck VOR to Brookhaven Airport.

The aircraft was sent to Lynchburg, W. Va. on April 13th for sampling in that area on April 14th. One traverse was made from White Sulphur Springs to Charleston, W. Va. on April 14th. Further sampling was cancelled due to high winds and thunderstorms in that area.

The next aircraft sampling was accomplished on April 22nd south and east of the high-density network. Traverses were made at several altitudes and spirals were taken. A cross-country traverse was then made from Findlay, Ohio to Clarksburg, W. Va.

Aircraft sampling on April 23rd took place just north of Baltimore, Md. where traverses were made at several altitudes between the Westminster and Phillips VOR's. A spiral was taken at the Westminster VOR and the last traverse was made from that location to Harrisburg, Pa.

SURFACE AIR CHEMISTRY

As described earlier, the major surface air chemistry measurement effort took place within the High-Density network. These measurements are expected to have applications to the nearby Intermediate-Density stations also. Surface air measurements of gases and aerosols at sites other than the Fort Wayne location made by MAP3S/RAINE personnel were limited to the following measurements at BNL.

Nitrogen oxides and ozones were measured for the periods 4/8 through 4/10, 4/11 to 4/15, and again 4/22 to 4/26 using the Monitor Labs 8440 and AID instruments, respectively. Sulfur dioxide was measured contiguously with NO_x and O_3 for the 4/8-10 and 4/22-26 periods and additionally during the daytime

period of 4/14. Sampling was from Bldg. 426 roof-level using a 2-in diameter manifold attached to a Hi-Vol sampler.

Aerosol sulfur, nitric acid and SO_2 were sampled for 6-hr intervals using the BNL filter pack consisting of treated quartz, NaCl-impregnated and K_2CO_3 -impregnated filters, respectively. Sampling periods included noon 4/8 to noon 4/10, 4/13-4/14 and ~1600, 4/22 to ~1500, 4/24. Sampling was done using the sequential Hi-Vol system located on the roof of Bldg. 426.

In addition to the data from sampling done at Fort Wayne and at BNL, it was highly desired to obtain supplemental air quality data from other monitoring-oriented networks. As described in Section 5, potentially operational sampling sites preferably in rural or remote areas in the Northeast were identified. Cooperative arrangements to obtain continuously measured data for sulfur dioxide and nitrogen oxides and also data from 24-hr, 6th day high volume filters analyzed for TSP, sulfate and nitrate at appropriate sites in New York, Pennsylvania, New Jersey, Delaware, and Ohio have been tentatively established. These data will be obtained from the responsible state officials after verification and converted into the appropriate format.

FORECAST CENTER OPERATION

A forecast center was operated by Atmospheric Sciences Division personnel at BNL for the following purposes:

1. To decide, in consultation with the center at Fort Wayne, which events to sample.
2. To inform stations in the Intermediate Density network that an event had been selected for sampling and to advise them when precipitation was expected to start at their location.
3. To direct flight activities of the BNL aircraft except when it was operated in support of the High Density grid and to direct flight activities of the PNL aircraft when they were operated in support of the Intermediate Density network.

4. To advise on deployment of mobile chemistry van personnel to Fort Wayne.
5. To obtain, analyze and archive all necessary meteorological data.

The forecast center was manned 24 hours per day during precipitation events, for a brief period each weekend day, and during normal working hours otherwise. Data sources include a circuit A teletype, a NAFAX weather facsimile receiver and a computer link between a BNL PDP 11/70 Computer and the National Weather Service (NWS) computer in Suitland, Maryland. Using this facility, all NWS bulletins could be obtained as soon as available. A weather radar facsimile receiver had been installed prior to the experiment but was inoperative during April due to a change in the telephone service at BNL.

The synoptic situation over the United States and the forecast products were examined daily for event selection. Cases with continuous warm front rain were preferred for the experiment, but classical open-wave warm front cases did not occur and the three events described below were selected for sampling. All stations in the network were notified by telephone well in advance of the beginning of precipitation that an event had been selected using a complete telephone number list compiled before the beginning of the experiment. A second alert was given, when possible, a few hours before the precipitation reached each station. Occasional difficulties were experienced in reaching some station operators but the system generally worked well. In event 2, particularly, many stations were alerted too early because a low center, forecast to develop in the plains states and move east, remained stationary for nearly two days. In a few instances, rain started at a station before the second alert was given, but in most of these cases, the operators were ready and started sampling on time.

Prior to each event, a decision was made jointly by the Forecast Center and the center at Fort Wayne on whether to use the BNL aircraft in support of the High Density grid. If so, the aircraft was deployed to the midwest prior to the event if adequate time existed. If not, the aircraft was deployed to a selected intermediate location to sample in support of the Intermediate Density experiment. The time, place and flight pattern of each sampling

flight was selected by the Forecast Center in consultation with the flight crew. The two centers agreed to use the PNL DC-3 in support of the Intermediate Density network during one event, but mechanical trouble prevented its use.

A BNL van, equipped with air chemistry instrumentation, was stationed at the Surface Air Chemistry site near Fort Wayne for the experimental period. It was manned continuously by one chemist, but two other chemists who were needed to obtain all of the desired measurements during events travelled to Fort Wayne on the advice of the Forecast Center.

During each event, as much pertinent meteorological data as possible was obtained both for operational decisions and for later data analysis. Hourly surface data were obtained from the circuit A teletype. Additional hourly data from circuits missing from or inadequately reported on the teletype schedule were obtained from the NWS by the computer link. Detailed surface maps of the eastern United States and southern Canada were hand plotted about every three hours. The intervening hourly reports were examined to determine the movement of precipitation areas and fronts. Maps received from the facsimile receiver included surface maps every three hours, 850, 700 and 500 mb maps twice daily, upper winds maps, weather radar maps and the various forecast products. Twice daily radiosonde data from stations in the experimental area were obtained from the NWS as were twice daily trajectory forecasts for stations in the eastern United States for trajectories ending at the surface, 850 and 700 mb levels. All data have been archived and are available to other analysts but will not be reproduced and distributed in report form because of its large volume.

SECTION 4

OSCAR EVENT DESCRIPTIONS

Four synoptic events were selected for sampling during the OSCAR study. All four events were sampled at the high-density network, and all but the third event were sampled by the intermediate-density network. A general discussion of the meteorological conditions associated with each storm event and a summary of data capture for each event is given below.

EVENT 1, APRIL 8-9, 1981

High pressure had dominated the OSCAR area for two days following a cold front, which had been too convectively active to warrant aircraft sampling. Event 1 was another cold frontal system, but was selected for sampling because no warm frontal system had yet occurred earlier in the month. Recent low pressure centers had followed a track across southern Canada, with only a cold front extending southward into the network area. A secondary purpose for selecting this event was to test sampling and communication procedures. Surface front positions for this event are shown in Figure 4-1.

At 1200 GMT on April 7, a deep low was located in central Manitoba. A cold front extended through western Lake Superior across southern Minnesota and southwestward. The cold front was forecast to move eastward across the network and a decision was made to sample the event.

By 1200 GMT, April 8, the front extended across Georgian Bay, central lower Michigan, southern Wisconsin, and central Iowa to a weak low center in east-central Kansas. Scattered showers and thunderstorms occurred along the front from Michigan southwestward but did not reach the westernmost stations (01, 02, and 50) until early or mid-afternoon. Radar indicated showers in the vicinity most of the day, but very few appeared to penetrate the High-Density network.

At 0000 GMT, April 9, the front had reached southern Michigan, northern Illinois and central Missouri. Showers had mostly extended to southwestern

Figure 4-1. Frontal positions associated with storm of April 8-10.

Michigan and northwestern Indiana, though a few showers were reported in western Ohio. Showers occurred with the frontal passage at Ft. Wayne at about 0600 GMT.

By 1200 GMT, the front extended from a low north of New York State through Ohio, extreme southern Illinois and southwestward. Showers were occurring as far east as eastern New York, western Pennsylvania, West Virginia, eastern Kentucky, and eastern Tennessee.

By 1800 GMT, the front crossed central New York, western Pennsylvania, and central Kentucky. Showers occurred eastward into Vermont, nearly all of New York except the southeastern portion, the western two-thirds of Pennsylvania, and southward into Virginia, Tennessee and North Carolina.

At 0000 GMT, April 10, the front extended from Maine through the New York City area, central Virginia, and southwestward near the Kentucky-Tennessee border. Showers had reached the easternmost stations from New Hampshire to coastal Virginia, but precipitation was spotty in southern portions of the Intermediate-Density network.

At 1200 GMT, April 10, the front was well off the east coast. A following high pressure area was centered over West Virginia and precipitation had ceased over the network.

Precipitation during the event included both showers and thundershowers. Durations were variable, from only one or two hours at a few stations to as much as 18 hours at others. Durations ranged from three to six hours at most stations.

On the intermediate-density network, 36 sites were operational and 35 received precipitation. A total of 234 precipitation samples from the network were analyzed. The BNL aircraft performed sampling over New Jersey from 1200 to 1400 EST on April 9 in support of the intermediate-density experiment.

On the high-density network, precipitation occurred between 0000 and 0400 EST on April 9. The automatic collectors were set out between 1000 and 1400 EST on April 8 and retrieved on April 9. A total of 336 samples from 44 sites

on the network were analyzed. All three aircraft were utilized between 1000 and 1430 EST on April 8 for clear air sampling near the network.

EVENT 2, APRIL 11-14, 1981

At 1200 GMT, April 11, a cold front extended from a low, north of New England across the Great Lakes, to a small low in western Kansas. A warm front had moved northward during the night across Illinois, Indiana and Ohio and was stationary, on a generally east-west undulating line from western New York to Iowa and the Kansas low. Periods of precipitation associated with the frontal zone occurred in the Ft. Wayne area on April 11. A Bermuda-type high extended into the southeastern states and another high was centered south of western Hudson Bay. The low was forecast to develop and move eastward. A decision was made to sample the system and preliminary alerts were given to some stations that evening. Surface front positions for this event are shown in Figure 4-2.

By 0000 GMT, April 12, the two fronts had merged and extended along the St. Lawrence River Valley through the lower lakes to Chicago and westward. A trough formed through eastern New England, New Jersey, and westward through West Virginia to Indiana. Showers and thunderstorms occurred both north and south of the front, but a decision was made to await the development of the low center before activating the Intermediate-Density network. However, a few station operators sampled on April 12 without receiving a final alert.

By 0600 GMT, April 12, the front had moved southward and extended from New Jersey westward through Pennsylvania, Ohio, Indiana, Illinois, and Missouri to a small low in southwestern Kansas. The northern high was centered over the western shore of James Bay and was instrumental in pushing the front southward. An unrelated front extended southeastward to northwestern Nebraska from a low north of Montana.

At 1200 GMT, the front extended from a very weak low in coastal Maryland and Delaware westward through northern Ohio and Indiana, north-central Illinois, and northern Missouri to a weak low center in central Kansas. The front extending southeast from the western Canadian low center had nearly joined the low in Kansas. Scattered showers and thundershowers occurred along the first

Figure 4-2. Frontal positions associated with storm of April 14.

mentioned front as it drifted southward across the High-Density network at about 1500 GMT. Only small and spotty precipitation areas showed on the Ft. Wayne radar after frontal passage, and the Battelle aircraft did not sample.

Little change occurred in the next twelve hours except for a weak wave or two moving eastward along the front.

By 0600 GMT, April 13, the front extended from northern North Carolina through Kentucky, southern Indiana, southern Illinois, and northern Missouri to a weak low in northeastern Kansas. The northern high, now north of New England, had extended a ridge down the east coast while the southern high still persisted over the southeastern and Gulf Coast states. Another weak low had formed in South Dakota on the front extending southeastward from the Canadian low now north of Minnesota.

At 1200 GMT, the cold front from the Canadian low, now just southwest of Hudson Bay, was approaching the weak low center on the east-west stationary front which now extended from northern Missouri to southern North Carolina. The northern high was centered north of Maine with a ridge extending southward to North Carolina. Western stations in the Intermediate-Density network were alerted at this time because the approach of the western cold front was expected to trigger development and movement of the weak low at the western end of the stationary front. Precipitation occurred in the vicinity of the High-Density network throughout the day.

By 1800 GMT, the ridge had pushed the eastern portion of the front to South Carolina. From there, it extended westward and northward to West Virginia and then west-northwestward to a junction with the northern cold front in the Iowa- Minnesota border region. The western portion of the stationary front had now assumed warm front characteristics and the rest of the Intermediate-Density network was alerted to sample when precipitation reached each station. The approach of the cold air west of the northern cold front started the system moving eastward although a significant low center never developed at the junction of the fronts.

At 000 GMT, April 14, the cold front extended from James Bay through Wisconsin to Oklahoma. The warm front extended from northern Illinois to West

Virginia and southeastward to South Carolina. The rain area extended in an east-west band over northern Indiana and most of Ohio. The high ridge persisted along the east coast. Moderate thunderstorms occurred over the High-Density network during the evening and night (0000-0900 GMT, April 14) as the cold front approached from the west. Some stations recorded more than 3 inches (7.6 cm) of precipitation from this storm.

At 0600 GMT, the cold front passed through Chicago. The warm front had reached northeastern Indiana, central Ohio and eastern Tennessee. Showers and thunderstorms occurred over much of the network north and east of the warm front into western New York and western Pennsylvania. None had reached the east coast where the ridge remained. Showers also occurred in the narrowing warm sector and for some distance behind the cold front. Shortly after 0900 GMT the cold air reached Ft. Wayne and precipitation soon ended.

At 1200 GMT, the cold front crossed Lake Huron, western Ohio, western Kentucky, and extended southwestward. It was catching up to the warm front which was held back by the large high now off the New England coast and by the coastal ridge. The warm front extended from the Detroit area through eastern Ohio, West Virginia and southward to Georgia where it turned eastward into the Atlantic. Rain had reached central New York, eastern Pennsylvania, and Maryland.

By 1800 GMT, the cold front crossed western Pennsylvania and eastern Kentucky while the warm front extended from central Pennsylvania to western North Carolina and southeastward. Rain had reached the easternmost stations by about 1500 GMT.

At 0000 GMT, April 15, the fronts had completely occluded and extended along the Vermont-New Hampshire border, along the New Jersey coast and southwest through Virginia and western North Carolina. The front cleared the coast shortly thereafter followed by a large high pressure system.

During the early part of the event, precipitation occurred largely as showers and thundershowers but the eastern part of the network experienced mostly steady warm front type rain.

On the intermediate-density network, a total of 475 precipitation samples from 31 of the sites were analyzed. The BNL aircraft performed sampling between White Sulphur Springs and Charleston, West Virginia from about 1300 to 1400 EST on April 14.

On the high-density network, precipitation occurred mainly between 0700 and 1100 EST on April 13. The samplers had been set out between 1400 and 1800 EST on April 12, and were collected on the afternoon of April 13 (except for six which were not collected until April 14). A total of 354 samples from 44 sites were analyzed. Aircraft operations were limited to in-cloud sampled by the DC-3 between 1110 and 1310 EST on April 13.

EVENT 3, APRIL 16-18, 1981

At 0000 GMT, April 16, the eastern half of the U.S. was under a huge dome of high pressure. A weak warm front followed the Gulf coast and another warm front from a small low in Saskatchewan extended southeastward to northern Michigan. Onshore flow of gulf air on the backside of this high pressure area was producing an area of precipitation in the Texas-Oklahoma panhandle area.

At 1200 GMT the high was centered over Chesapeake Bay; the eastern portion of the Gulf front had passed south beyond the tip of Florida then extended northwest through southern Louisiana into Texas then curved southward. The northern front was east-west about 100 miles north of the Canadian border from Lake Superior westward to the Continental Divide and beyond. The area of air mass precipitation had continued to move around the back side of the high and was now over northern Missouri and southern Iowa. The 1200 GMT 850 mb. chart shows an even more extensive area of moist air over much of Nebraska, Kansas, Oklahoma, western Missouri and northern Texas.

Overrunning type clouds were covering the sky early on the 16th at Ft. Wayne, and rain was forecast by evening. The decision was made to sample, and collectors were set out in the High-Density network in the afternoon.

At 1800 GMT a band of precipitation stretched east-west across central Indiana and into both Illinois and Ohio. No fronts were nearer than the

dissipating warm front in southern Arkansas and the Canadian warm front. Precipitation was also occurring in eastern Iowa.

By 2100 GMT precipitation had spread over northern Indiana and Illinois and into Wisconsin.

At 0000 GMT, April 17, the precipitation area was still intact over northern Indiana and Ohio, and the southern end of Lake Michigan. At 850 mb. convergence in a southwest-northeast zone from Oklahoma to the Great Lakes was evident, and moist air was present along the southern edge of this zone. The east-west front along the Canadian border had two low centers, one in Saskatchewan and the other in Manitoba. A cold front from one center dropped southward through North Dakota then southwestward to beyond the Rocky Mountains.

At 0600 GMT the cold front had moved to Minnesota, South Dakota, Wyoming and westward position. The precipitation area in the Ohio Valley had increased in size and extended south from northern Michigan through Ohio to Kentucky.

At 1200 GMT the moist air pattern at 850 mb was nearly matched by surface observations of precipitation in Michigan, New York and Pennsylvania southwestward to Tennessee and Arkansas. The cold front had just crossed into Wisconsin and Iowa then trailed westward. The MAP3S region was still being affected at both surface and aloft by the southwest to northeast air flow on the back side of the high which was now well out into the Atlantic.

At 1800 GMT the cold front was being speeded up by this flow and it extended from Lake Superior to northern Illinois and southwestward to Kansas and was stationary west of that point. Precipitation in advance of the front was occurring over Pennsylvania and Virginia. There were smaller areas of precipitation in New York and New England.

At 0000 GMT, April 18, the general precipitation was mostly over Vermont, New Hampshire and Maine with scattered showers and thundershowers along the Appalachian Mountains to Tennessee. The cold front was now in Eastern Michigan, northern Indiana then trailing out to Kansas. A trough had developed in the New England states at about 2100 GMT April 17.

The precipitation during this event seemed to be primarily air mass type with no identifiable fronts in the vicinity until late in the period. Samplers were not activated in the Intermediate-Density network for this event.

Precipitation at the high-density network was light and occurred intermittently between 1700 EST on April 16 to 0800 on April 17. Samplers were set out between 1400 and 1800 EST on April 16, and were retrieved on the afternoon of April 17. Aircraft sampling by the DC-3 (both clear-air and in-cloud) and the Cessna 411 (clear air) between 1430 and 1930 EST on April 16 was performed over the network area.

EVENT 4, APRIL 21-24, 1981

At 000 GMT, April 21, a large high, centered near James Bay, covered all of the United States east of the Rockies except the extreme south. A cold front extended from a low off New England to the Georgia coast. The front extended westward as a stationary front to New Mexico and northward as a warm front to a small low north of Montana. Surface front positions for this event are shown in Figure 4-3.

By 1200 GMT, a cold front from the west was approaching the north-south warm front and the low had moved to a position north of North Dakota. A decision was made to sample the system. The BNL aircraft was sent to Ft. Wayne and preliminary alerts were given to the western network stations.

At 0000 GMT, April 22, the two western fronts had merged into a single cold front extending from a low in northeastern North Dakota through Nebraska, Colorado and New Mexico. The stationary front was still located along the Gulf coast and through north-central Texas. The large high had weakened and was centered along a line from western New York to eastern North Carolina. Scattered showers were occurring east to western Illinois.

At 1200 GMT, the front extended from a low in northern Minnesota to northern Texas. A secondary cold front extended southwest, west and northwest of the low center. The stationary front was advancing northward as a warm front from coastal Mississippi to southern Arkansas. The high was reduced to a weak north-south ridge across New York State. A weak trough was beginning

Figure 4-3. Frontal positions associated with storm of April 23-24.

to form above an east-west line from central Illinois to southwestern Pennsylvania. Showers extended to eastern Ohio in the trough region.

By 1800 GMT, the cold front extended southward from a low in Minnesota and then southwestward through Oklahoma and Texas. The warm front reached from coastal Alabama through northern Mississippi and eastern Missouri and joined the cold front in southeastern Iowa. Detailed surface analysis showed warm frontogenesis along the trough line from the Pennsylvania-West Virginia border through Ohio, extreme northeastern Indiana and Wisconsin to the main low. Rain now extended eastward through most of Ohio and into northern West Virginia. The main mass of precipitation entered the High-Density network at about 1900 GMT.

At 0000 GMT, April 23, the low was located in southwestern Wisconsin with an occluded front to eastern Missouri. From there, the cold front extended southwest and the original warm front southeast. Another cold front from the northwest was approaching the low center. The warm frontogenesis was still evident and the high pressure was centered off the coast. Rain now extended into western New York, central Pennsylvania, and all of West Virginia.

At 0600 GMT, the low was located in eastern Wisconsin. The occluded front extended to southern Illinois with a cold front southwest and a warm front southeast. A secondary cold front curved from the low center southwest to Iowa and then northwest. The warm frontogenesis trough extended eastward from the low center to coastal Maryland. Rain had reached central New York, eastern Pennsylvania, and central Virginia.

At 1200 GMT, the low center was located in northern Lake Michigan. The occluded front crossed lower Michigan and extended along the Indiana-Ohio border and southwest. The warm front extended from central Kentucky southeastward. The warm frontogenesis had now resulted in a well-marked warm front from southern New Jersey through southern Pennsylvania, northeastern Ohio, and central Michigan to the low center. The complex frontal system now had two warm fronts and two cold fronts. The secondary cold front extended southwest from the low center and then curved to the northwest. Rain now covered most

of New York State, part of western New England, most of New Jersey and Maryland, and all except southeastern Virginia.

By 1800 GMT, the low center had moved to the north end of Lake Michigan with the occlusion through western Lake Huron and eastern Ohio. The cold front extended southward from there to eastern Tennessee. Two secondary cold fronts were now evident but the original southern one appeared to be dissipating. The original southern warm front appeared to be disappearing and the northern warm front extended from Delaware through central Pennsylvania, western New York and southern Ontario to meet the occlusion in Lake Huron. Rain had reached the coast from New England to southern New Jersey but had not reached east of Chesapeake Bay.

By 0000 GMT, April 24, the occluded front extended from the low center over lower Michigan to western Maryland. The warm front extended northeastward south of Long Island and Cape Cod and the cold front southwestward along the Appalachians. The secondary cold front extended southward from the low center to southern Illinois and then curved westward and northwestward.

By 0600 GMT, the cold front extended from eastern Massachusetts to Delaware and southwestward with the warm front eastward north of Cape Cod; the occlusion bent back to a low in northeastern Michigan. The secondary cold fronts had dissipated.

At 1200 GMT, the low and the front had completely cleared the coast north of Cape Hatteras but the occlusion extended across northern New England and southern Ontario to the low which was now north of Lake Ontario. Scattered showers and light rain and drizzle still occurred in eastern New England and through western New York and Ohio. Sampling was terminated at all stations by noon.

On the intermediate-density network, a total of 615 samples from 36 network sites were analyzed. The BNL aircraft performed sampling missions supporting the intermediate-density experiment between Ohio and West Virginia from 1432 to 1608 EST on April 22, and over Delaware and eastern Pennsylvania from 1149 to 1327 EST on April 23.

On the high-density network, the bulk of the precipitation occurred between 1300 and 2000 EST on April 22, but the northern row of sites received additional rain between 2300 April 22 and 0200 April 23. The samplers were set out between 0800 and 1200 EST on April 22 and were collected on the morning of April 23. A total of 346 precipitation samples from 47 sites were analyzed. All three aircraft were utilized at the high-density network. The Islander and the Cessna 411 performed clear air sampling between 0900 and 1300 EST. The DC-3 performed clear-air and in-cloud sampling from 0945 to 1300 EST, and more in-cloud sampling from 1560 to 1750 EST.

SECTION 5

CENTRAL DATA COORDINATION

RATIONALE

The wide variety of data generated by and needed for the OSCAR field experiment of the MAP3S/RAINE program clearly indicated the need to centralize the data coordination function. Thus a central facility was established at Brookhaven National Laboratory (BNL) to collect, integrate and disseminate the appropriate experimental data generated by OSCAR and the auxiliary data needed by program participants before, during and after the experimental phase of OSCAR. Merging of disparate data into working data sets as required allows different researchers to access the same information from one central location. This chapter describes the work of the central data coordination facility during the design, operation, and aftermath of the OSCAR experiment.

METEOROLOGICAL DATA

A communication link with the National Meteorological Center (NMC) in Suitland, Maryland provides BNL with real time computer access to weather data. This BNL/Suitland link was the primary source for meteorological data for the experimental period of OSCAR. All bulletins received via the Suitland link are archived on magnetic tape and can be produced in hard-copy form. A description of available bulletins is included in Appendix B.

Procedures were developed to process the bulletins containing the trajectory forecast from the Limited Fine Mesh (LFM) and the NMC Global Spectral models. These facilities were used during the OSCAR experimental period to decode the data on request and present it in the form of graphs and/or tables.

Twelve-hour upper air observations (radiosonde codes) have been obtained from the Air Resources Laboratory (ARL) in NAMER/WINDTEMP format (see Appendix C for details). These surface to 500 mb data are available for North American (above 20°N latitude excluding Alaska) from April 1 to April 30, 1981.

PNL conducted radiosonde observations at the Fort Wayne site of the intensive network. These data will be merged with the NAMER/WINDTEMP data set.

PRECIPITATION AND PRECIPITATION CHEMISTRY DATA

OSCAR High Density Network

The high-density network of 47 sites was equipped with the automatic samplers described in Section 2. Automatic rain gauges were operated in conjunction with each precipitation sampler. Chemical analyses were performed at PNL.

For each precipitation sample taken in the high-density network, the following data are available:

- Station ID
- Latitude/longitude
- Sample ID
- Start date/time of sample (GMT)
- End date/time of sample (GMT)
- Field analyses: pH
- Chemical analyses: pH, conductivity (micromhos/cm), NO_3^- , NO_2^- , $\text{SO}_4^{=}$, Cl^- , NH_4^+ , Ca^{++} , Mg^{++} , K^+ , Na^+ , $\text{PO}_4^{=}$ (micromoles/l)
- Sample volume (ml)
- Estimated precipitation amount (mm)

The raingauge data from the high-density network includes the following items:

- Date/site identification
- Precipitation start time for event (GMT)
- Precipitation end time for event (GMT)

- Total precipitation for event (mm)
- Cumulative precipitation amount (mm) vs. time throughout the event (manually digitized raingauge trace)

OSCAR Intermediate Density Network

Manual sequential samples were taken on the intermediate density network of 37 stations. No automatic precipitation gauges were used for the network. Analyses were also performed at PNL. For each sample taken the following data are available:

- Station ID
- Latitude/longitude
- Sample ID
- Start date/time of sample (GMT)
- End date/time of sample (GMT)
- Sample volume
- Field analyses: pH
- Chemical analyses: pH, conductivity (micromhos/cm), NO_3^- , NO_2^- , $\text{SO}_4^{=}$, Cl^- , NH_4^+ , Ca^{++} , Mg^{++} , Na^+ , $\text{PO}_4^{\equiv}$ (micromoles/l)

Data from individual sequential samples will also be aggregated to provide results on an event basis.

U.S. and Canadian Precipitation Data

Data collected in April 1981 by the cooperative rain network has been obtained for the National Climatic Center (NCC) in Ashville, NC and from the Canadian Climate Centre in Downsview, Ontario. Station history tapes have also been obtained from both agencies. The hourly precipitation data, including station information, is available in synoptic format.

AIR QUALITY DATA

High Density Experiment Surface Air Chemistry Site

An air chemistry site was operated by BNL at a location suitable for testing air quality at the high-density network.

Measurements undertaken include: SO_2 (Melo 285), $\text{HNO}_3/\text{NO}/\text{NO}_x$ (modified TECO 14B), strong acid aerosol, $\text{SO}_4^{=}$, NH_4^+ and second NO_3^- (filter samples), HNO_3 and aerosol NO_3^- (filter samples with denuder), aerosol sulfur (BNL-modified Melo 260), methane and total hydrocarbons (Melo 550C), light scattering coefficients (MRI Nephelometer), ozone (Monitor Labs), NH_3 (non-commercial analyzer of BNL design).

Peroxyacetyl nitrate (PAN) measurements were conducted by personnel from Battelle Columbus Laboratories. Measurements of H_2O_2 in rainwater and cloudwater and gaseous H_2O_2 measurements were conducted by personnel from Claremont College under sponsorship of the Coordinating Research Council. A low-pressure impactor was operated by personnel from UCLA at the Fort Wayne air chemistry site and onboard the PNL DC-3. Size fractionated samples were collected and analyzed for sulfur to obtain $\text{SO}_4^{=}$ size distribution data. The impactor provides sulfate concentration as a function of particle size for eight size ranges covering the range of .04 to 8.0 μm diameter.

BNL Site

Surface air measurements of gases and aerosols were obtained at a location within Brookhaven National Laboratory. Data included continuous measurements of gaseous NO_x , NO , O_3 , and SO_2 and H^+ , NH_4^+ , $\text{SO}_4^{=}$, NO_3^- , HNO_3 , and SO_2 from a BNL filter pack.

Other U.S. and Canadian Data

Using EPA's Directory of Air Quality Monitoring Sites, an initial search was made for aerometric stations in the area of the OSCAR intermediate network sites. Parameters examined first were location, supporting agency, and type of measurements being conducted. Emphasis was placed on SO_2 , $\text{SO}_4^{=}$, particulate, NO_3 , NO , O_3 , and NO_2 measurements. Operating agencies were contacted and data collected during OSCAR experimental days was requested.

The following data were received from each agency in their internal formats and converted to uniform units and integrated into a unified data base.

- a) State of Illinois - 8 stations reporting HIVOL TSP, 2 reporting hourly SO_2 .
- b) State of Michigan - 20 stations measured 24 hr. HIVOL total suspended particulates (TSP).
- c) State of New York - 7 stations reporting hourly SO_2 , 1 reporting hourly NO_2 , 1 reporting hourly NO and 6 reporting hourly O_3 .
- d) State of Pennsylvania - 20 stations measured 24 hr. HIVOL $\text{SO}_4^{=}$ or 24 hr. HIVOL $\text{SO}_4^{=}$ and NO_3^{-} ; 23 stations operated at least one of the following hourly determinations during this period - SO_2 , NO_x , NO_2 , O_3 and NO .

The states of Ohio and Indiana have also been contacted and data is expected. Five Canadian stations operated at least one of the following determinations during the OSCAR experimental days: 24 hr. HIVOL $\text{SO}_4^{=}$, 24 hr. HIVOL NO_3^{-} , hourly SO_2 , NO_x , NO_2 , O_3 , NO .

AIRCRAFT DATA

Both BNL and PNL operated research aircraft during the OSCAR experiment. Each laboratory reduced their continuous data in house; cloud-water samples were analyzed by PNL, the filter pack analyses were done by BNL. The data are listed below. (Note that not all of these measurements were available on each aircraft).

General information

- Type of flight (horizontal leg, vertical spiral, etc.)
- Starting latitude/longitude
- Starting altitude
- Ending latitude/longitude
- Ending altitude
- Ending date/time
- Aircraft code

Continuous measurements

- Location information (latitude, longitude, altitude)
- Date/time (GMT)
- Airspeed
- Temperature ($^{\circ}\text{C}$)
- Dew point ($^{\circ}\text{C}$)
- Relative humidity (%)
- Solar radiation (W/m^2)
- Ultraviolet radiation (W/m^2)
- bscat ($10^{-4}/\text{m}$)
- Condensation nuclei (no./cc)
- Aerosol sulfur ($\mu\text{g}/\text{m}^3$)
- Liquid water content (gm/m^3)
- NO
- NO_x
- NO_x - HNO₃ (ppb)
- O₃
- SO₂
- NH₃
- Total HC
- Wind speed (m/sec)
- Wind direction (degrees)
- Cloud droplet size distribution
- Aerosol size distribution
- Pressure (mb)

Filter Pack Data

- Sample ID
- Volume (m^3)
- Total sulfur (ppb)
- SO_2 (ppb)
- $\text{SO}_4^{=}$ ($\mu\text{g}/\text{m}^3$)
- Strong acid as H_2SO_4 ($\mu\text{g}/\text{m}^3$)
- NH_4^+ ($\mu\text{g}/\text{m}^3$)
- NO_3^- ($\mu\text{g}/\text{m}^3$)
- Extracted H_2SO_4 ($\mu\text{g}/\text{m}^3$)
- HNO_3 ($\mu\text{g}/\text{m}^3$)
- NO_3^- from denuder ($\mu\text{g}/\text{m}^3$)

Aircraft cloud-water samples

- Sample ID
 - pH
 - Conductivity (micromhos/cm)
 - NO_3^-
 - NO_2^-
 - $\text{SO}_4^{=}$
 - Cl^-
 - NH_4^+
 - Ca^{+++}
 - Mg^{++}
 - K^+
 - Na^+
 - Al^{+++}
 - $\text{PO}_4^{=}$
- (micromoles/l)

APPENDIX A

INTERMEDIATE-DENSITY PRECIPITATION CHEMISTRY NETWORK DESCRIPTIONS

All intermediate-density network station operators were requested to provide site descriptions of latitude and longitude, immediate surroundings (with distance and direction to any nearby obstacles), and the general area (with distance and direction to any significant pollution sources). The site descriptions received varied in the amount of detail included, and are presented as written except for minor editorial changes. The institutions and individuals responsible for operating each station and those persons who actually took the samples are listed as far as known. At some stations, individuals whose names were not reported assisted in various phases of the operation. Several site operators provided diagrams or photos as indicated below. These are not included in this report because they are not available for most sites but have been filed and are available for inspection.

Station 00, Huntington, Indiana

Site 00 was located at 40°49.8'N, 85°27.6'W on a grassy field on a U.S. Army Corps of Engineers site at Huntington Dam Headquarters, near Huntington, Indiana. This was a rural setting, with a two-lane highway running in a north-south direction, roughly 182 m from the sampler location.

The closest human activity was the Corps of Engineers operations 61 m directly north of the sampler. This included two domestic dwellings, and a moderately large garage. The tallest projections were approximately 15-m power poles servicing the houses; the samplers were not influenced by drip from these or any other vertical protrusions.

The most probable artifact pollution source, insofar as the precipitation samples were concerned, were farm animals located in a field 0.4 to 0.8 km away. These were mostly hogs, and could possibly contribute to the ammonia loadings. Substantial amounts of anhydrous ammonia being applied as

fertilizer throughout the general area during April might also have affected the site.

The station was collocated with the high-density network site 62, and was operated by Drs. Jeremy Hales and Richard Lee of PNL.

Station 01, Argonne, Illinois

The sequential rain collector for OSCAR at Argonne National Laboratory was located at 41°42'N, 87°59'W at an elevation of 227.4 m. The flat prairie land consists of loamy clay covered by grass. No tall objects are located within 50 m of the collector except for a 18 m mobile home trailer (about 3 m tall) located 15 m south. Trees (~15 m tall) are located about 75 m north of the collector and a lightly traveled, paved highway about 30 m to the east. Argonne is bordered by Forest Preserves W-S-E.

The Chicago urban area lies to the north and east, and significant pollution sources are located 9 km SW, 15 km SSW, and 22 km SSW. Only the closest source, a coal-fired power plant, can be clearly identified in air quality data at the Argonne site.

The station was operated by Douglas Sisterson and D. Wagner of Argonne National Laboratory.

Station 02, Hickory Corners, Michigan

The OSCAR site at the W.K. Kellogg Biological Station, Hickory Corners, Michigan was located at 42°24'N, 85°24'W. The sampler is located on a grass lawn at the W.K. Kellogg Biological Station. A tall tree is located 23 m west of the sampler and a bush about 3 m high about 17 m east. The sampler is within about 100 m of Gull Lake, a body of water about 4.8 km long by 1.6 km wide. The surrounding area is rural, although there is a concentration of residences around Gull Lake. Possible pollution sources are Kalamazoo, southwest of the Station (17-24 km), including a coal-burning power

plant and other industry, and light industry in Battle Creek, 10 km southeast of the Station.

The station was operated by John Gorentz and Robert Mueller of the W.K. Kellogg Biological Station. Arrangements for the station were made by ANL.

Station 03, Okemos, Michigan

The sample station 03 was located in Okemos, Michigan, which is a suburban area approximately 6.4 km east, 3.2 km south of Michigan State University and East Lansing, Michigan. The latitude is 42°41'33"N and the longitude 84°24'22"W. The sampler was located in a 24-ha stubble wheat field, approximately 91 m from the nearest trees or houses. The area surrounding the field is approximately 40% single unit housing and 60% old field-active farm land. The top of the funnel was approximately 1.2 m above the ground. There were no significant pollution areas in the immediate vicinity. The nearest pollution source would be the University-East Lansing-Lansing area. Each of these areas has significant coal-fueled power plants, and the Lansing area has a significant industrial zone.

The station was established at the request of Dr. Jeremy Hales by Frank D'Itri, Michigan State University and operated by Charles Annett.

Station 04, Long Point, Ontario

The site is at 42.6°N latitude and 80.5°W longitude on the Long Point peninsula which extends into Lake Erie. The immediate area is surrounded by marshland and low-lying shrubs. Nearby buildings are to the southeast and east of the site, one to two stories high and more than 9 m away.

The station was operated by Ann Brown under the direction of Dr. Tom Agnew, Atmospheric Environment Service, Canada and used a sequential sampler of the type used in the High-Density network.

Station 05, Marysville, Ontario

Station 05 is located at Marysville, Ontario (between Kingston and Belleville). The site is at 44°13'40"N latitude and 77°5'30"W longitude. The setting is rural, 1.2 km south of Hwy. 401 (a major E-W artery in Ontario),

0.4 km north of Hwy. 2. The sampler is at least two heights from the nearest tree or building. There is a large cement plant at Picton, about 30 km to the south.

The station was operated under the direction of Maris Lusi, Ontario Ministry of the Environment, by Beryl Orok and Paul Kehoe.

Station 06, Upper Arlington, Ohio

The site of the precipitation collections during the April OSCAR experiments was in the residential neighborhood of Upper Arlington, Ohio. The site was located at 40°01'06"N, 83°03'04"W. The nearest significant pollution source would be downtown Columbus, about eight km to the southeast. The collector was situated 2 m off the ground over a grassy surface. The nearest obstacle was a house, about 5 m away.

The station was operated by Chester W. Spicer, Battelle Columbus Laboratories.

Station 07, Loudenville, Ohio

Station 07 is located in Ashland County on route 97 southwest of Loudenville, Ohio. The station is located on private property within the Mohican State Forest at latitude 40°36'N and longitude 82°19'W. The terrain is composed of hills heavily forested several km in every direction excluding isolated areas with summer and winter cabins. The area is used primarily for recreation including boating on a nearby lake, river canoeing, camping and winter sports. The nearest industrial activity is located about 11 km northeast of the site in Loudenville. There are no continuous obstructions (treeline) within 45 m. The elevation of the site is approximately 400 m.

The station was established by Dan Strait, Mead Technology Laboratories, an EPA contractor, at the request of Robert W. Shaw, EPA, Research Triangle Park, North Carolina, and operated by D. Morehart. A sequential sampler of their own design was used.

Station 10, Whiteface Mountain, New York

The Atmospheric Sciences Research Center at Whiteface Mountain is located at 44°24'N and 73°52'W at an elevation of 613 m on the north slope of the mountain. The sampler was located in a 21x76 m clearing with other precipitation collectors. Bushes and small trees 2-4 m tall are located about 14 m to the west, and trees 7.6-9.1 m tall about 6.7 m to the east. The ASRC bunkhouse is about 14 m east and the ASRC lodge about 41 m southeast. There were no significant pollution sources in the area. A diagram of the site was provided.

The station was operated by Marc du Bois, ASRC under the direction of John Kadlecek, ASRC.

Station 11, Charlton, New York

The site at 42°57'N, 73°57'W is northwest of the Albany urban area and is rural-low density residential in use. Primary land use is wood lot with some tilled land mostly pasture, hay, and corn. Soils tend to be heavy and are generally shallow. Housing density is about 8 per 100 ha.

As to the site itself, it is a 4-ha abandoned pasture. Vegetation was mixed grasses less than 46 cm tall with the collector funnel supported 2.1 m above the ground. The nearest trees were in a fence row about 61 m to the south. To the west was a fence row about 300 m away, and to the north and east were woods. Because of limited access, it was not easy to service, but satisfied all criteria for a good collection site.

The station was established and operated by John Kadlecek, ASRC.

Station 12, Big Moose, New York

The sampler was located on a 1.2 m post in Big Moose, New York, latitude 43°48'N, longitude 74°55'W and elevation 621 m. Location was in a relatively open backyard, distance to house, about 23 m, distance to one shrub (about 1.5 m high), 9 m, some higher trees 27 m (or more) away. Big Moose has about 10 houses and there is an occasional car on a nearby road. No significant pollution sources within 48 km have been identified. The nearby railroad (Utica-Lake Placid) has been dormant since last year.

The station was operated by Tom Suleski, Tom Coats and Allen Wallter under the direction of Professor Elmer R. Altwicker, Rensselaer Polytechnic Institute, Troy, New York.

Station 20, Connecticut Hill, New York

This site is located at 42°22'N, 76°46'W at the MAP3S site (Ithaca - 2) approximately 25 km southwest of Ithaca. This is a remote site in a field surrounded by pine trees, none of which are higher than a 45° angle with the lip of the collector. The site is about 23 m uphill from a little-used, paved road. A hedge of pines separates the site from the road. There are no significant pollution sources in the immediate vicinity.

The station was operated by Tom Butler, John Eaton, Jim Low, Steve Nodvin and Bill McDowell under the direction of Tom Butler and Dr. Gene Likens, Cornell University.

Station 21, Letchworth State Park, New York

This site is located at 42°42'N, 77°55'W within the park boundary on a baseball diamond. A parking lot and information center are located about 23 m north of the site. However, little use is expected during the time of the precipitation experiment. The only possibility of local pollution would be a campsite about 4.8 km south of the site. Again, little use is expected at this time of the year.

The station was operated by Barbara Askew and Cathy Weiler under the direction of Tom Butler and Dr. Gene Likens, Cornell University.

Station 22, Hubbard Brook Experimental Forest, New Hampshire

The HBEF is located near West Thornton within the White Mountain National Forest of north central New Hampshire (Grafton County). Coordinates of 43°56'N, 71°45'W bisect the area. The Atlantic Ocean is about 116 km to the southeast; the largest metropolitan areas are Portland, Maine and Boston, Massachusetts, each about 150 km east and south, respectively. The altitude of the forest ranges from 229 to 1015 m.

The bedrock is derived from highly metamorphosed sedimentary and granitic rock, the soils are mostly well-drained sandy loam textured spodosols, and the vegetation (about 99% coverage) consists of uneven aged stands of Maple, Beech, Birch, Spruce, Fir, and Hemlock.

The U.S. Forest Service station at HBEF is located at the end of a gravel/asphalt-paved secondary road. All buildings in the vicinity of the area other than the station are full-time residences or summer cottages. The closest source of industrial pollution is a paper mill, 20 km north, defunct for the past 4-5 years. The nearest coal/oil fired power plant is in the Connecticut River Valley about 100 km southwest. Interstate highway 93 is 1.2 km east of the station.

The collection funnel holder was mounted on a 2-m-high post within a fenced-in instrument area (containing rain gauge, meteorological sensors, and bulk rain collector), 25 m north of the U.S.F.S. station, at an elevation of 274 m. A parking lot next to the collection area sees little traffic on an average basis (two cars in and out, at 0800 and 1630).

The station was operated by Don Buso, U.S. Forest Service. Participation was arranged by Dr. Gene Likens, Cornell University. A map and diagram of the area were provided.

Station 30, Pennsylvania State University

The site is at 40°47'N, 77°57'W in a leveled clear-cut square of 137 m on a side in forested state lands, and it is located 6.4 km west of the Penn State University main campus at University Park, which is almost entirely a residential and commercial community.

The largest source of pollution, a small coal-oil-gas fired power plant, is located on the Penn State University campus.

The station was established by Rosa de Pena and Jorge Pena, Pennsylvania State University, and operated by Jorge Pena, Ted Palma, Tim Krauss and Jim Holian.

Station 31, Scottdale, Pennsylvania

The rain collector was located at 40°05'N, 79°37'W in the backyard of August Simonsen's house which is surrounded by farms. The largest nearby obstacle, a line of 6-m-tall trees, was in the S and SE direction and the minimum distance to it was at least 27 m.

The nearby population, Scottdale, where there are a couple of small industries is 3.2 km to the east. The large V.W. assembly plant at New Stanton is 16 km to the North.

The station was established by Rosa de Pena and Jorge Pena, Pennsylvania State University, and was operated by August Simonsen and Mary Simonsen.

Station 32, Marvindale, Pennsylvania

The sampling was done at the backyard of John Brooke's house which is located at 41°45'N, 78°32'W on the U.S. 6, 3.2 km southwest of Marvindale. The house is on the slope of a hill and the samples were collected 13.7 m away and upslope from the house in such a way that the sampler was almost at the same level as the roof of the house. The closest obstacles were a few trees 3 m tall in the SE direction and 9 m away from the sampler. There are no nearby sources of pollution.

The station was established by Rosa de Pena and Jorge Pena, Pennsylvania State University, and operated by John Brooke.

Station 33, Hazleton, Pennsylvania

The sampler was located at 40°58'N, 76°00'W on the roof of one of the dormitories of the PSU Hazleton campus, on PA 97, 4.8 km west-northwest of the town of Hazleton. At this location the sampler was at the level of tree tops of the nearby hill in the north-northeast direction.

The station was established by Rosa de Pena and Jorge Pena, Pennsylvania State University, and operated by Alex Sosnowsky and Richard Paul.

Station 40, Charlottesville, Virginia

The collection site was located at 38°08'N, 78°23'W on a hilly area of a rural farm (non-working), about 16 km northeast of Charlottesville (pop.

~65,000). Elevation was 214 m. Nearest obstacles were as follows: house about 7.6 m tall 27 m northwest, tree about 15.3 m tall 24 m northwest, small shed about 4.6 m tall 25 m north, tree about 9.3 m tall 21 m north, fence surrounded by trees 6-9 m tall 9.5 m northeast, tree line (forest on rise of hill) 183 m east, level 21 m southeast, three about 18 m tall 34 m west.

One coal-burning smoke stack located on grounds of University of Virginia burns almost continuously. Two blue stone quarries are located in the vicinity of Charlottesville approximately 11.3 km southeast and 16.1 km southwest of the site.

The station was established under the direction of Dr. James Galloway, University of Virginia, and was operated by Deborah Briggs, Bill Keene and E. Day.

Station 41, Green Bank, West Virginia

The collection site is located at 38°25'39"N, 79°49'25"W at an elevation of 824 m on National Radio Astronomy Observatory property approximately 805 m due south of the NRAO office building.

Nearest obstacles were as follows: double garage 15 m east, wires 24 m east, fence row 92 m west, tree line 61 m south, fence row 46 m north, two-story house 38 m northeast and two-story house 38 m southeast. Nearby communities are Green Bank, 1.2 km south of collection site (pop. <10,000) and Arbovale, 1.2 km north of collection site (pop. <10,000). No pollution problems exist in the area.

The station was established under the direction of Dr. James Galloway, University of Virginia and operated by Kathy Norrod and Dort Oref.

Station 43, Edgewater, Maryland

The station is located at 38°53'N, 76°33'W. The collector is in a grass area at our weather station. It is about 100 m north of our laboratory building and perhaps 30 m west of a single story dormitory. The site is in a rural setting with about 50% forest and 50% agricultural land use. The nearest town, Edgewater, is several km northwest of the site.

The station was established by Dr. David L. Correll, Chesapeake Bay Center for Environmental Studies, and operated by Bill Peterjohn and Debra Ford.

Station 50, Champaign, Illinois

The station was located at 40°02'N, 88°16'W on a grassy lawn on the eastern side of the University of Illinois Willard Airport about 8 km south-southwest of Champaign Urbana.

The funnel opening was ~2 m over grass, and about 30 m east of a 7-m high quonset building. A modified funnel support was used as shown in a picture supplied. Also, the collar was modified to provide more protection against contamination of the sample. A push button was provided at the funnel location to allow printing of the sample change times on a printer located inside the quonset. A tipping bucket rain gauge adjacent to the collector funnel also printed times of each 0.25 mm of rain accumulation using the same printer tape as mentioned above for the bottle change times. A map of the area with the sample site indicated was provided.

The station was established by Dr. Donald Gatz, University of Illinois, and operated by Donald Gatz, Van Bowersox, Gary Stensland, Randy Stahlhut, Bruce Komadina, Lois Staggs, Kathy Eckstein and Susan and Warren Rodie.

Station 60, Upton, New York

The sampling site at Brookhaven National Laboratory is located at 40°52'N, 72°53'W on a grassy lawn near the L-shaped, one-story, 7-m-high meteorology building. The sampler was about 9.2 m north and 16.5 m east of the building. A 3-m-tall instrument shelter is located 10.7 m northeast of the sampler and the 1.2-m-high Brookhaven sequential rain collector is located 34 m to the east. Trees about 9.2 m high are located 26 m northeast and 20 m north of the sampler. A domestic type oil-fired furnace provides heat and hot water to the building. The chimney is located near the southwest corner of the building. Traffic near the sample site is infrequent and all on the opposite sides of the building.

The major developed portion of the Laboratory is located from 450 to 1525 m east of the sampling site and contains laboratories, office buildings

and various research facilities; a small oil-fired power plant is located about 1830 m east of the sampler.

The remainder of the Laboratory property and much of the surrounding region is largely forested. The region within ten miles also includes cultivated fields, small residential communities and small retail and service businesses. The nearest large pollution sources are LILCO oil-fired power plants at Port Jefferson about 21 km northwest and at Northport about 42 km west-northwest. New York City is located from 80 to 97 km to the west. Pictures of the sampler location are on file.

The station was established by Gilbert S. Raynor and operated by John McNeil, Carmen Benkovitz, Kathy Norden and Cathy Henderson.

Station 61, Hightstown, New Jersey

The station was located at 40°17'N, 74°31'W in Hightstown, New Jersey approximately 458-610 m west of the New Jersey Turnpike at Exit 8 on the site of the Town House Motel.

The sampler was placed in an opening about 23 x 46 m on the northwest corner of the motel property. There was no drip-off from high trees, telephone wires, etc. A possible local pollution source was the Waterbury Products Corporation located west to northwest of the sampling station, which has a 9-m stack. Their burner, used only for heating purposes, operated at intermittent periods using No. 4 low-grade sulfur oil burned at 8 lbs. of pressure. Pictures of the station and a map of the area are on file. Hightstown is about 64 km southeast of the New York Metropolitan area.

The station was established by Gilbert S. Raynor, Brookhaven National Laboratory, and operated by Rickey Petty, Ari Patrinos and Seymour Fink.

Station 62, Port Jervis, New York

The station was located at 41°21'N, 74°40'W on the grounds of the Holiday Inn in Port Jervis. The Inn is about 0.4 km east of Route 23 and 3.2 km southeast of Port Jervis. The sampler was located in a flat grassy area about 24 m from the end of the building, 15 m from trees and 6 m from a utility pole. No pollution sources were identified.

The station was established by Gilbert S. Raynor, Brookhaven National Laboratory and operated by Joe Forrest, Robert Doering, Robert Wilson and Cleveland Dodge.

Station 63, Granby, Connecticut

The sampling site is located at 41°55'N, 72°50'W at the Granby Motel which is about 4.8 km north of the Village of Granby on U.S. Route 202. It is about 11 km northwest of Bradley International Airport and about 27 km north-northwest of downtown Hartford.

The sampler was located on the lawn of the motel 12.2 m southeast of the southeast corner of the motel building, 46 m east of a north-south pine wind break of 4.6- to 9-m trees, 12.5 m north of an east-west pine wind break of 3.7- to 6.1-m trees, and 27.5 m west of the pavement of Route 202. Pictures and a sketch map of the area are on file.

The general area is a wide, fairly flat sandy valley flanked by north-south ridges.

As possible unusual sources of pollutants, it should be noted that the motel is heated by a hand-fired coal burning boiler about 30 m north of the collector. Also, during the April 23-24 sampling period, a large persistent fire in a tire junkyard was burning in Waterbury about 48 km south-southwest.

The station was established by Gilbert S. Raynor, Brookhaven National Laboratory and operated by Bill Bornstein, Larry Kleinman and John McNeil.

Station 70, Lewes, Delaware

The station was located at the College of Marine Studies, University of Delaware, 38°47'N, 75°09'W. The collector was situated on the upwind side of the roof of the Cannon Laboratory building (electrically heated), two stories above ground level, and 1.5 m above the roof level. The building is situated between a large salt marsh (to the west and south), Delaware Bay (to the north), and Atlantic Ocean (approx. 8 km east). In experiments conducted during the initial MAP3S site selection at Lewes, analyses of samples obtained from this roof site corresponded well with those obtained from the present MAP3S collection site (approx. 7.5 km east).

The station was established by Joe Scudlark, University of Delaware and operated by Joe Scudlark and Underhill.

Station 71, Kembelsville, Pennsylvania

The station was located at 39°44'N, 75°50'W. The collector was located in the middle of a small, brushy field, about 2 m above ground level. To the west was an open corn field, to the east (50 m) was a two-story brick building; to the north and south was rolling, brushy terrain. Kembelsville is about 16 km west of Wilmington, Delaware and 6.4 km southwest of Philadelphia.

The station was established by Joe Scudlark, University of Delaware and operated by Jack Tramontano.

Station 72, Smithville, New Jersey

The station was located at 39°30'N, 74°28'W. The collector was placed in the middle of an open, grassy field, approx. 0.75 m above ground level. The site is about 50 m from a lightly traveled rural road, and about 10 m from the canopy of a large tree. Smithville is about 13 km north-northwest of Atlantic City and about 13 km from the Atlantic Ocean. Philadelphia is about 80 km northwest.

The station was established by Joe Scudlark, University of Delaware and operated by Harlan Dean, Pat Kobe and Kathy Drew.

Station 73, Cheriton, Virginia

The station is located at 37°17'N, 75°58'W on the southern part of the Delmarva Peninsula. The site was manned for the initial two OSCAR events (9 and 12 April). It is located on the eastern shore of Chesapeake Bay, in a remote campsite area. The collector was situated about 1 m above ground level, in the middle of a grassy playing field (ca. 20 m x 20 m). The terrain was characterized by pine trees and drainage canals. The location is about 16 km from the Atlantic Ocean and 13 km from Chesapeake Bay.

The station was established by Joe Scudlark, University of Delaware and operated by Tom Church and Joe Scudlark.

Station 74, Cape Hatteras, North Carolina

This station was located at 35°16'N, 75°33'W. It was established by Joe Scudlark, University of Delaware and operated by Sandy Slates for the first two rain events. No description is given because no rain occurred at the station.

Station 75, Exmore, Virginia

This station located at 37°32'N, 75°49'W replaced station 73 after the second event and is only a short distance away. This site was manned during the third (final) OSCAR event. The terrain is essentially the same as the Cheriton site. The collector was situated at ground level, in the middle of a small field, between a house and a trailer. Adjacent to the field was a creek and a grassy intertidal area. The nearest road was a lightly used rural road. This site is utilized by researchers from Old Dominion University for their acid rain studies.

The station was established by Joe Scudlark, University of Delaware and operated by Tom Church.

Station 80, Oxford, Ohio

The station was located at 39°32'N, 84°45'W at the Ecology Research Center, Miami University. The sampler was mounted about 0.9 m above a grass surface. A 3.7- to 4.6-m-tall building was located about 9 m northwest and a 12.2-m tower about 30 m east. A gravel drive was 18-21 m north and a line of 6- to 9-m trees about 23 m north. The site is in a rural area about 3.2 km north-northeast of Oxford which has a population of <20,000.

The station was established by John Klink, Miami University and operated by Robert Moore, Lee Wood and Nancy Jacoby.

Station 81, South Charleston, Ohio

The station was located at 39°50'N, 83°45'W on the grounds of a Branch Farm of the Ohio Research and Development Center. The site is in a rural area about 12.9 km southeast of Springfield on Route 41. The sampler was mounted about 1.1 m above a grassy surface. A 4.6- to 6.1-m-tall house was located

about 9 m north and 18-m trees about 37 m southwest. Limestone driveways extended east-west about 12 m south of the sampler and north-south about 15 m east.

The station was established by John Klink, Miami University and operated by Beckie Erwin.

Station 82, Jackson, Ohio

The station was located at 38°58'N, 82°40'W on the grounds of a Branch Farm of the Ohio Research and Development Center. The site is in a rural area about 4.8 km south-southeast of Jackson. The sampler was mounted about 1.2 m above a grass surface about 9 m northwest of a 4.6- to 6.1-m-tall house. No other obstacles were nearby. A limestone driveway was located about 12 m west and 34 m south of the sampler location.

The station was established by John Klink, Miami University and operated by Betty McConnell.

Station 90, Oak Ridge, Tennessee

The sampler is located in a field in Oak Ridge National Laboratory at 35°58'N, 84°17'W. The field is bounded on the north and west sides by pine forest 20 m or less in height. The edge of the forest is 60 m from the sampler to the north and 160 m away to the west.

The trailer (3 m tall) we worked from is 15 m east of the sampler. There is a gravel road running north/south immediately east of the trailer and a 25-m electrical tower 30 m east of the sampler in line with the trailer.

There are three major pollution sources in the area which all burn coal. The farthest from the site is 18 km southwest (TVA 1200 MW power plant), next farthest is 17 km east-northeast (TVA 900 MW power plant), then 7.4 km northeast (DOE small non-commercial steam generation plant).

The station was established by Steve Lindberg, Oak Ridge National Laboratory and operated by Steve Lindberg and Jan Coe.

Station 91, Franklin, North Carolina

The Coweeta Hydrologic Laboratory is located 21 km south of Franklin, North Carolina, off U.S. Highway 441 at coordinates 35°3'N, 83°27'W. The major urban areas in our vicinity are Atlanta, Georgia, 201 km to the south, Asheville, North Carolina, 129 km to the north and Greenville, South Carolina, 121 km to the southwest. There are no major pollution sources in our immediate area and vehicle traffic is minimal.

The sampling site is located approximately 11 m away from our Administrative Office building at a height of approximately 1 m. The elevation at this location is 686 m. Tree populations are a substantial distance away and the samples collected should be unaffected by any blowoff either from the trees or the building itself.

The station was established by Dr. Wayne Swank, Coweeta Hydrologic Laboratory and operated by Wayne Swank and Richie Beale.

Station 92, Lexington, Kentucky

The precipitation sampling station for Site 92 is situated in the yard at 1381 Tanforan Drive in Lexington, Kentucky 40502. The general area is residential suburban with single family dwellings. The station is located approximately 5.5 m west of the street and 11 m east of the single-story house. A small tree (about 3.7 m high) is located 7.3 m north of the collector. The collector is placed on a 0.71-m-high metal table which has a 34 x 41 cm top surface. Splashing from the table top cannot occur since the base of the wood funnel support covers the metal table top.

Lexington is located at 38°03'N, 84°28'W. The street (Tanforan Drive) experiences limited local residential traffic. Approximately 31 m north is a slightly more heavily traveled residential street, and about 0.8 km north is a four-lane highway. The closest traffic generators are shopping areas about 2.4 km to the east, 3.2 km to the northwest and 6.4 km to the west. The closest stationary pollution sources are at the University of Kentucky, about 9.7 km northwest of the sampling site.

The station was established and operated by Dr. Len Peters, University of Kentucky.

APPENDIX B

NATIONAL METEOROLOGICAL CENTER (NMC) BULLETINS AVAILABLE FROM THE BNL-SUITLAND LINK

A. Observational Data

1. Hourly surface observations and special reports.

This is airways code similar to circuit "A" teletype. The area covered is the contiguous United States.

2. Three-hourly surface observations including some ship and buoy reports.

These are in synoptic code similar to circuit "C". Area covered is North America.

3. Twelve-hourly upper air observations.

These are the radiosonde codes. The area covered is the United States.

B. Forecast Data

1. Terminal forecasts and amendments.

The typical aviation terminal forecasts, generally received every three hours but varying depending on the station. Area covered is the contiguous United States.

2. Model Output Statistics MOS.

Various advisories for stations are derived from model output. The type of information is probability of precipitation (POP), probability of severe weather, max/min temperature forecasts, and probability of freezing precipitation. Area covered is the LFM model domain.

3. Gridded forecast data from the Limited Fine Mesh (LFM) model.

The temperature, moisture, and wind fields on the mandatory levels at LFM model grid points are received in a pseudo-ASCII delta-packed

transmission. The non-standard format does not allow direct scanning of fields.

4. Trajectory forecast.

One trajectory forecast is from the NMC global spectral model. The other trajectory forecast is from the LFM model.

5. Miscellaneous forecast products.

There are a number of miscellaneous forecast products including English language air stagnation narratives; flash flood guidances; East Coast wind, wave, and swell forecasts; etc.

APPENDIX C

NAMER-WINDTEMP DATA

NAMER-WINDTEMP data tapes contain radiosonde observations for North America (north of 20°N latitude excluding Alaska) from the surface to 6 km (or 500 mb).

TAPE ORGANIZATION

All reporting stations, in block-station sequence, are compiled for each sequential observation time.

4 observation times per day (0,6,12,18 GMT)
1 files per month
12 files per tape (12 months)

DATA ORGANIZATION FOR EACH OBSERVATION TIME

TIME REC (FOR WINDS)
 STA REC (STATION 1)
 TEMP REC (HEIGHT 1)
 TEMP REC (HEIGHT 2)
 ETC.
 STA REC (STATION 2)
 TEMP REC (HEIGHT 1)
 TEMP REC (HEIGHT 2)
 ETC.
 ETC.

DATA FORMAT

TIME REC:	MONTH (1st 3 LETTERS) A3	YEAR I4	DAY I2	HOUR (GMT) I2	NUMBER OF REPORTS I4	NUMBER OF RECORDS I5	MET FIELD A1 W = WINDS T = TEMPS
STA REC:	BLOCK STATION I5	LATITUDE (DEG*100) I5	LONGITUDE (DEG*100) I7	STATION HGT (M,MSL) I5	AVG TERRAIN HGT (M,MSL) I5	NUMBER OF LEVELS I2	
WIND REC:	WIND HGT (M,MSL) I5	WIND DIRECTION (DEG) I3	WIND SPEED (M/S*10) I4				
TEMP REC:	TEMPERATURE HGT (M,MSL)	PRESSURE (Mb*10)	TEMPERATURE (DEG K*10)	DEW POINT (DEG K*10)			

DISTRIBUTION

PNL-4869
UC-11

No. of
Copies

No. of
Copies

OFFSITE

27 DOE Tech. Information Center

Elmer R. Altwicker
Dept. of Chem. Eng. & Env. Eng.
Rensselaer Polytechnical
Institute
Troy, NY 12181

Dr. Leonard Barrie
Atmospheric Environment Service
4905 Dufferin Street
Downsview, Toronto
Ontario, Canada M3H 5T4

Carmen Benkovitz
Energy & Environ., Bldg. 051
Brookhaven National Laboratory
Upton, NY 11973

Van Bowersox
Illinois State Water Survey
P.O. Box 5050, Station A
Champaign, IL 61820

Tom Butler
Ecology & Systematics
Biological Science Bldg.
Cornell University
Ithaca, NY 14853

Jan Coe
Environmental Sciences Div.
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, TN 37830

Tom Church
Dept. of Marine Sciences
University of Delaware
Newark, DE 19711

Ellis B. Cowling
North Carolina State University
P.O. Box 5397
Raleigh, NC 27606

Rosa de Pena
Dept. of Meteorology
Pennsylvania State University
University Park, PA 16802

Marc DuBois
Atmospheric Sciences Research
Center
Whiteface Mtn. Field Station
Wilmington, NY 12997

5 Dr. Jack Durham
U.S. Environmental Protection
Agency
ESRL MD-80
Research Triangle Park, NC 27711

Dr. James N. Galloway
Dept. of Environmental Sciences
University of Virginia
Charlottesville, VA 22903

Bruce B. Hicks, Director
Atmospheric Turbulence and
Diffusion Laboratory
P.O. Box E
Oak Ridge, TN 37830

J. Holian
503 Walker Building
Dept. of Meteorology
Pennsylvania State University
University Park, PA 16802

No. of
Copies

R.B. Husar
CAPITA
Washington University
P.O. Box 1124
St. Louis, MO 63130

John Jansen
Southern Company Services
P.O. Box 2625
Birmingham, AL 35202

Dr. Stan A. Johnson
Chemical Technology Division
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

John Kadlec
Atmospheric Sciences Research
Center
SUNYA ES-324
1400 Washington Avenue
Albany, NY 12222

Mr. Bill Keene
Dept. of Environmental Sciences
University of Virginia
Charlottesville, VA 22903

Dr. John Klink
Department of Geography
Miami University
Oxford, OH 45056

Gene Likens
Ecology & Systematics
Biological Sci. Bldg. Rm E-304
Cornell University
Ithaca, NY 14853

Steve Lindberg
Environmental Sciences Division
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, TN 37830

No. of
Copies

Dr. Maris Lusia
Ministry of the Environment
Air Resources Branch
880 Bay Street
Toronto, Ontario
Canada M5S 1Z8

Dr. Paul Michael
Energy & Environ. Bldg. 051
Brookhaven National Laboratory
Upton, NY 11973

Dr. John Miller
NOAA Air Resources Lab (RD/R32)
6010 Executive Blvd.
Rockville, MD 20852

Donald H. Pack
1826 Opalocka Drive
McLean, VA 22101

20 Mr. Gilbert S. Raynor
Atmospheric Sciences Division
Brookhaven National Laboratory
Upton, NY 11973

LeRoy Schroder
U.S.G.S. MS-407
P.O. Box 25046
Denver, CO 80225

Joseph Scudlark
University of Delaware
Dept. of Marine Sciences
Lewes, DE 19958

10 Dr. Jack D. Shannon
Environmental Research Div.
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

Dr. Jimmie Sheih
Environmental Research Div.
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

No. of
Copies

Dr. Roger L. Tanner
Environmental Chemistry Div.
Brookhaven National Laboratory
Upton, NY 11973

FOREIGN

Lennart Granat
Department of Meteorology
University of Stockholm
S-106 Stockholm
SWEDEN

Peringe Grennfelt
Pollution Research Institute
P.O. Box 5207
S-40224 Gothenberg
SWEDEN

Dr. Sjaak Slanina
ECN
1755 2G Petten
THE NETHERLANDS

ONSITE

DOE Richland Operations Office

H.E. Ransom

33 Pacific Northwest Laboratory

K.M. Busness
E.G. Chapman
M.T. Dana (10)
R.C. Easter (10)
J.M. Hales
N.S. Laulainen
W.G.N. Slinn
J.M. Thorp
Technical Information (5)
Publishing Coordination (2)