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Winter Study of Power Plant Effects

A. A. N. Patrinos

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WINTER STUDY OF POWER PLANT EFFECTS

A. A. N. Patrinos

Date Published: October 1980

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Prepared by the
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Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
DEPARTMENT OF ENERGY

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SUMMARY

This report describes the activities of the Winter Study of Power Plant Effects (WISPE). This December 1979 study was undertaken on behalf of the Meteorological Effects of Thermal Energy Releases (METER) program by Battelle Pacific Northwest Laboratories (PNL), Pennsylvania State University (PSU), and Oak Ridge National Laboratory (ORNL). The study encompassed several joint field endeavors at the Bowen Electric Generating Plant (Plant Bowen) in northwestern Georgia. Plant Bowen is a 3200 MWe coal-fired power plant utilizing four natural draft cooling towers and two smokestacks and is the site of an on-going METER study of potential plant-induced precipitation modification.

The primary objectives of WISPE were the determination of the effects of the smokestack effluents on aerosol characteristics and precipitation chemistry as well as an experimental investigation of the cooling towers' temperature and humidity (T/h) plumes. Secondary objectives included a plume observational program and airborne measurements of drift drop concentrations. The studies involved an instrumented aircraft, pilot balloons, a tethered balloon system, ground-based and tower-based meteorological instruments and a dense network of automatic (HASL-type) and manual wetfall collectors. The data acquired by these instruments were supplemented, where necessary, by data from the METER-ORNL raingage network and the National Weather Service (NWS).

The general meteorology during WISPE is described in considerable detail particularly for the period embracing the single significant precipitation event of December 13, 1979. Associated with a cold front this event lasted approximately eight hours and produced a fairly uniform rainfall distribution. The rainfall samples collected by the wetfall chemistry networks were analyzed for pH, sulfates, nitrates, ammonium, and trace metals. Based on the plume observations during the storm and the windset readings, appropriate control and target areas of the networks were identified. The preliminary analysis of the data suggests some evidence of plume washout of sulfates in the target area.

The tethered balloon system was operated for 6 d during the WISPE experiments in an effort to discern the temperature and humidity effects of the cooling tower elevated plumes with rather inconclusive results. It was felt that the simultaneous sampling of background or ambient conditions (with another tethered system) was necessary.

The airborne experimental program involved ten flights for plume chemistry measurements and three for drift drop measurements. The plume chemistry work involved aerosol collection for sizing as well as the study of SO_2 to sulfate conversion. The results of one flight (December 10, 1979) indicated that the SO_2 /sulfate conversion occurred mostly on existing particles.

The plume observation program was undertaken primarily to ascertain the suitability of the available windsets in determining plume direction. Results indicated that the windset on Hodge Mountain (4.5 km from the plant) approximated plume direction quite well with a few limitations due to an apparent topographical effect.

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PREFACE

This report deals with a joint field study undertaken on behalf of the Meteorological Effects of Thermal Energy Releases (METER) program by Battelle Pacific Northwest Laboratories (PNL), Pennsylvania State University (PSU), and Oak Ridge National Laboratory (ORNL). It represents an integration of several contributions submitted by the various participants of WISPE. The author has attempted to provide a free-flowing narrative and to highlight, where possible, the joint nature of this endeavor.

The following individuals participated in WISPE:

From Battelle Pacific Northwest Laboratories: P. W. Nickola, N. S. Laulainen, J. M. Thorp, D. W. Glover, O. B. Abbey, M. T. Dana, and R. I. Schreck.

From Pennsylvania State University: R. G. de Pena, J. A. Pena, E. A. Liebsch, C. R. Chelius, and R. Thompson.

From Oak Ridge National Laboratory: N. C. J. Chen, L. Jung, R. L. Miller, R. E. Saylor, and A. A. N. Patrinos.

The following individuals contributed material for this report:

P. W. Nickola from PNL provided the local and regional meteorological data for the entire WISPE period as well as a considerable part of the description of the state of the atmosphere during the period December 11 to 15, 1979, which embraced the only significant precipitation event of December 13, 1979. He also presented the results of the temperature and humidity plume studies undertaken by PNL with the Tethersonde System.

R. G. de Pena and E. J. Liebsch contributed the report on the influence of the smokestack effluents on downwind aerosol characteristics.

J. A. Pena presented the results of the study of drift drop concentration in the cooling tower plumes measured at different distances from the source.

N. C. J. Chen and R. E. Saylor supplied the details of the wetfall chemistry investigations undertaken by ORNL.

R. L. Miller contributed the meteorological details of the storm of December 13 and the discussion and conclusions from a series of plume observations performed during WISPE.

Anyone fortunate enough to have been involved in field studies can fully appreciate the author's frustration in attempting to articulate the laborious task of planning and preparation involved in every field endeavor and to extend the appropriate credit to all the individuals who contributed to its success. It suffices to emphasize that WISPE apart from its scientific contributions highlighted the importance of teamwork in the tackling of the serious environmental problems which face us today.

The METER program is grateful to the Georgia Power Company and to the management of Plant Bowen for its continued support of the program, particularly during the WISPE study.

The advice and assistance of S. E. Lindberg, R. R. Turner, and P. D. Lowry of ORNL's Environmental Sciences Division are greatly appreciated.

To W. F. Savage (Advanced Nuclear Systems and Projects Division) and H. Moses (Office of Health and Environmental Research) of DOE the author extends the appreciation of the entire WISPE crew for their support and commitment to the METER objectives. This was symbolized by the presence of Harry during the high point of the WISPE effort: the important precipitation event of December 13. Maybe he should get the credit of bringing the rain we all needed so badly...

WINTER STUDY OF POWER PLANT EFFECTS

A. A. N. Patrinos

ABSTRACT

As a part of DOE's Meteorological Effects of Thermal Energy Releases (METER) program a field study was undertaken at the Bowen Electric Generating Plant (Plant Bowen) in December 1979. The study was a joint endeavor of Battelle Pacific Northwest Laboratories (PNL), Pennsylvania State University (PSU), and Oak Ridge National Laboratory (ORNL) with the main objective of determining the effects of the plant's smokestack effluents on aerosol characteristics and precipitation chemistry. Other objectives included studies of cooling tower temperature and humidity (T/h) plumes and drift drop concentrations. Conducted over a period of three weeks, the study involved an instrumented aircraft, pilot balloons, a tethered balloon system, a dense network of wetfall chemistry collectors and numerous ground- and tower-based meteorological instruments.

Rainfall samples collected during the precipitation event of December 13, 1979, revealed some evidence of plume washout. The tethered balloon flights rarely detected the faint presence of the T/h plumes while the airborne measurements program concentrated on the study of SO₂ to sulfate conversion. A series of plume observations confirmed the suitability of the plant's windset for plume direction determinations.

1. INTRODUCTION

This report contains the highlights of the Winter Study of Power-Plant Effects (WISPE), a joint field endeavor undertaken by Battelle Pacific Northwest Laboratories (PNL), Pennsylvania State University (PSU), and Oak Ridge National Laboratory (ORNL) on behalf of the Meteorological Effects of Thermal Energy Releases (METER) Program.¹ This Department of Energy (DOE) program is studying the inadvertent weather modification caused by heat and moisture releases from the cooling towers and cooling ponds of large power-generating facilities.

Although activities within the METER Program have spanned the range of available scientific tools (mathematical modeling, physical modeling, statistical assessments), emphasis has been placed on acquiring good quality and appropriate field data for validating the current models treating atmospheric effects of waste heat. Indicative of this emphasis are the drift deposition experiments by PNL at the Pittsburgh plant,² the airborne measurements program by PSU at the Keystone plant,³ and ORNL's rainfall modification study near the Bowen Electric Generating Plant.⁴ These studies have produced substantial and relevant data bases and are contributing to the increasing understanding of the potential deleterious atmospheric effects of power production.

The independence of the METER participants' efforts during the first few years of the METER Program was desirable in view of the suspected broad spectrum of possible atmospheric effects and the need for a multifaceted approach to delineating the important effects. A consequence of this independence was the wide range of results as evidenced in the published annual progress reports of the METER Program.¹ Recently, however, an attempt has been made to focus the METER efforts on selected issues and to involve as many of the METER participants as possible in joint field endeavors to address these issues. The decision to focus these efforts was based on two important realities: the shrinking METER budget and the METER participants' increased interest in the problems of wetfall

chemistry. The reality of a shrinking budget is an unavoidable product of our inflationary times; the METER staff's considerable attention to problems of wetfall chemistry is a result of increased public concern with the problem, known also as "acid rain." Exploratory studies⁵ were launched under the auspices of the METER program to identify elements of wetfall chemistry research that were within the scope of the METER Program. Most wetfall chemistry investigations, such as the MAP3S Program,⁶ have been regional in nature, whereas the problem of close-in plume washout (within 25 to 30 km from the source) has been, with a few exceptions, largely ignored. The "close-in" problem was, in fact, deemed quite important—not just because of its potentially serious impact on nearby vegetation and water quality but also because of the excellent opportunity to investigate the physics of the scavenging mechanism, which is the main difficulty in predicting and analyzing wetfall deposition. Examining wetfall deposition on the local scale has an advantage because the plumes are easily tracked and sampled and the results can be correlated with ground-level measurements. Obviously the study of close-in wetfall deposition requires a multifaceted experimental program with extensive airborne and ground-level meteorological measurements. The convergence of the METER groups in a joint field study presented the necessary conditions for this effort, and WISPE was born.

The Bowen Electric Generating Plant was chosen as the test site for WISPE. The choice was ideal since Plant Bowen is a large, coal-fired, 3160-MWe power plant utilizing four natural-draft cooling towers and two smokestacks. Furthermore, it is the site of ongoing rainfall modification studies and thus is instrumented with a dense recording rain gauge and windset network. Table 1.1 presents further detailed information about Plant Bowen.

Table 1.1. The Bowen Electric Generating Plant

Location: Lat. 34°07'32" N., Long. 84°55'16" W

Unit	Nameplate rating (MWe)	Commercial operation date	Cooling tower height (m)	Smokestack height (m)
1	700	10-21-71	119	305
2	700	9-26-72	119	shared with unit 1
3	880	12-11-74	119	305
4	880	11-14-75	119	shared with unit 1

Coal analysis (units 1 and 2) during December 1979

As burned	Percentage weight
Moisture	8
Ash	12
Sulfur	1.6
Btu/lb	1200

Constitution of fly ash during December 1979

Oxide	Percentage weight
SiO ₂	49.14
Al ₂ O ₃	26.93
Fe ₂ O ₃	14.58
MgO	1.14
SO ₃	0.74

The month of December was chosen for WISPE because of the need for large-scale frontal precipitation events for wetfall chemistry sampling. A detailed study of the area's climatology suggested that this choice was appropriate. Appendix A contains the program plan for WISPE, which was released as part of the METER monthly report for September 1979.⁷ The program plan outlined two primary and two secondary objectives. The primary objectives were (1) the study of plume washout in the vicinity of the plant and (2) an investigation of the extent and magnitude of the cooling tower temperature and humidity plume. Secondary objectives were to study (1) drift-drop concentrations as a function of height and (2) plume condensate scavenging by rainfall.

With regard to the primary objective, to study plume washout, the joint feature of the various endeavors clearly was an integral part to its success; the other objectives, one can argue, could have been obtained independently by the individual METER partners. The complexity of the plume washout mechanism and the multitude of accompanying meteorological measurements necessitated extensive and varied approaches to the problem. All airborne measurements were made by PSU using their instrumented Aerocommander 60E aircraft, while PNL undertook the task of providing surface air chemistry data as well as supporting meteorological measurements. ORNL was assigned the rainwater sample collection task. The ideally visualized scenario for the plume washout study hypothesized a reasonable number of well defined precipitation events with spatially uniform rainfall volumes. Although airborne chemistry measurements during precipitation events, were ruled out, PSU was expected to provide these measurements at times relatively close to the onset and cessation of rainfall, thus providing reasonably accurate descriptions of the chemical state of the smokestack plumes during the precipitation events. Similar demands were placed on the PNL task force insofar as surface air chemistry data and pilot balloon data were concerned. Acquisition of the remaining meteorological data was expected to continue uninterrupted during the precipitation event. The activities of ORNL which were geared intensively for the precipitation event period, involved making sure the automatic wetfall collectors operated satisfactorily as well as installing the manually operated samplers a short time prior to the onset of rainfall and retrieving them just after the cessation of rainfall. This task was ideal for ORNL because it required a thorough knowledge of the area and experience in accurate timing of the various sampling stages; ORNL has undertaken similar missions around Bowen in the past⁵ and has been operating the METER-ORNL raingage network since February 1978. On-the-field analysis of the rainwater samples was planned to avoid deterioration of the samples during transportation to Oak Ridge.

The particular nature of the wetfall chemistry experiments was instrumental in making their description the central theme of this report. The results of the other facets of the WISPE effort are included as separate chapters and presumably will be further analyzed and published by the individual contributors. The results of the plume condensate scavenging experiment are not included in this report while the surface air chemistry measurements proved somewhat unreliable and will not be presented. The time lapse photography undertaken by PNL has been arranged into a movie which provides a descriptive overview of the weather around Plant Bowen during WISPE.

Rain is obviously a basic requirement for the wetfall chemistry experiments, and several precipitation events were expected to occur during the first three weeks of December, the official WISPE time. However, only one significant precipitation event occurred during that time: the event of December 13, 1979. Consequently, most of the results presented in this report are centered on the December 13 storm.

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2. METEOROLOGY AND WETFALL CHEMISTRY

The state of the atmosphere during the two-week period of the December 1979 Winter Study of Power Plant Effects (WISPE) can be described in a meteorological sense through two types of measurements: (1) those made by participating research groups in the vicinity of Plant Bowen and (2) routine meteorological observations reported by U.S. National Weather Service (NWS) stations, which present the weather picture on a larger regional scale.

2.1 Local Meteorological Measurements

Local meteorological measurements are presented in Tables B.1, B.2, and B.3 of Appendix B. The types and periods of these measurements are indicated in Fig. 2.1. These measurements are emphasized in a later section of this report that specifies the state of the atmosphere near Plant Bowen during portions of WISPE.

Single theodolite pilot balloon observations were made at Oak Ridge National Laboratory (ORNL) Site 24 (Fig. 2.2) December 5 through December 16, 1979. Weather permitting, winds were derived for elevations up to 1800 m (5800 ft) above grade. Usually, the last pilot balloon release of the

		DECEMBER 1979 DATE											
TABLE NO.		5	6	7	8	9	10	11	12	13	14	15	16
	PNL SITE 24												
B-1	PILOT BALLOON OBSERVATIONS	---	..	---	---	---	---	---	---	..	---	---	---
B-2	WIND SPEED / DIRECTION			---	---	---	---	---	---	---	---	---	---
B-2	TEMPERATURE			---	---	---	---	---	---	---	---	---	---
B-3	ORNL WIND STATIONS												
	BOWEN NO. 1												
	BOWEN NO. 2												
	SITE 17												
	SITE 24 (SPEED ONLY)												
B-3	HODGE MOUNTAIN												
	TEMPERATURE												
	TEMPERATURE DIFFERENCE												
	DEW POINT												
	TOTAL RADIATION												
	WIND SPEED / DIRECTION												
B-4	NWS 3-HOURLY OBSERVATIONS												
	BIRMINGHAM												
	HUNTSVILLE												
	CHATTANOOGA												
	ATHENS												
	ATLANTA												
	ROME												

Fig. 2.1 Meteorological data tabled in Appendix B.

Fig. 2.2 Regional and local meteorological observational sites.

day was made at a motel location about 11 km (7 miles) northeast of Plant Bowen. Winds measurements from pilot balloon observations are listed in Table B.1 of Appendix B.

Wind speed and direction were monitored at Site 24 by Pacific Northwest Laboratory (PNL) by means of a Gill three-component anemometer mounted atop a 10-m tower. Only the mean horizontal vectors are presented in Table B.2 of Appendix B. Temperature at the 10-m level was monitored by a thermistor at Site 24 and is also presented in Table B.2. Wind data were derived from magnetic tape records, and temperature data were reduced from strip charts.

The period of operation of the PNL wind and temperature sensors at Site 24 was restricted to the period of operation of an electrical generator—usually 5 to 6 hours during the day. However, measurements continued for a period of 12 hours on December 13, 1979, in order to embrace the period of precipitation. The times specified in Table B.2 are the beginning of the 10-min increments over which winds and temperatures are averaged.

The meteorological data given in Table B.3 of Appendix B came from several sources. The ORNL cup anemometer and vane data listed at the right of this table resulted from records on strip charts of relatively low resolution (about 6 cm of chart width for both direction and speed). From the chart, directions were estimated to the nearest ten degrees and speeds to the nearest mile per hour. Wind records were averaged by eye for hourly periods. The exception to the hourly averaging is for a portion of the data for December 13, 1979, when 10-min averages were derived.

Four ORNL wind stations were operated—one at Site 17, one at Site 24, and two within the confines of Plant Bowen. All were not in continuous operation.

Stations labeled Bowen 1 and Bowen 2 in Fig. 2.1 were operated at the same site. A comparison of simultaneous strip chart data shows generally good agreement and hence bolsters confidence in these relatively simple instruments. Derived directions occasionally differ by as much as 30° but are generally in better agreement. Derived speeds are within 1 mph of each other more than 85% of the time.

Data at the left of Table B.3 of Appendix B were taken from instruments owned and maintained by Georgia Power Company at a location atop Hodge Mountain. The meteorological sensors (with the exception of a pyranometer mounted at the surface) are mounted on a 35-m (115-ft) tower. Heights of the sensors on that tower are listed at the bottom of the first page of Table B.3. The winds at the Hodge Mountain site were measured at the top of the tower and hence can be expected to be generally greater than winds measured at lower elevations.

The base of the tower is at an elevation of about 330 m (1090 ft)—the same elevation mean sea level (MSL) as the tops of the 119 m (390 ft) Bowen Plant cooling towers.

Data for the Hodge Mountain station were reduced from strip charts of 11.5 cm (4.5 in.) width and thus offered a better prospect of data resolution than did the narrow ORNL wind station charts.

Times listed under START TIME in Table B.3 specify the beginning of the time increment for which the corresponding meteorological data apply. The period for which the recorded data apply ends at the next time for which more data are given in a specific column. For example, the data recorded for December 8, 1979, 0900 eastern standard time (EST) apply to the period 0900 to 0910 EST for the Hodge Mountain parameters, and to the period 0900 and 1000 EST for the ORNL wind station data.

In most cases, Hodge Mountain data are presented as hourly averages. However, for some periods, 10-min averaging increments are used. Although difficulties have arisen in reducing and interpreting PNL tethered data, the periods for which Hodge Mountain data are given in 10-min increments embrace tethered operation periods. Hodge Mountain meteorology is also specified by 10-min increments for most of December 13, 1979, the day of rain during WISPE.

2.2 Regional Meteorological Observations

Weather observations taken at three-hour intervals at six southeastern U.S. National Weather Service (NWS) stations were obtained from the National Climatic Center. The stations are Athens, Atlanta, and Rome, Georgia; Huntsville and Birmingham, Alabama; and Chattanooga, Tennessee. Their locations are shown in Fig. 2.2.

Table B.4 of Appendix B reproduces tables of the meteorological observations made at these stations at three-hour intervals for the first 18 days of December 1979. These data, supplemented by local meteorological measurements and by NWS surface and upper air charts, have been used to generate a regional image of atmospheric conditions during WISPE.

Figure 2.3(a to e) depicts average daily wind speed, wind direction, and dry bulb and dew point temperatures for a region of the southeastern United States centered on Plant Bowen. The winds depicted are vector averages of the three-hourly winds given in Table B.4 of Appendix B. The temperatures are means of the tabled values. Thus, the maps are not a snapshot at an instant (as are most weather maps), but a daily average. Dry bulb temperature isopleths are presented as solid lines; dew points are dashed. In keeping with current reporting procedures of the NWS, temperature units are degrees Fahrenheit; wind speed is in miles per hour.

The NWS data on Fig. 2.3(a through e) have been supplemented with data from Hodge Mountain station. The wind speeds for Hodge Mountain are given in parentheses as a reminder that they will generally be high because of their 35-m measurement elevation.

Figure 2.3(a) shows that on Friday, December 7, 1979, flow in the mapped area was generally from southwest in advance of a weak, dry, cold front which passed Plant Bowen in the late evening. passage of the frontal trough, the mean flow on December 8, 1979, was from the north (N), dropped slightly as the drier continental air replaced the flow from the Gulf of Mexico.

The surface weather picture on Sunday, December 9, 1979, was dominated by an elliptical high area with its major axis extending from Arkansas to Pennsylvania early in the day, then rotating to an east-west line from northern Mississippi to North Carolina by 2200 EST. Resulting surface level winds in the southeastern United States were light from the east-northeast (ENE), and the continental source air continued to lower dew points. Temperatures in the relatively stagnant air stabilized.

Pilot balloon observations during daylight hours near Plant Bowen showed a strong clockwise shear with elevation. The layer from surface to about 600 m had wind flow from the east (E) through south (S). From 600 to 800 m the wind veered through west (W) to become almost northerly above 800 m.

By Monday, December 10, 1979, the surface high had moved slightly eastward and a light flow was observed. Dew points and temperatures began an upward trend.

Winds continued from the south (S) and increased on December 11 in response to a deepening low center moving east from Montana to Wisconsin. As this flow continued through December 12, moist and very warm air from the Gulf of Mexico covered the region to a height of ~900 mb. The aforementioned low by this time had moved into Quebec and was filling, but a long cold front extended from its center southwestward to Texas. Increasing high and middle clouds from this advancing front covered northwest Georgia by evening of December 12, and precipitation was reported in central Tennessee.

On Thursday, December 13, 1979, the NE-SW—oriented cold front passed slowly through Georgia. Although NWS analysis suggested frontal passage at ~1400 EST, local winds near Bowen from southerly to westerly or northwesterly about four hours earlier.

Fig. 2.3(a). Resultant winds, temperatures, and dew points for 7 and 8 Dec. 79. Winds in miles per hour. Temperatures in degrees Fahrenheit.

Fig. 2.3(b). Resultant winds, temperatures, and dew points for 9 and 10 Dec. 79. Winds in miles per hour. Temperatures in degrees Fahrenheit.

Fig. 2.3(c). Resultant winds, temperatures, and dew points for 11 and 12 Dec. 79. Winds in miles per hour. Temperatures in degrees fahrenheit.

Fig. 2.3(d). Resultant winds, temperatures, and dew points for 13 and 14 Dec. 79. Winds in miles per hour. Temperatures in degrees fahrenheit.

Fig. 2.3(e). Resultant winds, temperatures, and dew points for 15 and 16 Dec. 79. Winds in miles per hour. Temperatures in degrees fahrenheit.

Maximum temperatures, which had reached the mid-seventies in the Bowen area on December 12, were about 6°C (10°F) cooler on December 13. After the frontal passage in midmorning, the temperatures began dropping and were down to 2.5°C (49°F) by midnight. The daily resultant winds for December 13 show Atlanta and Athens still under the influence of the prefrontal SW winds while the rest of the mapped area had postfrontal NW resultant winds. Cool and dry continental air continued to into the area on December 14, 1979, from an elongated NE-SW—oriented high pressure area centered Missouri in the early morning hours and in Ohio by late evening.

On December 15, 1979, resultant surface-level winds in the mapped area reflected the anticyclonic circulation from the SW portion of the slowly passing ridge. Trajectories into northern Georgia indicated little if any possibility of marine modification of this cold air. Hence, temperatures and dew points remained low in the near-surface layers of the atmosphere.

Resultant vector winds for December 16, 1979, were very light. They resulted from SE winds in the early part of the day and NW winds following passage of a cold front in the afternoon. The only station in the area reporting measurable rain was Huntsville with 0.03 inches ending at 0600 EST. Average temperatures near Plant Bowen changed little from the day before, although temperatures to the NW were colder and to the SE were warmer than on December 15, 1979. Dew points in the area averaged several degrees higher than the previous day—likely reflecting the impact of air from the Atlantic (during the earlier part of the day) at low levels and from the Gulf at elevations above a few hundred meters.

2.3 Profile of a Storm

The major interest during the 1979 WISPE field program centered on the precipitation accompanying the storm of December 13, 1979. Although the general weather picture in the southeastern United States during that period was previously discussed, further meteorological details centering in time on December 13, 1979, are pertinent to a better understanding of the storm and its interaction with Plant Bowen effluents.

2.3.1 Conditions before the storm

The weather in northwestern Georgia on December 11 and 12, 1979, was under the influence of an easterward-moving low pressure center. The resultant surface winds [Fig. 2.3(c)] for the entire region were from the south. Winds determined by pilot balloons for December 11 and 12 were also southerly. Table B.1, Appendix B, pibal data show that all winds to the maximum measured elevation of 1800 m were in the range of 160° to 215° on December 11 and 12.

Maximum temperatures and dew points for the month were reached during this period of southerly flow. The monthly temperature (23°C) and dew point (14°C) maxima were reached at Hodge Mountain on the afternoon of December 12, 1979. Dew points remained within 4°C of that high until the precipitation of December 13, 1979 ended. The progression of temperatures and dew points is graphically portrayed by the daily mean values shown in Fig. 2.4.

The NWS climatological summaries of Table B.4 in Appendix B reveal the cloudless sky of December 10, 1979, replaced by partly cloudy skies on December 11, with overcast conditions on December 12 for Birmingham, Huntsville, and Chattanooga, Atlanta and Athens, farther from the approaching front, did not become overcast until the evening of December 12.

Fig. 2.4. Progression of daily mean temperature and dew point for selected southeastern stations.

The Hodge Mountain pyranometer indicated a total radiation of 398 langleys on the cloudless December 10, 1979. If this incoming radiation is considered the standard, on December 11 and 12, 77 and 65% of possible radiation was recorded respectively, and on overcast and rainy December 13 only 13%.

2.3.2 The storm

Figure 2.4 shows that the difference between mean daily dry and dew point temperatures was at a minimum on December 13, 1979. Mean temperatures dropped at all represented stations except Athens, where the cold front did not pass until midafternoon.

At the surface level, the southerly prefrontal flow of December 12, 1979, continued into the morning hours of December 13. The regional and local scale maps for 0100 and 0400 EST show winds

with southerly components at all stations. [Figure 2.5(a to r) maps winds, temperatures and dew points in chronological sequence for December 13, 1979.] By 0700 EST, the wind at Huntsville was from the west and the temperature had begun to decline with passage of the cold front. Winds still had a southerly component at all other stations.

The local winds at 0800 and 0900 EST continued from the south and temperatures rose slightly. Pibal data from Site 24 at 0825 EST showed winds veering from near south at the surface at 245° as the balloon penetrated the ceiling at 1700 m.

The first sprinkling of light rain at Plant Bowen was observed falling from the solid deck of stratus clouds at 0925 EST. At this time, the smokestack and cooling tower plumes were traveling from SSW to NNE. The plumes from the twin smokestacks were relatively narrow horizontally, merging approximately 1 km downwind. The visible plumes from the two cooling towers in operation were estimated to be about 250 m long and to rise about 100 m above the tower mouth.

The charts from the Hodge Mountain meteorological tower and the surface windsets within the network indicate that a wind shift marking the passage of the cold front occurred in the Plant Bowen area between 0930 and 0950 EST. Pibal data at 1002 EST showed a clockwise shift from the previous pibal observations at all elevations. The balloon entered the cloud base at an elevation of $\dagger 1000$ m. By 1010 EST, the direction of the smokestack and cooling tower plumes had also shifted: the smokestack plumes were moving from SW to NE, while the cooling tower plumes initially tracked from west to east and backed with height to assume a SW-NE orientation.

On the regional scale at 1000 EST, winds at Huntsville were stronger from the NW and temperatures had dropped 6°C in three hours. Winds at Rome also included a northerly component, yet winds at Chattanooga were southerly, so that doubt was cast on the position of the front with respect to that city.

Local surface winds were light and from the west through north for the 1000 to 1200 EST period. The smokestack and cooling tower plumes were primarily traveling from west to east during this period. The length of the visible cooling tower plumes was increasing dramatically with time. Moderate rain began about 1040 EST. Temperatures stayed warm, and, with the rain, the dew point actually increased near the surface.

The 1300 EST regional winds indicated the front had definitely passed Birmingham and Chattanooga. Although the 1300 EST observation at Rome showed a southwesterly wind, the local Bowen winds at 1300, as well as at 1400 and 1500 EST, were from the NW, confirming frontal passage. The local pibal indicated a ceiling of $\dagger 200$ m at 1307 EST. Precipitation had decreased to a light rain by 1300 EST.

At 1400 EST, the smokestack and cooling tower plumes were observed to move toward the east for $\dagger 300$ m and then to shift slightly to the ESE. The visible cooling tower plumes stretched downwind as far as the eye could see with a rise of only about 100 m above the tower mouth. Observers noted that the sky was very dark, with obviously heavier precipitation directly beneath the plumes. Thus, rainfall enhancement by the cooling tower plumes was detected by visual observation, later confirmed by examination of the rain gauge charts. The second surge of moderate rain within the network began about 1430 EST.

By 1600 EST, the regional map showed that Atlanta and Athens winds were from 290° and 280° respectively, with the front likely in that area. Thus, by 1600 EST all observed local and regional winds included a northerly component. The northerly postfrontal winds continued at all local and regional stations throughout the rest of the day (with the exception of a calm wind reported at Athens at 1900 EST).

13 Dec 79
0100 EST

T S
D

S - wind speed in mph
T - temperature in °F
D - dew point in °F

Fig. 2.5(a). Observed winds, temperatures, and dew points at and near Bowen Plant. Winds in miles per hour. Temperatures in fahrenheit degrees.

13 Dec 79
0400 EST

Fig. 2.5(b). Observed winds, temperatures, and dew points at and near Bowen Plant. Winds in miles per hour. Temperatures in fahrenheit degrees

13 Dec. 79
0700 EST

Fig. 2.5(c). Observed winds, temperatures, and dew points at and near Bowen Plant. Winds in miles per hour. Temperatures in fahrenheit degrees.

13 Dec 79
0800 EST

Fig. 2.5(d). Observed winds, temperatures, and dew points at and near Bowen Plant. Winds in miles per hour. Temperature in fahrenheit degrees.

13 Dec 79
0900 EST

Fig. 2.5(e). Observed winds, temperatures, and dew points at and near Bowen Plant. Winds in miles per hour. Temperatures in fahrenheit degrees.

13 Dec 79
1000 EST

Fig. 2.5(f). Observed winds, temperatures, and dew points at and near Bowen Plant. Winds in miles per hour. Temperatures in fahrenheit degrees.

13 Dec 79
1100 EST

Fig. 2.5(g). Observed winds, temperatures, and dew points at and near Bowen Plant. Winds in miles per hour. Temperatures in fahrenheit degrees.

13 Dec 79
1200 EST

Fig. 2.5(h). Observed winds, temperatures, and dew points at and near Bowen Plant. Winds in miles per hour. Temperatures in fahrenheit degrees.

13 Dec 79

1300 EST

Fig. 2.5(i). Observed winds, temperatures, and dew points at and near Bowen Plant. Winds in miles per hour. Temperatures in fahrenheit degrees.

13 Dec 79
1400 EST

Fig. 2.5(j). Observed winds, temperatures, and dew points at and near Bowen Plant. Winds in miles per hour. Temperatures in fahrenheit degrees.

13 Dec 79
1500 EST

Fig. 2.5(k). Observed winds, temperatures, and dew points at and near Bowen Plant. Winds in miles per hour. Temperatures in fahrenheit degrees.

13 Dec 79
1600 EST

Fig. 2.5(l). Observed winds, temperatures, and dew points at and near Bowen Plant. Winds in miles per hour. Temperatures in fahrenheit degrees.

13 Dec 79
1700 EST

Fig. 2.5(m). Observed winds, temperatures, and dew points at and near Bowen Plant. Winds in miles per hour. Temperatures in fahrenheit degrees.

13 Dec 79
1800 EST

Fig. 2.5(n). Observed winds, temperatures, and dew points at and near Bowen Plant. Winds in miles per hour. Temperatures in fahrenheit degrees.

13 Dec 79
1900 EST

Fig. 2.5(o). Observed winds, temperatures, and dew points at and near Bowen Plant. Winds in miles per hour. Temperatures in fahrenheit degrees.

13 Dec 79
2000 EST

Fig. 2.5(p). Observed winds, temperatures, and dew points at and near Bowen Plant. Winds in miles per hour. Temperatures in fahrenheit degrees.

13 Dec 79
2100 EST

Fig. 2.5(q). Observed winds, temperatures, and dew points at and near Bowen Plant. Winds in miles per hour. Temperatures in fahrenheit degrees.

13 Dec 79
2200 EST

Fig. 2.5(r). Observed winds, temperatures, and dew points at and near Bowen Plant. Winds in miles per hour. Temperatures in fahrenheit degrees.

Rainfall intensity decreased again to a steady, light rain at approximately 1630 EST; the sky remained overcast with stratus clouds. The plumes continued their gradual clockwise shift, traveling from NW to SE at this time. The length and rise of the cooling tower plumes were unchanged from the 1400 EST observation. The smokestack plumes, which were just barely visible above the cooling tower plumes, appeared to be interacting with the latter plumes. Additionally, observers noted that fly ash was being deposited on a vehicle parked approximately 3 km downwind of Plant Bowen.

The rainfall ended about 1800 EST; by this time, the plumes were tracking from NNW to SSE. Figure 2.6 shows the rainfall trace from a raingage near Plant Bowen. The two periods of moderate rainfall during the storm are clearly reflected by the corresponding steep increases in the value of the ordinate. The shape of the rainfall trace is remarkably similar at all raingages within the network; thus little spatial variability is indicated.

Figure 2.7 is a graph of total rainfall amounts (in mm) during the storm for the entire METER-ORNL raingage network. The average rainfall amount for the 49 operating raingages was 6.7 mm, with a standard deviation of 1.5 mm. The smallest amount (4.1 mm) was recorded in the NE corner of the network, whereas the largest amount (10.7 mm) was recorded along the southern border of the network. The general trend is an increase, from north to south, in the amount of rainfall recorded during the storm.

The mean rainfall rate during the storm is displayed in Fig. 2.8 for those raingages within the METER-ORNL wetfall chemistry network. The mean rainfall rate is calculated as the ratio of the total rainfall amount to the duration of the rainfall. The minimum value (0.56 mm/h) is located in the NW corner of the network, and the maximum value (1.32 mm/h) is located immediately east of Plant Bowen. The general trend is an increase in mean rainfall rate from NW to SE. Significantly, the higher values occurred primarily at raingage sites that were underneath the cooling tower plumes for an extended period during the storm.

The regional rainfall amounts exhibit a definite pattern of decreasing values from west to east, which corresponds to the dissipation of the storm as it tracked from west to east. The rainfall amounts are as follows: Birmingham, 19.1 mm; Huntsville, 12.7 mm; Rome, 8.6 mm; Chattanooga, 6.6 mm; Atlanta, 1.3 mm; and Athens, 0.3 mm. Interestingly enough, this pattern is not reflected at all on the smaller scale of the METER-ORNL network even though the network-averaged rainfall amount of 6.7 mm fits well with the surrounding regional amounts.

Temperatures and dew points at stations where the front passed earlier in the day showed significant drops by the end of December 13. Athens, where frontal passage occurred later in the day, did not show such dramatic changes. The change in temperature/dew point for Hodge Mountain was $-9/-7^{\circ}\text{C}$ for the period ending 0100 EST December 14, 1979. Similarly, changes for the other stations were as follows: Huntsville, $-14/-14$; Birmingham, $-12/-9$; Chattanooga, $-7/-12$; Atlanta, $-6/-3$; and Athens, $-4/+1$.

2.3.3 Conditions after the storm

Mean temperature and dew points for December 14, 1979 (Fig. 2.4), reflect the impact of the postfrontal cold, dry air. Dew points dropped even more dramatically than temperatures. The local surface winds at Plant Bowen remained northerly all day, although pilot balloon observations throughout the day showed a zone of easterly winds at 800 to 1200 m with another northerly flow above.

On December 15, 1979, temperatures and dew points stabilized at Bowen and to the north and west of the plant (Fig. 2.4). These cool and dry conditions near the surface continued despite winds from the

Fig. 2.6. Chart of a recording rain gage near Plant Bowen depicting the storm of December 13.

Fig. 2.7. Isopleths of total rainfall amounts (in mm) over the METER-ORNL network for the storm of December 13.

south and east near the surface—winds that generally would be associated with warm, moist air. However, trajectories suggest a southward movement of continental air through the Carolinas followed by westward movement into northern Georgia.

Pilot balloon wind readings at Bowen on December 15 were from the ESE at nearer surface levels and veered through south to southwest or west at 1800 m. Although some cloudiness was associated with this southerly flow, the total radiation received on December 15 at Hodge Mountain was 87% of that received on the cloudless December 10, 1979. Stations south of Plant Bowen showed overcast skies in the latter half of the day, while to the north, Chattanooga and Huntsville were clear to partly cloudy during those hours.

2.4 Plume Washout

2.4.1 The wetfall chemistry network

The wetfall chemistry network used during WISPE consisted of a primary network and a secondary network. The primary network included 19 sites equipped with Health and Safety Laboratory-type or automatic collectors,¹ while the secondary network included 24 sites with manually operated "simple" collectors. Both networks were designed with several considerations in mind. A study of the December climatology of northwestern Georgia (see Appendix A) revealed predominant easterly winds during storms; the position and shape of the network were arranged to accommodate a large possible target area to the west of Plant Bowen. Fifteen sites of the primary network were also stations of the METER-ORNL network. They are shown in Fig. 2.9 by the identification numbers of

Fig. 2.9. The primary and secondary wetfall chemistry networks used during WISPE.

the rain gage stations (15, 16, 17, 18, 19, 22, 23, 24, 25, 26, 29, 30, 31, 32, 33). The highly accurate measurements of rainfall volume and rainfall rate supplied by the existing recording raingages were felt to be a great advantage for analyzing wetfall deposition. Additional benefits were prior consent and approval of the individual landowners, excellent exposure, safety characteristics, and (for some stations) the availability of electrical power for the automatic collectors. Of the remaining four sites in the primary network, two had been used on a regular basis (the plant's meteorological station MET, atop Hodge Mountain, and the plant's substation, SUB, in Taylorsville); and the other two were secured during a trip in November 1979 (these are sites as S1 and S2 in Fig. 2.9). Eight of the automatic collectors (15, 18, 19, 24, 29, 30, 31, 33) were operated off 12-V batteries because electrical power was not available at the sites.

The collectors of the secondary network were simple contraptions (2-m-high poles with receptors at the top for the bottles). Many of the sites of the secondary network were used during previous field trips² that were undertaken to collect rainwater samples on an event basis. Most of them were secured, with appropriate permissions reobtained, during the scouting trip of November 1979. The basic reason for the secondary network was to increase the density of the sampling area while taking advantage of the available manpower during WISPE. Some of these collectors were installed along roads; most of them were placed on private property. The collectors of the secondary network are identified in Fig. 2.9 by the symbols R1 (for round cross-section bottle 1), R2, and on through R21. (The collectors R6 and R19 were never installed.) A few collectors were kept on reserve and were installed a short time before the sampled precipitation event of December 13. At that time, winds were from the SSW, and the reserve collectors were installed to the NNE of Plant Bowen to increase the sampling density in the expected target area. These collectors were installed by two groups; the first group installed T₁, T₂, and T₃, (as designated in Fig. 2.9) while the second group deployed X₁, X₂, and X₃ (as designated in Fig. 2.9).

For the automatic collectors operating off batteries, certain modifications were deemed necessary to maximize battery life. The heaters in the sensor heads were rewired to operate only when the collectors were open. This modification presented a potential problem because a heavy morning dew could have triggered the opening of the collectors. However, the collectors were expected to remain open a maximum of one-half hour, and the resultant dryfall contamination was expected to be minimal. Preliminary testing indicated that these collectors operated continuously (collectors open with the heaters in action) for a total of eight hours; therefore, arrangements were made for replacing and recharging the batteries every eight hours during a long precipitation event. The presence of the entire METER-ORNL crew (five persons) during WISPE facilitated the quality assurance of the data acquisition system. Fifteen of the utilized wetfall collectors were relatively new instruments constructed by ORNL according to a TVA design, specifically for the WISPE experiment. They proved to be quite temperamental in their operation and required frequent on-the-field maintenance and repairs.

The rainwater samples were collected with two kinds of polyethylene bottle and funnel combinations. For the primary network, the combination was a 1-liter bottle (square cross-section) with a 10.3-cm-diam funnel. Two such combinations were placed inside the bucket of the wetfall collector: the first was acid-washed and was intended for trace-metal deposition sampling, while the second was distilled water-washed and was intended for sampling pH, conductivity, and major chemical species (sulfates, nitrates, and ammonium ions). For the secondary network, the combination was a round (cross-section) 1-liter bottle with an 11.5-cm-diam funnel which was distilled water-washed only.

Preparation of the bottle-funnel combinations was performed according to the specifications of the Geochemistry Laboratory of ORNL's Environmental Sciences Division.³ For the acid-washed

combinations, the polyethylene bottles, lids, and funnels were thoroughly cleaned in this laboratory using dilute (2N) nitric acid and high-quality deionized water. After the acid cleaning, the bottles, lids, and funnels were rinsed and soaked repeatedly in fresh distilled, deionized water to eliminate all traces of residual acid and finally were dried in an oven. The same elaborate procedure was followed for the distilled water—washed combinations, excluding, of course, any contact with the acid. All bottle and funnel combinations were individually packed in plastic bags and transported to the field in sealed boxes.

2.4.2 Wetfall chemistry sampling

The first attempt at plume washout sampling was unsuccessful. It was made on December 6 and was based on a weather prediction of precipitation associated with an advancing cold front. The front weakened considerably at the time it moved through northwestern Georgia, and precipitation was negligible. Since the accuracy of the rain forecasts was doubtful only the automatic collectors (primary network) were activated and equipped with the two bottle-funnel combinations (acid-washed and distilled water washed). Because the buckets of the automatic collectors were large enough to accommodate four bottle-funnel combinations, the bottles and funnels installed on December 6 were left in the buckets as a means of testing the sealing ability of the collectors. This test was somewhat compromised since some rain did occur on December 6—not enough to register on the raingage charts but enough to trigger some of the collectors—and therefore the extent to which each collector was exposed to dryfall contamination could not be determined accurately. Another envisioned test was a comparison between the two types of automatic collectors (AC driven vs DC driven) since it was anticipated that, because of the necessary design modifications of the DC-driven units, these collectors were expected to be triggered by early morning fog and therefore to be exposed to longer periods of dryfall contamination. Unfortunately, because of manpower limitations, neither of these tests was undertaken. The current conviction is that such quality assurance is of paramount importance.

The first and only successful plume washout sampling event occurred in association with the December 13 storm, whose meteorological profile is given in great detail in the previous chapter. The plant generated ~1600 MWe during this storm. Both the primary and secondary networks were activated in the morning of December 13, starting at 7:00 a.m. Some light drizzle did occur at certain sites during the activation sequence, but the process was completed before the onset of the main precipitation event. The presence of considerable manpower during the precipitation event facilitated precise monitoring of the position of the cooling tower and smokestack plumes as well as periodic inspection of the operation of the instruments (wetfall collectors, windsets, raingages). Comparisons of recordings of the available windsets with visual observations revealed that the meteorological station wind data accurately described the behavior of the smokestack plumes. Consequently, these data were used in determining the wind directions during the storm. A low-pass filter, which was a seven-point weighting scheme performed on the windset readings at 10-min intervals, was used to smooth these data. Once the predominant plume direction was determined for each 10-min interval, the plume outline was assumed to spread by 10° on each side of this predominant direction, with the choice of 10° based on visual observations. As the plume's position gradually moved from an almost due north direction through a due east to an almost due south direction during the course of the rainfall event, the total plume residence time over the various stations of the eastern part of the network was computed as the sum of the 10-min intervals during which the plume outline covered the various stations. Table 2.1 presents these times for the various stations of the primary network. Clearly, the target area for this storm was to the east of Plant Bowen, while the stations to the west formed the control area.

Table 2.1. Plume residence time during the storm

Site	Plume residence time (h)	Event duration
18	0	1030-1730
MET	0.17	1030-1730
19	0.17	1000-1730
25		Inoperable
26	1.83	1000-1700
32	2.00	1030-1700
33	3.00	1030-1810

When the rainfall ceased in the early evening, bottle retrieval began and was completed at ~12:00 p.m. All samples were returned to a central location at the motel headquarters and promptly refrigerated. Original plans called for immediate analysis of the samples for pH and conductivity. Because the analysis instruments malfunctioned, however, the samples were returned to Oak Ridge the following day, and the planned analyses were conducted at the Geochemistry Laboratory at ORNL. Because of the limited sample amount (all bottles contained less than 25 ml), testing conductivity was sacrificed in favor of testing pH, sulfate, nitrate, and ammonium. Immediately upon return to the laboratory (<24 h), a combination reference-pH electrode was used to measure pH in samples that were equilibrated with atmospheric CO₂ at 24°C. Sulfate analyses were performed using a modified methylthymol blue colorimetric method⁴ with a Technicon Auto Analyzer II system. Nitrate was analyzed by the cadmium reduction method and ammonium by the indophenol method. Each of the three methods is accurate within ~±10%. The sulfate, nitrate, and ammonium analyses were performed <3 d after the sample collection. Samples collected in the acid-washed bottles of the primary network were subsequently analyzed for trace metal concentrations. Trace metals were analyzed on separate aliquots acidified upon collection to 0.1 N HNO₃ (Ultrex ultra pure) using graphite furnace atomic absorption spectrophotometry.³

2.4.3 Results

As mentioned in the previous section, the plume residence times during the rainfall event were calculated on the basis of wind recordings at the plant's meteorological station; the validity of this assumption was confirmed by visual observations during the precipitation event. Another assumption involved in calculating residence times was that during each 10-min interval the plume remained steady along the predominant wind direction during that interval. Clearly the southeastern part of the network was the predominant target area, for the plume remained over that area for ~3 h (the storm's duration was 7.5 h).

Three automatic collectors—25, S1, and S2—malfunctioned during the rainfall event; therefore, data from these stations were unavailable. Broken shear pins and electronic foul-ups were the primary reasons for these malfunctions. The round bottle collection fared somewhat better, with only one casualty—a sample contaminated by bird droppings at R11.

The results of all chemical analyses performed on the samples are contained in Tables 2.2 and 2.3. The contour plots of pH for the primary and secondary network are depicted in Figs. 2.10 and 2.11. A

Table 2.2. Analysis of data from the primary network

Site	pH	SO ₄	NO ₃	NH ₄	Al	Fe	Mn	Cu	Pb	Zn	Ni	Cr
		mg/l			ng/ml							
15	4.69	1.97	0.70	0.26	20.0	12.0	0.79	0.44	7.2	9.5	0.93	0.14
16	4.40	1.84	0.66	0.26	17.0	4.6	0.58	0.48	7.4	5.1	0.10	0.07
17	4.41	1.59	0.59		15.0	4.9	0.54	0.45	4.7	5.4	1.10	0.08
18	4.45	1.88	0.60	0.30	15.0	4.5	0.50	0.37	4.6	3.9	1.20	0.10
19	4.31	1.95	0.56	0.22	19.0	16.0	0.76	1.10	4.5	2.7	0.65	0.10
22	4.30	1.42	0.51	0.15	14.0	9.4	0.47	0.71	3.7	6.0	0.70	0.07
23	4.52	1.26	0.37	0.25	8.3	11.0	0.60	0.60	2.8	4.8	1.30	0.09
24	4.42	1.42	0.45	0.27	13.0	10.0	0.36	0.21	3.1	3.1	19.00	0.07
26	4.50	1.42	0.46	0.15	11.0	7.6	0.43	0.33	3.7	2.6	0.10	0.08
29	4.91	1.00	0.30	0.12	31.0	12.0	0.74	0.81	3.9	5.0	1.20	0.13
30	5.10	1.10	0.39	0.17	34.0	25.0	0.56	1.80	4.3	12.0	1.30	0.16
31	4.68	1.17	0.37	0.10	9.7	3.3	0.19	0.25	2.7	2.7	1.70	0.07
32	4.58	1.30	0.43	0.14	20.0	12.0	0.42	0.45	3.0	3.1	0.18	0.10
33	4.78	1.52	0.53	0.15	18.0	7.7	0.45	0.69	4.5	11.0	4.90	0.12
MET	4.51	1.51	0.53	0.22	12.0	8.0	0.51	0.67	5.1	8.3	0.05	0.15
SUB	4.55	1.17	0.41	0.14	11.0	3.9	0.42	0.90	3.2	3.3	1.20	0.14

Table 2.3. Analysis of data from the secondary network

Site	pH	SO ₄	NO ₃	NH ₄
		mg/l		
R1	4.29	1.84	0.61	0.19
R2	4.00	1.58	0.67	0.18
R3	4.22	1.67	0.52	0.21
R4	4.49	1.84	0.58	0.30
R5	4.20	2.11	0.72	0.19
R7	4.47	1.51	0.51	0.19
R8	4.15	1.93	0.56	0.21
R9	4.20	1.68	0.52	0.19
R10	4.19	1.48	0.50	0.17
R12	4.22	1.47	0.45	0.14
R13	4.62	1.26	0.43	0.17
R14	4.85	1.34	0.43	0.19
R15	4.48	1.24	0.40	0.17
R16	4.48	1.49	0.43	0.19
R17	4.31	1.51	0.51	0.16
R18	4.65	1.17	0.37	0.13
R20	4.30	1.32	0.43	0.16
R21	4.25	1.41	0.47	0.14
T1	4.53	1.57	0.49	0.20
T2	4.45	1.51	0.48	0.20
T3	4.42	1.59	0.52	0.19
X1	4.50	1.66	0.52	0.22
X2	4.24	1.68	0.55	0.20
X3	4.20	2.05	0.65	0.23

discrepancy appears between the values of pH for the two networks; that is, the patterns and values are not comparable. This discrepancy does not appear in the corresponding plots for the concentrations of sulfates (Figs. 2.12 and 2.13), nitrates (Figs. 2.14 and 2.15), and ammonium (Figs. 2.16 and 2.17), which are in fair agreement. This discrepancy has not, at this time, been explained.

The next set of plots (Figs. 2.18 through 2.23) presents the patterns of deposition rates of the various chemicals. The deposition rate is the product of the concentration and the rainfall rate (see Fig. 2.8). The deposition rates of hydrogen and ammonium ions display no discernable spatial pattern, whereas the deposition rates for sulfate and nitrate present a definite spatial pattern that possibly suggests a plume washout effect. Particularly for sulfates, the deposition rates present a positive gradient from the control to the target area, with the concentration considerably stronger in the target area. The maximum deposition rate occurs at site 33, the most important target station in terms of plume residence time.

The extent to which the plume could have contributed to the excess deposition of sulfate can be estimated using a simplified washout model.⁵ Excess deposition rate is defined as the difference in deposition rate between the target station and the mean deposition rate of the control area.

The model was applied to the data from target area station 33 because the in-plume sulfate aerosol data were collected at the same downwind distance from the stack day (12 km), although not the same day. Furthermore, the site exhibited the highest sulfate deposition rate and longest plume residence time and yet not the highest rainfall rate. Those features make it a likely candidate for the maximum possible plume influence. The parameters used in the calculation are presented in Table 2.4. For sulfate aerosol the computed washout was $0.4 \text{ nmole cm}^{-2} \text{ h}^{-1}$, a figure that accounts for $\sim 70\%$ of the observed excess deposition rate for site 33. This conclusion should be regarded as tentative. The data are currently being carefully analyzed, and any further conclusions will be presented in future publications.

Fig. 2.12. Sulfate concentrations (mg ft^{-3}) over the primary network for the storm of December 13

ORNL-DWG 80-4618 ETO

Fig. 2.13. Sulfate concentrations (mg l^{-1}) over the secondary network for the storm of December 13.

ORNL-DWG 80-4602 ETO

Fig. 2.14. Nitrate concentrations (mg l^{-1}) over the primary network for the storm of December 13.

ORNL-DWG 80-4614 ETD

Fig. 2.15. Nitrate concentrations (mg l^{-1}) over the secondary network for the storm of December 13.

ORNL-DWG 80-4603 ETD

Fig. 2.16. Ammonium concentrations (mg l^{-1}) over the primary network for the storm of December 13.

Fig. 2.17. Ammonium concentrations (mg l^{-1}) over the secondary network for the storm of December 13.

Fig. 2.18. Sulfate deposition rates ($\text{nmole cm}^{-2} \text{h}^{-1}$) over the primary network for the storm of December 13.

ORNL-DWG 80-4617 ETD

Fig. 2.19. Sulfate depositions rates (nmole cm⁻² h⁻¹) over the secondary network for the storm of December 13.

ORNL-DWG 80-4422A ETD

Fig. 2.20. Nitrate depositions rates (nmole cm⁻² h⁻¹) over the primary network for the storm of December 13.

ORNL-DWG 80-4615 ETO

Fig. 2.21. Nitrate deposition rates ($\text{nmole cm}^{-2} \text{h}^{-1}$) over the secondary network for the storm of December 13.

ORNL DWG 80 4418R ETO

Fig. 2.22. Ammonium deposition rates ($\text{nmole cm}^{-2} \text{h}^{-1}$) over the primary network for the storm of December 13.

Fig. 2.23. Ammonium deposition rates ($\text{nmole cm}^{-2} \text{h}^{-1}$) over the secondary network for the storm of December 13.

Table 2.4. Parameters of the simplified washout model

Mean raindrop radius, μm	500
Collection coefficient	0.1
Plume thickness, m	300
Rain intensity, mm h^{-1}	1
Sulfate aerosol mean radius, μm	1
Particulate number density, cm^{-3}	1

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3. TEMPERATURE AND HUMIDITY PLUMES

A tethered balloon system* was operated at locations near Plant Bowen for 6 d during the WISPE experiments in an effort to discern the effects on temperature and humidity of the cooling towers' elevated plumes. Up to 1000 m of tether line was unreeled during vertical profiling at Plant Bowen.

The sensor package suspended from the tethered balloon transmitted signals proportional to barometric pressure, wind speed, wind direction, dry bulb temperature, and wet bulb temperature to a ground FM receiver, which processed and sent the signals to a calculator/printer and to a cassette tape recorder. The modified HP-97 calculator associated with the system is normally programmed to convert the sensor data to engineering units, permitting onsite examination a few seconds after data are received, but failure of this processing option led to onsite printed digital output in relative rather than engineering units. Data for all six airborne measurements were transmitted and recorded once every 12 to 15 s.

Prior to the actual WISPE field experiments, the possibility of tethered balloon flights at more than one crosswind position in the plume and at more than one downwind location had been considered, but in the field these plans proved impossible to carry out with a single balloon. The actual flight time involved (when 1000 m of tether line was payed out and retracted) approached 1 h. Mean wind directions changed frequently during this time period. Furthermore, finding a road-accessible launching area that was free of trees and overhead utility lines and that was still within the estimated bounds of the cooling tower plumes proved difficult. Finally, movement from one location to another entailed loading the balloon, the tether winch, and a portable electric generator into a truck and then unloading at the new location. After only two flights, it was concluded that the best approach was to launch within 1 or 2 km of the cooling towers and in a direction as much as possible directly downwind. Of course, with up to 1 km of tether line out, the sensor package could be flying significantly farther from the towers than when only a few meters of line were out. In this compromise from the preexperimental plan, the reasoning was that if the temperature/humidity plume could be detected at all through tethered balloon flights, it would surely be detectable at these near-source distances.

Reduction of the WISPE tethered balloon data has been further hindered by difficulties in implementing a computer program using the onsite cassette records as input. The major problems were specifying an appropriate initial pressure to be used in computing height of the sensor package and editing out spurious signals (generally pressure signals) from the vertical profile data recorded on cassette.

Although the Tethersonde was flown on six different days during WISPE, and a total of 42 vertical profiles (21 ascents/descents) were obtained, only ten of these temperature/humidity profiles will be examined in this report. Since the remainder of the Tethersonde data is expected to be examined (and published if meaningful data can be extracted), the profiles reported here will be identified by their sequential number in the flight series. Much of the data to be presented was processed by hand from the printed digital tapes generated by the Tethersonde system HP-97 calculator.

The procedure that evolved during WISPE was to make one planned flight (2 profiles—one up, one down) each day as a background or ambient condition flight. The remaining flights were directed toward getting to the plume centerline as best estimated from the visible extent of the cooling tower and plant boiler stack plumes. The natural draft cooling towers are 119 m (389 ft) tall, and the two plant stacks are 305 m (1000 ft) tall. Buoyancy and/or effluent exit velocities made effective stack heights considerably higher.

*Tethersonde System manufactured by Atmospheric Instrumentation Research, Inc., Boulder, Colorado.

Tethersonde temperature and humidity data for two presumably in-plume flights and one background flight will be examined for 10 December 1979. One in-plume and one background flight will be examined for 11 December 1979. Table 3.1 gives information pertinent to these flights.

Table 3.1. Data Pertinent to Tethered Balloon Flights of 10 and 11 Dec 79

Date	Flight No.	Profile No.	Profile		Maximum elevation	Comments
			Begin (EST)	End (EST)		
10 Dec 1979	9	9 ^a	1043	1057	830 m	Light winds. Visual observation suggested balloon in tower 4 plume.
		9D ^b	1059	1133		
10 Dec 1979	10	10A	1300	1316	900 m	Very light winds, but stack effluent suggested flight in right location. Visual observation suggested plumes vertical to 400 m directly over cooling towers.
		10D	1317	1351		
10 Dec 1979	11	11A	1438	1453	810 m	Very light winds; balloon nearly directly overhead with 700 m line out. Background data.
11 Dec 1979	12	12A	0901	0922	300 m	Background data. Low winds near surface but about 10 m/s approaching 300-m elevation.
	12D	0923	0945			
11 Dec 1979	13	13A	1033	1054	410 m	Still light winds near surface but strong at 300 m and above. Below and side visual observations put Tethersonde package within and through cooling tower plume (i.e., encountered liquid droplet plume).
		13D	1056	1120		

^aThe suffix A indicates ascent.

^bThe suffix D indicates descent.

Cooling towers 1 and 4 were in operation during the flights of 10 and 11 December 1979. Flights 11 and 12 were background flights launched 1 km west of the plant on these days, with southerly component winds. Flights 9 and 10 were launched from a location at 50°/1.1 km from cooling tower 1 and 80°/0.9 km from cooling tower 4. Flight 13 originated at a point 355°/1.1 km from tower 1 and 325°/1.2 km from tower 4. Cooling tower 1 is approximately 0.6 km west of cooling tower 4, and the two stacks are located roughly on the east-west line between the two towers.

Perhaps the detail with which instrumentation, experimental procedures and field geometry have been presented is superfluous inasmuch as the results of the experiments are inconclusive, even conflicting; however, such detail is presented for the sake of completeness.

Figures 3.1 through 3.3 give vertical profiles of potential temperatures for the three flights of 10 December 1979. These profiles unquestionably indicate warming of the near surface layers with time. For example, the potential temperature in the lowest hundred meters for profile 9A was about 281.5K; for 9D, 284K; for 10A, 288K; for 10D, 289K; for 11A, 290K; and for 11D, 290.2K. Since the purpose of flying the tethered balloon system was to gather information about the elevated temperature/humidity plume, this observation of warming might be considered irrelevant. However, it does point out the difficulty of obtaining a meaningful ambient measurement with which to compare an "in-plume" profile when the two profiles cannot be obtained simultaneously.

Despite the difference in slopes of the temperature-versus-height curves, much greater variability is found in the measured temperatures during the two in-plume flights than in ambient flight 11. This

Fig. 3.1. Vertical profile of potential temperature during tethered flight 9.

variability is particularly obvious in the range of 350 to ~600 m for profiles 9D and 10D. This variability may well be due to the influence of the warm cooling tower (or stack) plumes mixing with ambient air.

Figures 3.4 through 3.6 present mixing ratios for Tethersonde flights 9 through 11. The contrast between the nearly constant water content of flight 10 and the fluctuating profiles of the other two flights is at least as striking as the contrast in potential temperatures. Again, one can postulate that the variance was due to the cooling tower plumes. However, the magnitude of the mixing ratio dropped to less than 1 g/kg during profile 9D. This *reduction* in moisture content below that observed at any other point or time on that day can hardly be attributed to physical processes associated with the moist cooling tower plume. Also, since the mixing ratio is an absolute moisture measurement (as opposed to relative humidity), the reduction is not easily associated with the stack plume.

The possibility that moisture from the unevaporated water in the cooling tower plume affected the dry bulb thermistor sensor has been considered. This water, upon evaporation, could cause a false indication of cooler dry bulb temperature. Assuming that the wet bulb temperature (a thermistor in a

Fig. 3.2. Vertical profile of potential temperature during tethered flight 10.

Fig. 3.3: Vertical profile of potential temperature during tethered flight 11.

Fig. 3.4 Vertical profile of mixing ratio during tethersonde flight 9.

Fig. 3.5 Vertical profile of mixing ratio during tethered flight 10.

Fig. 3.6 Vertical profile of mixing ratio during tethered flight 11.

wick) remains accurate despite the effects of moisture, the erroneously low dry bulb temperature would lead to erroneously high computations of mixing ratio. The questioned profile 9D mixing ratios are low. In fact, photographs suggest that the visible plume from the cooling tower did not extend far enough from the plant to intersect the Tethersonde package during flight 9.

Data from two flights of 11 December 1979 have been reduced to generate the profiles in Figs. 3.7 and 3.8. Winds aloft were much stronger during these flights (10 m/s), so even with 800 to 900 m of tether line payed out, the sensor package reached only 300 to 400 m. Of course, the higher wind speeds also inhibit plume rise, so the plumes from the 119-m tall cooling towers could reasonably be expected to be found in the measurement layer. Whereas on the previously discussed flights of 10 December 1979, the ambient flight followed the in-plume flights, the initial flight on 11 December 1979 was the ambient atmosphere flight.

Fig. 3.7. Vertical profiles of mixing ratio and potential temperature during tethered flight 12.

Fig. 3.8. Vertical profiles of mixing ratio and potential temperature during tethered flight 13.

Once more the warming in the lower layers was demonstrated by the progression of potential temperature curves with time. As before, this changing ambient profile complicated any attempt to compare ambient and in-plume profiles. The comparison is further complicated by the lack of measurements above 300 m on the ambient flight. Though somewhat less conclusive than the data from 10 December 1979, the data from 11 December 1979 indicate that both potential temperature and mixing ratio for in-plume curves display a greater variation near a given elevation than do the ambient.

The graphic procedure of tracing the upward and downward progress of the balloon and transmitter by connecting the dots is not carried out near the top of flight 13. A continuous progression

in elevation did not occur as more tether line was payed out or retracted. Thus the Tethersonde package frequently sampled within thinner layers, and the "feel" for the range in mixing ratio or temperature in the 300- to 400-m height range is enhanced. Perhaps the most noticeable point on the graphics is the temperature range of 287.4 to 289.7 K at the 370-m elevation during flight 13, yet without a simultaneous ambient plume measurement, it is risky to state that the variation is due to plume effects.

Reporting the results of decisive field data is satisfying, but the Tethersonde data reported here are not decisive. The discussions have been in qualitative terms, and reduction of the remainder of the profile data may not clarify the picture. (The profiles examined here are among those felt most likely to yield "in-plume" measurements.)

One firm conclusion can be drawn from these Tethersonde experiments: the most glaring difficulty in the temperature/humidity measurement program is the lack of valid background or ambient measurements. If such experiments are repeated, a second tethered balloon package should be flown in conjunction with the first so that simultaneous in-plume and ambient conditions can be monitored.

4. AIRBORNE MEASUREMENTS PROGRAM

The Pennsylvania State University participation in the WISPE program focused on two different studies: (1) the influence of the effluents of the Bowen plant on downwind aerosol characteristics and precipitation patterns and (2) the change in plume drift drop concentration as a function of distance from the source. For both studies, airborne measurements were made with the instrumented research aircraft, an Aerocommander 680E. In Table 4.1 a summary of the flights performed is presented.

Table 4.1. Summary of flights

Flight	Date	Time of day	Downwind distances sampled	No. of plume penetrations	Nature
1	12/4/79	07:08-09:38	3	21	Plume chemistry
2	12/5/79	06:52-09:28	4	24	Plume chemistry
3	12/7/79	10:35-12:41	3	16	Plume chemistry
4	12/8/79	06:51-09:21	4	22	Plume chemistry
5	12/10/79	08:00-09:45	3	15	Plume chemistry
6	12/10/79	15:50-17:44	3	12	Plume chemistry
7	12/11/79	11:35-13:05	2	9	Plume chemistry
8	12/12/79	11:30-12:24	2	6	Drift drops measurements
9	12/14/79	07:33-08:57	3	13	Drift drops measurements
10	12/16/79	10:11-11:28	3	15	Drift drops measurements
11	12/18/79	07:14-09:01	3	16	Plume chemistry
12	12/18/79	14:59-16:59	3	17	Plume chemistry
13	12/19/79	07:12-08:48	2	9	Plume chemistry

4.1 Influence of Effluents of Fossil Fuel-Operated Power Plants on Downwind Aerosol Characteristics and Precipitation Patterns

4.1.1 Introduction

The plumes of coal-operated power plants have been shown to serve effectively as atmospheric laboratories for the production and growth of atmospheric sulfate particles.^{1,2} Sulfate particles formed and grown in the plumes add to the atmospheric aerosol, increasing the total number concentration and modifying the size spectrum.

This change in aerosol characteristics could affect the precipitation pattern by modifying the colloidal stability of the clouds. A larger number of giant particles ($r \geq 1 \mu\text{m}$) will tend to decrease the colloidal stability and thus to accelerate the precipitation process; a larger number of small particles will increase the stability. The aerosol characteristics do not constitute the only parameter that influences the precipitation process (the release of large amounts of heat and water vapor may have a larger effect), but certainly these characteristics cannot be neglected.

This activity of the Pennsylvania State University was directed toward two in the WISPE program objectives: (1) to determine the degree of downwind modification of characteristics of the aerosol and gases by the effluents of the Bowen power plant and (2) to determine downwind modification in precipitation patterns and precipitation chemistry as related to modification of the aerosols and gases.

4.1.2 Experimental procedures

The Pennsylvania State University research aircraft and on-board instrumentation. Flights were made using the Pennsylvania State University research aircraft, a twin-engine Aerocommander 680E equipped with an instrument package designed to monitor atmospheric aerosol particles in eight distinct size ranges spanning the entire size spectrum of particles pertinent to this study. To ensure that the aerosol particles followed the air streamlines and entered the sampling inlets with little change from their ambient concentrations, an isokinetic intake probe³ was installed at the top of the aircraft. This device decelerates the air flow from that of aircraft speed, approximately 70 m/s, to 4 m/s. The airplane is also equipped with rapid-response SO₂ and NO_x analyzers, as well as an assortment of instruments capable of supplying meteorological and aircraft position data.

On-board meteorological monitoring included temperature, dewpoint, and pressure. Measurements of true air speed, heading, and Doppler radar ground speed and drift angle were combined to provide estimates of vector winds. Integrated Doppler radar and recorded navigational DME and VORTAC data were used to determine aircraft position. Flight data were recorded at 0.5-s intervals on magnetic tape, thus establishing approximate horizontal and vertical spatial resolutions of 35 m and 2.5 m respectively, for those sensors with sufficiently short time constants (assuming an aircraft flight speed of 70 m/s in the horizontal and roughly 5 m/s in climb or descent).

The general pattern of the flights consisted of an upwind sounding followed by a series of crosswind plume penetrations at selected distances downwind.

Aircraft Aerosol Instrumentation. On-board aerosol sampling instrumentation included an Environment One Model Rich 100 Condensation Nucleus Counter (CNC), and a TSI Model 3030 Electrical Aerosol Analyzer (EAA). The CNC tabulates total number concentration for particles of diameter larger than 0.0025 μm , while the other instruments yield particle size distributions in distinct size intervals.

In the CNC the particles are exposed to supersaturations such that particles greater in diameter than 0.0025 μm are activated and can be counted. In particular, the instrument operates on the principle of a cloud chamber, in which the ambient air containing primarily submicron-sized particles is first humidified and then directed into a chamber where a fixed volume expansion occurs, causing a supersaturation of at least 300%. This process produces a cloud of droplets that have grown by condensation into the light-scattering size range, approaching 1 μm diam. The droplet concentration is equal to the original particle concentration, and because the growth process is diffusion limited, all droplets tend to achieve about the same size.⁴ This cloud causes attenuation of a light beam that is focused on a solid-state, light-sensitive element. The resultant change in electrical resistance of this element is then monitored and electronically converted to a reading of condensation nuclei concentration. Zero and span checks were routinely performed on all the aircraft instrumentation before each flight.

Considerable uncertainty exists concerning the size of the smallest detectable particle measured by condensation nucleus counters. As a result of variations in the chemical nature of the nuclei and in the supersaturation obtained within the cloud chamber, this minimum size can be as large as 0.0100 μm diam.⁴ Recently Liu and Kim⁵ have shown that the smallest size detected by the Environment One CNC counter is about 0.006 μm . Nuclei of this size or smaller account for a negligibly small fraction of the total aerosol mass, and their omission from gas-to-particle conversion rate calculations does not constitute an important source of error.

In the EAA, use is made of the relationship between particle size and electrical mobility.⁴ Particles initially receive a charge when they are mixed in a chamber with negative ions generated by a corona discharge and are then exposed to an electric field of known magnitude. Particles too large to be collected by a given field are deposited on a filter and produce a current that is measured and related to particle number concentration. By varying the magnitude of the electric field in stepwise manner, particle number concentrations for specified size ranges are obtained. The EAA on the Pennsylvania State aircraft measures particle size distribution in logarithmically divided channels: 0.0100–0.0178, 0.0178–0.0316, 0.0316–0.0562, 0.0562–0.100, 0.100–0.178, 0.178–0.316, 0.316–0.562, and 0.562–1.00 μm respectively. An entire sampling cycle over this size range requires approximately 77 s, which is not suitable for on-line aircraft plume sampling. A bag sampling system designed to collect a sufficient supply of ambient air in a considerably shorter time, 10–15 s, was therefore installed. Sampling by the EAA proceeded immediately after this collection process.

Aerosol Collection and Sulfate Analysis. Atmospheric particles within the size range 0.10–2.0 μm diam were collected for sizing and sulfate analysis by a Casella cascade impactor.⁶ Particles were collected directly onto 3 mm copper electron microscope screens that had been coated with a formvar membrane and a carbon film and placed onto the impactor plates exactly below the jet nozzles of the third and fourth stages.

A quantitative method developed at Pennsylvania State⁷ for analysis of individual sulfate particles using a transmission electron microscope (TEM) allowed identification and sizing of the sulfate aerosol collected. After sampling, a film of BaCl_2 of thickness 300 ± 60 Å is vacuum evaporated onto the screens, after which they are exposed in a sealed chamber to a relative humidity of approximately 70% for 1 h. Soluble sulfate particles that have collected onto the screens react with the BaCl_2 , forming a characteristic spot or halo composed of insoluble barium sulfate, which is stable and recognizable under the TEM. The size of the halo is a function of particle size, the thickness of the BaCl_2 film, and the relative humidity at which the reaction takes place.⁷ If the BaCl_2 film thickness and relative humidity are kept constant, a relationship between particle and halo size can be established. Mamane and de Pena⁷ found the halo-to-particle-size ratio to be 1.66 for laboratory-generated ammonium sulfate particles and roughly twice that for sulfuric acid aerosols. A careful comparison of the particle size distributions before and after BaCl_2 treatment for a particular sample thus represents a possible means of determining the relative amounts of ammonium sulfate and sulfuric acid. By tediously counting and sizing a representative sample of halos on each screen and then applying the appropriate halo-to-particle-size ratio and correction factor for particle impaction efficiency, one obtains a detailed, accurate sulfate particle size distribution.

Sulfur Dioxide Measurement. Measurements of SO_2 were made with a Thermo Electron model 43 SO_2 pulsed fluorescent analyzer. This instrument measures the intensity of the fluorescent emission of SO_2 excited by pulsating ultraviolet light. A procedure to correct empirically for the quenching of excited SO_2 molecules by water vapor was applied to the data. The response time of the SO_2 monitor (5 s to achieve 95% of the actual value) agreed well with the response times of the aerosol instruments. As with the CNC and the OPC, readings of SO_2 were recorded on magnetic tape every 0.5 s.

NO_x Measurement. NO_x (NO_2 and NO) measurements were made with a Thermo Electron model 14 DIE chemiluminescent analyzer, which converts NO_2 to NO and then measures the total $\text{NO} = (\text{NO} + \text{NO}_2)$. The NO is also measured directly. NO_2 is obtained by the difference of the two measurements.

Data Analysis. A computer printout of aerosol and SO_2 concentrations, meteorological variables, and aircraft position at 0.5-s intervals was obtained for each flight. These data, coupled with the flight

notes compiled during the course of each experiment, served to identify the "in" and "out" times for each plume penetration performed. Averages of these parameters were then obtained by computer for each crosswind traverse. Particle size distributions from the EAA were hand computed.

4.1.3 Results

As shown in Table 4.1, of the 13 flights conducted at Plant Bowen, 10 focused on plume chemistry. Unfortunately, the NO_x analyzer was inoperable after flight 2. Impactor samples were not taken in flight 1.

At present all tapes have been processed, and the aerosol samples with the impactor have been "developed" for sulfate analysis. A complete analysis of the data has been completed only for flight 5 and is presented in this report. Further data analysis and conclusions will be the subject of later publications.

Meteorological and upwind aerosol parameters. Flight 5 was made on a clear morning with strong stability and very light winds. The air was only slightly hazy on this day, as illustrated by Fig. 4.1, a photograph taken near the end of the flight. Relative humidity was low, with values from 30 to 40% at plume height. Figure 4.2 shows the vertical variations of temperature and Aitken particle concentration (APC) measured upwind of the plant, as well as the wind speed and direction from pibal measurements made by the Pacific Northwest Laboratory personnel. Background SO_2 values were less than 0.03 ppm throughout the sounding.

As seen in Fig. 4.2, a well-mixed layer of constant temperature and constant APC is present up to 650 m. A slight temperature inversion, a significant wind shift and an accumulation of Aitken particles before a sharp decrease can be seen just above this layer.

The plume was found in the transition zone between 700 and 850 m.

Fig. 4.1. Photograph of the plant and plumes taken early morning during flight 5.

Fig. 4.2. Vertical soundings of APC, T, wind direction, and wind speed at a location upwind of the plant.

Plume characteristics. Because of the strong stability and light winds, horizontal meandering of the plume was considerable. As expected under these conditions, vertical dispersion was inhibited. The fanning of the plume was reflected in the plume penetrations, which have been plotted from a top view in Fig. 4.3. In the plot of these penetrations, the starting and ending points are defined by SO_2 concentration equal to 0.1 ppm. This concentration is large enough to distinguish the plume from background air, yet small enough to include virtually all of the plume. Table 4.2 gives a summary of plume penetrations numbered in chronological order with the average height of each penetration and the maximum observed SO_2 concentration for each.

Figures 4.4 and 4.5 are smoothed SO_2 concentration isopleths in the Y-Z plane made at approximately 10 km and 25 respectively. Figure 4.5 probably does not represent a true cross-plume slice, since the plume appeared to curve sharply to the right near this point. Several penetrations were attempted at a more distant location in a line with the first two penetration areas. Only small wisps of plume under 0.5 ppm of SO_2 were found there. Measurements in the direction of the apparent bending again showed a wide plume with concentrations in excess of 2 ppm of SO_2 , thereby confirming the bending. Measurements were made then at three distances in terms of total plume length; these distances were converted to plume travel times, with the wind speed assumed to be approximately constant with time along the plume axis.

Sulfate particle analysis. Samples collected on the fourth stage of the cascade impactor were treated with BaCl_2 as described earlier. Then they were photographed under the TEM, sized, and counted to give the distribution shown in Table 4.3.

To obtain statistical samples, totals of 24, 18, 15 and 15 photomicrographs were taken from upwind and from 10, 25, and 35 km downwind respectively. A small percentage of nonsulfate and mixed particles were also identified, but only the sulfate particles were included in the table.

Fig. 4.3. Detail of plume penetrations.

Table 4.2. Flight No. 5: summary of plume penetrations

Penetration No.	Height (m)	SO ₂ _{max} (ppm)
1	840	0.15
2	808	3.35
3	778	3.26
4	749	2.03
5	725	1.57
6	703	0.47
7	840	2.33
8	790	2.99
9	765	0.88
10	875	0.45
11	870	0.38
12	870	0.26
13	825	2.33
14	800	2.61
15	800	1.81

Fig. 4.4. SO₂ concentration isopleths at ≈ 10 km downwind of the plant.

Fig. 4.5. SO₂ concentration isopleths at ≈ 25 km downwind of the plant.

Table 4.3. Size distribution of impactor-collected sulfate particles with respect to sampling location

Particle diameter (μm)	Upwind	10 km	25 km	30 km
0.21	53	165	121	80
0.22-0.36	50	86	137	134
0.37-0.51	13	11	54	63
0.51	0	0	11	17
Total	126	262	323	303
Average diameter	0.22 μm	0.21 μm	0.27 μm	0.38 μm

Figures 4.6, 4.7, and 4.8 illustrate some representative particles sampled at 10, 25, and 35 km downwind respectively. Figure 4.9 represents an upwind sample.

In these figures the smaller, more or less uniformly shaped particles are barium chloride crystals. Nonsulfate particles are opaque, whereas sulfate particles are characterized by the lighter-colored particles. A "mixed" particle can be identified as an opaque particle with a sulfate halo around it.

As shown in Table 4.3, the number of particles larger than 0.2 μm increases with plume travel time, which is reflected in the increased average diameter of the particles.

The average diameters calculated for the impactor samples were compared with those computed from the EEA in the size range from 0.1 μm to 1 μm . The average diameter from EEA measurements indicated only a small increase from 0.155 to 0.165 μm between 10 and 35 km downwind. This is a much smaller increase than that found for the impactor samples; the size of the increase is not surprising because the two instruments cover a different size range and because the numbers obtained from the impactor were not corrected for collection efficiencies.

Aitken particles analysis. The Aitken particles as measured with the condensation nuclei counter were normalized with respect to the SO_2 concentration. Dittenhoefer⁸ has shown that for plume travel times of ~ 1 to 2 h, SO_2 can be considered as a conservative plume tracer. Figure 4.10 shows the SO_2 normalized Aitken particle concentration as a function of plume travel time for flight 5. The observed decrease of particle concentration with plume travel time suggests that coagulation between particles is the mechanism responsible for the growth of sulfate particles as observed in Table 4.3

Comparison with the Keystone plant plume. Flight 5 was compared with a flight made under similar conditions at the Keystone Power Plant in western Pennsylvania on December 14, 1976.⁹ The Keystone flight was also made in the early morning, with clear skies, low relative humidity, and strong stability. A stronger windspeed at Keystone, about 14 m/s, was the most significant difference in meteorological conditions.

Because of the strong wind speed, the longest plume travel time at which sulfate samples were taken was only 32 min for the Keystone flight; the shortest travel time sampled for flight 5 was 55 min. Similarly to flight #5 at Plant Bowen, the data for the Keystone plant showed a decrease of SO_2 normalized Aitken particles with plume travel time and an increase of the mean particle diameter as measured with the EEA.

The maximum sulfate particle frequencies were at 0.18 and 0.28 μm for flight 5 and the Keystone flight respectively.

Fig. 4.6. Sample of treated sulfate particles at 10 km downwind of the plant.

Fig. 4.7. Sample of treated sulfate particles at 25 km downwind of the plant.

Fig. 4.8. Sample of treated sulfate particles at 35 km downwind of the plant.

Fig. 4.9. Sample of treated sulfate particles upwind of the plant.

Fig. 4.10. SO₂ normalized APC as a function of plume travel time.

4.1.4 Summary

The results of flight 5 indicate that the conversion of SO₂ to sulfate takes place mostly on existing particles rather than by forming new particles (APC/SO₂ decreases with time). Because of the low relative humidities, this process was slow. The process of coagulation also contributes to the formation of larger particles.

In order to calculate rates of oxidation and rates of formation of new particles, the remaining data will have to be analyzed.

4.2 Drift Drop Concentration in Cooling Tower Plumes Measured at Different Distances from the Source

These measurements are designed to obtain information as a basis for modeling the drift drop breakaway. With the use of the PSU aircraft equipped with the drift drop sampler,¹⁰ samples of drift drops in the cooling tower plumes of Plant Bowen have been obtained in three different flights.

A summary of the altitudes, distances from the tower, and volume of air sampled can be seen in Table 4.4. Preliminary results of flight 8, showing the drift drop concentration in the plume at two

Table 4.4. Measurements of altitude, distance, and air volume

Flight	Date	Altitude (m/sl)	Distance (km)	Air volume (m ³)
8	12-12-79	984	2.72	6.2
		891	4.00	3.3
9	12-14-79	600	0.95	8.4
		555	1.76	10.8
		600	2.72	4.7
10	12-15-79	920	0.40	15.0
		735	2.32	33.3
		729	4.24	19.2

distances from the tower, are shown in Table 4.5. More results of this and the two other flights, as well as an analysis of all these data, will be presented in a future report.

Table 4.5. Concentration of drift drops (n/m^3)

Drop diameter (μm)	Distance (km)	
	2.72	4.00
70	187	68
90	33	30
110	8	2.5
130		2.5
210	1.3	
250	1.3	

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5. TRACKING OF SMOKESTACK AND COOLING TOWER PLUMES USING WIND MEASUREMENTS AT DIFFERENT LEVELS

5.1 Abstract

Relationships between cooling tower and smokestack plumes at the Bowen Electric Generating Plant in northwestern Georgia and wind direction measurements at levels from the surface to 850 mb (± 1.5 km) are examined. The wind measurements play an important role in estimating plume directions, which in turn are utilized to establish control and target (upwind and downwind) areas for a study of plant-induced precipitation modification. Fifty-two plume observations were made during a 3-week period in December 1979. Results indicate that a windset (4.5 km from the plant) mounted at a level approximating that of the cooling tower plume is a better predictor of plume direction than surface windsets (1.0 km from the plant) or 850-mb level winds. However, an apparent topographical influence on the wind direction measurements at the plume-level windset site rather limits its plume tracking capability, at least for ambient winds from the SW quadrant.

5.2 Introduction

Determining the directions along which cooling tower and smokestack plumes from power plants travel is a major concern for studies using the upwind-downwind approach to investigate plant-induced weather modification.¹ Approximation of plume directions is complicated by research requiring knowledge of the directions at given times rather than on a climatological basis.² Tracking plumes on the basis of wind measurements at different levels is a challenging task.

In an effort to establish the best method for estimating plume directions from available wind measurements, members of Oak Ridge National Laboratory (ORNL) made observations of the cooling tower and smokestack plumes at the Bowen Electric Generating Plant (Plant Bowen) in northwestern Georgia during a 3-week period in December 1979. The observations provided a comparison with wind data at levels from the surface to 850 mb to determine the extent to which the wind directions at those levels reflected the plume directions. This investigation was part of a joint field study named Winter Study of Power-Plant Effects (WISPE), involving Battelle Pacific Northwest Laboratories, The Pennsylvania State University, and ORNL. The overall goal of WISPE was an improved understanding of the effects of cooling tower and smokestack plumes on local weather and atmospheric conditions. The field study was a part of the Meteorological Effects of Thermal Energy Releases (METER) Program,³ which is sponsored by the Department of Energy (DOE). Plant Bowen was selected as the site of WISPE because it is the largest U.S. coal-fired power plant with cooling towers; furthermore, it has been the target of extensive field studies by ORNL since February 1978: a recording rain gage and windset network has been in continuous operation around the plant to evaluate the potential precipitation modification by the heat and moisture releases.² Plant Bowen, located about 64 km northwest of Atlanta and owned and operated by the Georgia Power Company, is a 3160 MW(e) plant with two smokestacks and four natural-draft cooling towers. The height of each smokestack is 305 m, and the towers stand 119 m above the ground level of 220 m MSL.

Incorporating the plume observations in WISPE involved addressing the problem of estimating the plume directions prior to and during storm events from available wind measurements. Knowledge of the approximate cooling tower plume direction is crucial to the ORNL study of potential precipitation modification; specifically, the statistical design employed in most analyses of the network rainfall data is based on the control-target (upwind-downwind) concept, resembling the designs of

many cloud-seeding experiments.^{4,5} Thus, given the wind directions near the surface and at 850 mb for a particular storm event, the question is whether plume directions can be estimated satisfactorily. Additionally, the wind measurements and plume observations provided an excellent opportunity to examine the influence of topography on wind direction. Previous investigations⁶⁻⁸ have found local topography to perturb both direction and speed of the wind near the surface. The general topographical features in the study area have been described in detail by Patrinos et al.;¹ specific features at the windset sites are discussed in the following section.

5.3 Observations

Fifty-two observations of the cooling tower and smokestack plumes were made during the period Dec. 5-18, 1979; two morning and two afternoon observations were scheduled daily, regardless of atmospheric conditions, with additional observations taken during storms. The following items were recorded at each observation:

1. date and time,
2. description of sky,
3. occurrence of precipitation,
4. directions of cooling tower and smokestack plumes (based on a 16-point compass),
5. estimated length and height of visible cooling tower plume, and
6. additional remarks (plume bifurcation, strong shear, etc.).

The plume directions are taken to be the directions from which the winds are approaching, so they correspond to the wind measurements.

Simultaneous wind direction readings were obtained from three recording windsets in the study area: two windsets located 1.0 km NNE of Plant Bowen at a height of 6 m above ground level, and a meteorological station situated 4.5 km NE of the plant with wind instrumentation at the top of a 35-m tower. The former two windsets, which are separated from each other by ~50 m, are in a flat, well-exposed area. The meteorological station, however, stands at the crest of a 120-m hill in a large clearing that is surrounded by trees with heights of less than half the height of the tower. Additionally, the wind direction at the 850-mb level was derived for each observation by interpolation of the National Weather Service maps.

5.4 Analysis

Analysis of the data was directed toward the previously mentioned objectives of (1) investigating the relationships between plume observations and wind measurements and (2) studying the influence of topography on wind direction. Initially, a few fundamental stratifications were performed. Table 5.1 displays the wind direction distributions for observations and measurements. A comparison with climatological wind records would be of limited value, because the distributions contain a maximum of only 52 observations or measurements taken at varying intervals during the daylight hours; furthermore, care must be exercised in comparisons between distributions because of missing data which preclude a one-to-one correspondence. Nevertheless, several general results are noted. The majority of cooling tower and smokestack plumes traveled from the northern or southern sectors, with few occurrences from the east or west. Differences can be detected between the two plumes, but the overall pattern is quite similar (64% of the observations matched identically). The surface windset measurements display prevailing winds in the northwestern and southeastern quadrants; the

Table 5.1. Wind direction distributions

	Surface windset		Meteorological station	Plume		850 mb level winds
	No. 1	No. 2		Cooling tower	Smokestack	
N	8	4	12	9	6	7
NNE	1	3	2	0	2	0
NE	1	1	0	0	0	0
ENE	2	2	0	1	0	0
E	3	3	3	1	2	0
ESE	7	3	1	4	4	0
SE	4	3	10	3	2	0
SSE	1	1	3	3	1	0
S	0	0	5	7	7	0
SSW	1	2	3	3	4	3
SW	2	1	0	3	5	6
WSW	0	1	2	3	0	12
W	1	1	1	0	2	6
WNW	4	5	2	2	3	9
NW	2	2	6	6	3	7
NNW	7	3	2	6	7	2
Total	44	35	52	51	48	52

distributions would be almost identical because of the small separation distance, except that both windsets were inoperative at different periods of the field study because of power supply problems. The wind direction distribution at the meteorological station appears to be bracketed by the surface windset and plume distributions. Finally, the distribution of the winds at the 850-mb level is markedly different from the others: there are no occurrences of winds with an easterly component. This finding suggests that the latter wind would be a poor predictor of plume direction.

Figure 5.1 presents a further analysis of the data by plotting the wind directions from all observations and measurements as a function of observation number. This graphic display provides the opportunity for comparing wind directions at a set time and for following the trend from one observation to the next. The ordinate is displayed as several complete cycles of wind direction, thereby permitting a constant comparison of winds as they rotate around the compass. The wind at the 850-mb level, however, has two breaks in its trace because it oscillates around the western sector rather than rotating around through the eastern sector. This is another indication that the 850-mb wind level is inadequate as a predictor of plume direction. Apparently the meteorological station estimates the cooling tower plume considerably better than the two surface windsets. Indeed, for most observations the meteorological station is an acceptable predictor of the cooling tower plume (within 22.5° for 88% of the observations).

An interesting feature of Fig. 5.1 is the shifting back and forth of the six traces. The fluctuations tend to lessen with height, with the 850-mb level wind being quite steady in comparison with the others. The traces are often aligned in an order corresponding to height, following either the familiar Ekman spiral model or some inverse of it. The meteorological station trace is frequently positioned between the surface windsets and the cooling tower plume, suggesting that its effective height also lies between the two. In terms of absolute height, the windset at the meteorological station is ~ 35 m above the mouth of the cooling tower; but since the elevation is greater at the former site and since plume rise should also be considered, the relative order of the wind direction traces is as expected.

Fig. 5.1. Wind directions from all observations and measurements as a function of observation number.

Only three periods of precipitation occurred during the field study, as denoted in Fig. 5.1. This was unfortunate because one of the primary objectives of the observations was to study wind relationships prior to and during storm events. The available data points are too few to allow any conclusions regarding relationships during storms.

Another analysis was performed by computing the correlation coefficients for five of the six wind directions. The 850-mb level wind direction was subtracted from each of the three windset measurements and two plume observations to obtain five angular differences for each time of observation. This technique of sacrificing one set of wind directions allows the remaining five sets to be readily correlated. The results are presented in Table 5.2. The highest correlation is between the two surface windsets, and the lowest correlation involves the second surface windset and the cooling tower plume. The correlations indicate that the meteorological station, with its higher coefficient, is a better predictor of the cooling tower plume direction than the two surface windsets.

Table 5.2. Correlation coefficients between wind directions

	Surface windset		Meteorological station	Plume	
	No. 1	No. 2		Cooling tower	Smokestack
Surface windset No. 1	1.000	0.995	0.922	0.824	0.824
Surface windset No. 2		1.000	0.906	0.769	0.797
Meteorological station			1.000	0.906	0.906
Cooling tower plume				1.000	0.979
Smokestack plume					1.000

Previous results have shown that out of the available measurements, the meteorological station has best estimated the cooling tower plume direction. Concern has existed, however, regarding the topographical influence on the wind direction measured at the meteorological station because the station is located on the crest of a 120-m hill. Therefore, the meteorological station and the cooling tower plume were compared by computing the difference between the two wind directions at a given time, $\theta_{\text{MET}} - \theta_{\text{C.T.}}$ (where θ is in degrees of the compass) and stratifying each difference according to the cooling tower plume direction in which it occurred. This technique is quite similar to the method used by Weidner and Stearns.⁷ The differences were stratified by cooling tower plume direction since the plume was assumed to be uninfluenced by the topography. Figure 5.2 displays a graph of the mean differences, $\overline{\theta_{\text{MET}} - \theta}$, because of the limited number of observations, some directions contain no points, and others are based on one to nine observations. The only direction which appears somewhat out of line is SSW. The other graph depicted in Fig. 5.2 is the mean absolute value of the differences, $|\overline{\theta_{\text{MET}} - \theta_{\text{C.T.}}}|$. Large values (too great to be explained by a difference in effective heights) occur in the SSW and SW directions, each the mean of three observations. A check of the absolute value of the differences, $|\overline{\theta_{\text{MET}} - \theta_{\text{C.T.}}}|$, for all observations reveals six cases with magnitudes of 45° or more: three

Fig. 5.2. Mean differences between the directions of the meteorological station windset and the cooling tower plumes.

with the cooling tower plume direction from the SW and one each from the directions of S, SSW, and NW.

Because of the sparsity of data, the differences were grouped together by quadrants; for example, the four cooling tower plume directions S, SSE, SE, and ESE—were combined to form the SE quadrant. Table 5.3 presents, for three quadrants (the NE quadrant contained only two observations), the calculations of $\theta_{MET} - \theta_{C.T.}$, $|\theta_{MET} - \theta_{C.T.}|$; the standard deviation $\sigma(\theta_{MET} - \theta_{C.T.})$; and the number of observations n . The values of $|\theta_{MET} - \theta_{C.T.}|$ and $\sigma(\theta_{MET} - \theta_{C.T.})$ are substantially greater for the SW quadrant than for the other quadrants. However, this n of the SW quadrant is about half of the other two.

Results of comparing the meteorological station windset with the cooling tower plumes indicate a topographical influence on the wind direction recorded by the former for cooling tower plume directions from the SW quadrant. Because of the small number of observations, no definite conclusions can presently be drawn; further observations are planned in an upcoming field study. Moreover, assuming that a topographical effect is prevalent for ambient southwesterly winds, a physical explanation is difficult if the other quadrants are not also affected, for the hill is located in the SW

Table 5.3. Wind direction differences grouped by quadrants

Quadrant	$\overline{\theta_{\text{MET}} - \theta_{\text{C.T.}}}$	$ \overline{\theta_{\text{MET}} - \theta_{\text{C.T.}}} $	$\sigma(\theta_{\text{MET}} - \theta_{\text{C.T.}})$	n
SE	0.0	15.9	21.0	17
SW	-7.5	42.5	68.4	9
NW	5.9	11.7	16.9	23

corner of a "matrix" of other hills of similar height; this location would seem likely to influence wind direction at the meteorological station for ambient winds from other quadrants. In any case, current speculation on the cause of a topographical effect is that the southwesterly flow is channeled through the small valleys to the north and east of the hill, and this shifting of flow in the valleys influences the flow at the crest of the hill.

5.5 Conclusions

Observations were made of the cooling tower and smokestack plumes at Plant Bowen in Georgia for comparison with wind measurements at heights from the surface to 850 mb. This investigation was directed primarily toward determining the relationships between observations and measurements of wind direction prior to and during storm events. On the basis of results of several analyses, the meteorological station was found to be a better predictor of the cooling tower plume direction than were the surface windsets or 850-mb level winds. A possible complication is the apparent topographical influence on the wind direction measurements of the location of the meteorological station on top of a hill; however, according to available data, the influence is noticeable only, for cooling tower plume directions (assumed to be the ambient flow) from the SW quadrant. Further observations planned for a future field study should answer existing questions concerning the best measurement or combination of measurements for plume directions prior to and during storm events and the extent of a topographical effect of the location of the meteorological station on measurements of the wind direction.

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Appendix A

**WINTER STUDY OF POWER PLANT EFFECTS
(WISPE)**

**Program Plan for a Joint Field Study by
Battelle Pacific Northwest Laboratories
Oak Ridge National Laboratory
The Pennsylvania State University**

**A. A. N. Patrinos
Oak Ridge National Laboratory**

September 1979

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INTRODUCTION

The first three weeks in December have been slated for a field study around the Bowen Electric Generating Plant (Plant Bowen) in Northwestern Georgia. This field study will be a joint endeavor involving the Battelle Pacific Northwest Laboratories (PNL), The Pennsylvania State University (PSU), and the Oak Ridge National Laboratory (ORNL). In general terms, the goal of this study is an improved understanding of the effects of cooling tower and smokestack plumes on local weather and water quality.

Plant Bowen has been the target of extensive field studies by ORNL. Specifically, since February 1978, a raingage and windset network has been in operation around the plant to address the potential precipitation modification by the heat and moisture releases. Prior to that, climatological studies with National Weather Service (NWS) data revealed evidence of some rainfall modification. Since November 1978 the ORNL studies have been extended to incorporate wetfall chemistry. For that purpose, automatic wetfall collectors (HASL) were installed at key locations, and field trips for the collection of rainwater samples on an event basis were undertaken. The above ongoing studies are expected to be enhanced by the planned joint field studies in December, while simultaneously providing the necessary background work for those joint studies.

The integration of all data acquired during the field activities in December is expected to provide a comprehensive description of the various atmospheric phenomena to which the plant's heat, moisture, and pollution emissions are suspected to have an effect. The following are the primary goals of the field study:

- (A) Examination of the influence of the plant's smokestack effluents on the downwind aerosol characteristics and precipitation chemistry

- (B) Investigation of the extent and magnitude of the cooling tower temperature and humidity (T/h) plumes

The secondary objectives are as follows:

- (A) A study of the drift-drop concentration in the cooling tower plumes as a function of height

- (B) A study of cooling tower plume condensate scavenging by rainfall.

It should be emphasized that the on-going ORNL study of the plant-induced potential rainfall modification will continue uninterrupted through the duration of the joint activities.

SITE DESCRIPTION

The Bowen Electric Generating Plant (Plant Bowen) is a 3,160-MWe coal-fired power plant of the Georgia Power Company. It is situated in the southern part of a broad valley, approximately 64 km northwest of Atlanta, Georgia (Fig. A-1). The terrain consists of gently rolling hills with a minimum elevation of 183 m MSL; the elevation of the plant is 213 m MSL. The southern tips of the Appalachian Mountains, having elevations of greater than 914 m, are situated 72 km to the northeast of the plant. Narrow ridge and valley structures which are oriented NE-SW arise to the northwest of the plant at a distance of 48 km. In the southern section the elevation increases gradually with several isolated high points, e.g., Kennesaw Mountain. The general orientation of the hills and valleys within the study area is approximately along the SW-NE direction. Noteworthy features in the study area include Allatoona Lake, located approximately 15 km east of the plant and created by the damming of the Etowah River, which flows W-E in the central valley, and the cities of Cartersville and Rome, situated 8 km east and 20 km northwest of the plant, respectively.

Fig. A-1. Topographical map of the area around Plant Bowen depicting stations of the NWS.

Plant Bowen is one of the largest plants in the world, especially among those using cooling towers as the sole cooling method. It is composed of four units (the first unit was completed in October 1971 and the last in November 1975) and utilizes four 119-m, natural-draft cooling towers and two 305-m smokestacks.

METEOROLOGICAL BACKGROUND

The climate of the study area during the month of December is influenced by both the orographic and maritime features (the Gulf of Mexico and the Atlantic Ocean are approximately 500 km south and

southeast of Plant Bowen). The mountains to the north tend to retard the southward movement of cold air masses, resulting in fairly mild temperatures; the large bodies of water provide an abundant supply of moisture for feeding the frequent storms.

The normal daily maximum temperature for December at Atlanta, based on the 30-year period from 1941 to 1970 is 11.5°C (52.7°F). The normal daily minimum and normal monthly temperatures are 1.3°C (34.3°F) and 6.4°C (43.5°F), respectively. The recorded extremes range from -17.2°C (1°F) to 25°C (77°F). The mean number of days with minimum temperatures at 0°C (32°F) or below is 15.

The normal precipitation at Atlanta for December is 107.7 mm (4.24 in.), with extremes ranging from 27.4 mm (1.08 in.) to 252 mm (9.92 in.). The maximum amount recorded for a 24-h period is 97.8 mm (3.85 in.). The mean number of days with precipitation of 0.3 mm (0.01 in.) or more is 10. There is one day on the average in which a thunderstorm occurs. Snow is not common during this month; the record snowfall is 63.5 mm (2.5 in.).

The METER-ORNL precipitation network around Plant Bowen recorded 12 precipitation events (storms) during its first December of operation in 1978. Seven of the twelve storms were associated with a frontal system, with the prevailing storm type (four occurrences) being the cold front. The primary direction of storm movement in Northwest Georgia during December is from WSW to ENE.

The normal relative humidity at Atlanta varies according to the hour of the day for December: 75% (0100 EST), 80% (0700 EST), 59% (1300 EST), and 66% (1900 EST). On the average, a heavy fog is encountered on five days of the month. The mean wind speed is 15.8 km/h (9.8 mph), and the prevailing surface wind direction is NW, although the latter varies considerably during storms. The percent of possible sunshine averages at 50 during the month.

EXISTING EXPERIMENTAL FACILITIES

As mentioned in the Introduction, the ongoing ORNL studies around Plant Bowen utilize an established network of instruments in the vicinity of the plant, which is expected to enhance and complement the planned activities in December:

a. The METER-ORNL Precipitation Network is composed of 49 recording raingages and five recording windsets (Fig. A-2). The raingages are situated on a 7 × 7 square grid (with a 42-km side) centered at Plant Bowen. Additional raingages are located at two of the wetfall collector sites and in the immediate vicinity of the plant. The windsets are located at key locations around the power plant for the tracking of surface winds.

b. Plant Bowen's meteorological station is located on top of a 120-m hill approximately 5 km northeast of the plant. The station is equipped with a 35-m meteorological tower. Wind speed and direction are monitored at tower height together with temperature (this temperature is recorded as ΔT , temperature difference between tower top and base). Other monitored meteorological parameters include ambient temperature and dew point temperature.

c. Four permanently installed wetfall-only collectors (HASL) have been deployed around the plant: at the plant's substation, 10 km to the southwest, at the plant's meteorological station, and on private land to the northwest (10 km) and east (3 km). Primitive collectors (poles with appropriate receptors for the bottles) exist at all the inner 5 × 5 regular sites of the METER-ORNL Network, while an additional 18 sites, mostly along roads, will be available (these sites were used during last winter's event samplings). A total of 15 portable, battery-operated, HASL collectors will be used for the event samplings.

Fig. A-2. The METER-ORNL precipitation network. The rain gages are depicted by dots, while crosses denote the windsets.

THE PRIMARY OBJECTIVES

Aerosol Characteristics and Precipitation Chemistry

There are many advantages to applying the airborne measurements technology developed at Penn State University for air chemistry analyses and SO_4^{2-} particle production to Plant Bowen's plumes:

1. The environment around Plant Bowen is much cleaner than that surrounding the Keystone plant (site of previous PSU studies) which is often under the influence of the Pittsburgh industrial zone. The differences between the plume and background concentrations are expected to be higher and easier to detect.
2. Coal consumption at Bowen is almost double compared with the Keystone plant. Moreover, the coal sulfur content is almost double. This should result in a much faster $\text{SO}_2/\text{SO}_4^{2-}$ conversion rate and a larger particle concentration in the plumes.
3. The photochemical effect is expected to be somewhat enhanced at Plant Bowen as it is located several degrees further to the south. Summarizing, the higher concentration of SO_2 and the higher solar radiation intensities are expected to contribute to a larger concentration of particles with a modified size spectrum.

The change in aerosol composition could affect precipitation by modifying the colloidal stability of the clouds; a larger amount of giant particles will tend to decrease the colloidal stability and accelerate the precipitation process. On the other hand, a larger amount of small particles will increase the stability. The existing METER-ORNL Precipitation Network will be used to examine possible relationships between precipitation characteristics (total amount and distribution) and airborne particle number concentration and distribution.

The second investigation attempting to relate airborne with ground-level measurements deals with the $\text{SO}_2/\text{SO}_4^{2-}$ conversion and the precipitation scavenging of the large sulfate particles and gaseous SO_2 and their contribution to the acidity and sulfate content of precipitation. The airborne detailed measurements by PSU before and after a precipitation event will be complemented with the ORNL wetfall chemistry studies utilizing the permanent and temporary wetfall collector sites. A possible relationship between the pH and SO_4^{2-} content in precipitation and the SO_4^{2-} and SO_2 concentrations in the plume will be established. The conversion rate studies will be enhanced by their extension to higher SO_2 concentration and larger zenith angles. Use will be made of the surface and tower windsets as well as the PNL pibal data for the tracking of the plumes.

In detail, the airborne studies will include: horizontal and vertical measurements of condensation nuclei, large particles (with the optical counter), size distribution of particles (with the electrical aerosol analyzer), concentrations of SO_2 , and number concentration and size distribution of sulfate particles with the electromicroscopic technique. The ground-level measurements will involve the collection of rainwater samples on a precipitation event basis with both the permanent and temporary wetfall collectors (total of 40 combined) and the monitoring of winds for the tracking of the plumes. The rainfall samples will be analyzed for pH, conductivity, sulfates, nitrates, ammonia, and selectively for trace metals.

The measurement of wind up to 3000 m is planned by PNL by means of a double theodolite/pilot balloon release. Summaries of the various meteorological observations will be available to the PSU group to assist with its aircraft operations and data interpretation. In addition, PNL will provide ground-level concentrations of NH_3 and perhaps SO_2 and NO_2 . The data may be acquired by means of bubbler or high-volume filter samplers for integrated atmospheric concentrations or by means of real-time instruments (SO_2 and NO_2) for continuous concentration measurements. Analysis of the trace

gas concentration samples is a straight-forward, well-documented procedure at PNL. The results of the bubbler samplers should be available within three weeks of completion of the experiment.

Cooling Tower T/h Plume Study

The objective of the cooling tower T/h plume studies is to examine the modifications of near-field ambient atmospheric conditions caused by the release of heat and water by the cooling towers. To meet this objective, it will be necessary to measure in some detail the spatial distribution of several meteorological parameters, including temperature and humidity (T/h) near the surface (i.e., from the ground up to about 300 m). Measurements will be required upwind of the towers to provide information of the characteristics of the inflowing air mass. Downwind of the towers, measurements along arcs across the plume at several distances will be required.

A majority of the measurements will be made with an instrumented tethersonde system. This system has the capability of measuring wet- and dry-bulb temperatures, wind speed, and direction and pressure altitude. Data acquired from the instrument package are telemetered to a ground receiver. At this point the data may be recorded or fed into a desk-top calculator, converted to engineering units and printed out on paper tape. The tethersonde system has been used extensively in other field programs and has been used to a limited extent on the METER drift and plume condensate scavenging studies.

It appears necessary to instrument several smaller meteorological towers, e.g., 10 to 20 m, at several levels with fast response sensors to monitor the temperature, moisture, and the three-component wind. These parameters will be used to evaluate the net transport of heat and moisture on a continuous basis. The towers are to be erected at sites which are predominantly influenced by the cooling towers and ambient atmospheric conditions, respectively. Measurements made with the tethersonde system can be referred back to measurements made on these towers in order to distinguish between the effects of the cooling towers on atmospheric state parameters and natural variability. Documentation of the near-tower visible plume will be provided by time-lapse photography.

Extensive analysis of the meteorological data is anticipated. In addition to the average summaries PNL will provide to the other groups, detailed comparisons and correlations of the various atmospheric state parameters obtained from the tethersonde and tower systems will be made. Special consideration will be given to small differences of these parameters between natural and cooling tower influenced air parcels. Plant and cooling tower operational data are expected to be available for the interpretation of the results of this analysis. Analysis of these data should be complete within ten weeks of the completion of the experiment.

The Secondary Objectives

Drift-drop concentration vs plume heat

The prediction of drift deposition is highly sensitive to the choice of the breakaway point, but so far observations are not available on which to base a particular device for this point. The breakaway point is determined theoretically by the velocities of the plume updraft and that of the wind. The velocity of the plume updraft is obtained from the plume theoretical models.

The observations of counter-rotating vortices in the plumes suggest that the internal pattern of movement is far more complex than the one used in the theoretical calculations. Furthermore, measurements of cooling tower plume vertical velocities show the presence of downdrafts at the edges of the plume. Therefore, drops of any size entering these downdrafts will be removed, and the

breakaway point will be different from the one computed theoretically. In order to improve the drift deposition models, two methods are recommended:

1. Develop a model of the plume circulation and validate it.
2. Determine from measurements in real plumes how the concentration of the drift drops changes with the height of the plume. This could provide the modelers with at least an empirical rule to handle the drift-drop depletion in the plume.

The second method will be pursued, and measurements of drift-drop concentrations will be made with the PSU drift sampler onboard the aircraft. Every plume will be penetrated at three different levels. The comparison of the concentrations found at the three different levels will indicate how and when the drift drops leave the plume. Along with the drift-drop sampling, data of temperature, humidity and liquid water content will be obtained. For the liquid water content, parallel measurements with the Johnson Williams device and the PSU continuous cloud sampler will be made. This latter instrument can also provide number concentration and size distribution of the plume droplets. The above information will be used to establish the plume dilution as a function of height.

Cooling tower plume condensate scavenging study

Continuation of an experiment carried out at Plant Bowen during March–April 1978 (described in the September 19, 1978, PNL METER program plan) is suggested during the December 1979 field experiment. Despite the overall poor experimental conditions during the March–April series, the feasibility of measurement of rainfall enhancement was demonstrated. Since most of the sampling network remains in place, little extra effort beyond the activities described above will be required to study condensate scavenging under, hopefully, more favorable frontal rain conditions.

REPORTING

A report summarizing the results of all field activities should be available in June 1980 for review by the METER Coordinator and the DOE Project Monitor. Contributions, submitted separately by PNL, PSU, and ORNL, will be integrated, and the final report will be published in the format of the METER Annual Report.

ACKNOWLEDGEMENTS

The December field trips around Plant Bowen will be undertaken with the full approval and cooperation of the Georgia Power Company. The assistance of the management of Georgia Power and the personnel at Plant Bowen is greatly appreciated.

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Appendix B
GENERAL DATA

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Table B.1. Pilot balloon winds

		RELEASE TIME (EST)											
DATE	HEIGHT A.C. M	0834			0907			1353					
		DIR	SPEED		DIR	SPEED		DIR	SPEED		DIR	SPEED	
		DEG	M/S	MPH	DEG	M/S	MPH	DEG	M/S	MPH	DEG	M/S	MPH
5	210	240	4	9	235	3	7	215	4	9			
	300	240	5	12	240	5	11	210	5	10			
	400	240	6	14	240	6	13	210	5	12			
	500	240	7	15	240	7	16	205	5	12			
	600	240	8	17	240	8	18	205	5	12			
	800	250	10	23	250	10	23	215	7	16			
	1000	255	12	27	260	12	28	235	12	28			
	1200	250	11	25	255	13	30	240	15	35			
	1400	230	9	21	245	12	27	235	17	39			
	1600				240	12	28	240	16	36			
	1800				250	13	29	245	15	36			
6	210	170	6	13	RAIN. INTO			INTO LOW			215	1	2
	300	195	7	16	LOW CLOUDS			CLOUDS AT			220	4	9
	400	195	3	19	AT 300M.			300M.			230	5	11
	500	205	8	18							230	7	16
	600	215	8	18							230	8	18
	800	215	8	18	1110			1455			225	10	22
	1000	210	5	11							220	11	25
	1200	225	5	11	INTO LOW			INTO CLOUDS			220	11	25
	1400	230	6	13	CLOUDS AT			AT 300M.			230	12	27
	1600	230	8	18	300M.						240	13	29
	1800										245	15	34
7	210	290	4	9	300	3	7	280	4	9	245	6	13
	300	300	5	11	305	4	9	280	4	9	250	7	16
	400	305	6	13	305	5	11	280	4	9	255	7	16
	500	305	7	16	305	6	13	295	4	9	265	7	16
	600	305	8	18	305	7	16	290	6	13	270	7	16
	800	310	9	20	310	8	18	295	10	22	280	9	20
	1000	FDG			295	9	20	295	11	25	290	14	31
	1200				290	12	27	300	14	31	300	18	40
	1400				290	13	29	295	15	34	290	18	40
	1600				285	12	27	280	14	31	280	18	40
	1800				280	14	31	270	13	29	280	21	47

* RELEASE FROM LOCATION 20 KM NORTHEAST OF BOWEN PLANT

Table B.1 (continued)

		RELEASE TIME (EST)											
		0823			1008			1305			1610*		
DATE	HEIGHT A.G.	DIR	SPEED		DIR	SPEED		DIR	SPEED		DIR	SPEED	
DEC	M	DEG	M/S	MPH	DEG	M/S	MPH	DEG	M/S	MPH	DEG	M/S	MPH
8	210	340	10	22	345	4	9	340	5	13	340	9	20
	300	345	12	27	345	5	11	340	7	16	340	10	22
	400	345	13	29	350	7	16	345	8	18	340	10	22
	500	350	14	31	345	9	20	345	8	18	340	10	22
	600	355	14	31	340	11	25	345	9	20	340	9	20
	900	350	14	31	335	15	34	350	8	19	345	9	20
	1000	335	15	35	325	16	36	345	12	27	350	12	27
	1200	320	13	40	320	14	31	335	14	31	345	14	31
	1400	310	21	47	320	13	29	325	13	29	345	11	25
	1600	310	21	47	310	15	34	330	11	25	330	11	25
	1800	310	19	43	305	18	40	320	11	25	320	13	29
9	210	085	7	16	090	8	18	100	2	4	150	1	2
	300	095	10	22	100	10	22	110	2	4	165	1	2
	400	100	12	27	110	12	27	125	2	4	180	1	2
	500	110	13	29	120	12	27	145	2	4	190	1	2
	600	120	12	27	135	10	22	165	2	4	195	1	2
	800	150	7	16	255	6	13	210	2	4	295	2	4
	1000	250	4	9	305	3	7	340	2	4	325	3	7
	1200	310	5	11	325	5	11	335	4	9	330	4	9
	1400	320	6	13	325	6	13	330	6	13	320	6	13
	1600	320	7	16	325	7	16	320	6	13	315	6	13
	1800	315	8	18	325	8	18	320	6	13	310	6	13
10	210	205	3	7	185	2	4	100	1	2	185	2	4
	300	215	4	9	190	3	7	140	2	4	180	2	4
	400	225	4	9	190	3	7	160	2	4	175	3	7
	500	225	3	7	190	3	7	180	3	7	170	3	7
	600	225	2	4	190	3	7	195	4	9	170	4	9
	900	230	2	4	220	5	11	215	3	7	185	4	9
	1000	270	3	7	265	2	4	220	2	4	210	4	9
	1200	285	4	9	280	3	7	245	3	7	225	4	9
	1400	290	5	11	280	4	9	260	3	7	230	4	9
	1600	285	6	13	285	5	11	275	3	7	230	3	7
	1800	280	6	13	285	5	11	270	4	9	235	4	9

* RELEASE FROM LOCATION 20 KM NORTHEAST OF BOWEN PLANT

Table B.1 (continued)

		RELEASE TIME (EST)											
		0822											
DATE	HEIGHT A.G.	DIR	SPEED			DIR	SPEED			DIR	SPEED		
DEC	M	DEG	M/S	MPH		DEG	M/S	MPH		DEG	M/S	MPH	
11		LOW CLOUDS. 300M											
		0915			1012			1311			1559*		
11	210	180	7	16	170	7	16	170	5	11	160	5	11
	300	185	9	20	175	9	20	180	5	11	170	6	13
	400	190	11	25	180	11	25	190	5	11	170	6	13
	500	190	12	27	185	12	27	195	7	16	175	7	16
	600	190	12	27	185	12	27	200	9	18	175	7	16
	800	190	11	25	195	11	25	200	11	25	175	8	18
	1000	205	9	20	200	11	25	200	12	27	180	8	18
	1200	LOW CLOUDS			220	9	20	205	12	27	185	10	22
	1400				215	7	16	205	11	25	190	12	27
	1600				200	7	16	200	10	22	200	14	31
	1800				200	8	18	LOW CLOUDS			210	14	31
		0830			1005			1308			1553*		
12	210	LOW CLOUDS.			190	5	11	190	10	22	185	10	22
	300				195	6	13	190	10	22	185	11	25
	400				200	8	18	190	10	22	190	11	25
	500				200	10	22	190	8	18	190	11	25
	600				200	12	27	190	7	16	190	10	22
	800				LOW CLOUDS.			195	5	13	185	9	20
	1000							190	7	16	180	8	18
	1200							INTC CLOUDS.			180	9	20
	1400										180	12	27
	1600										185	13	29
	1800										195	12	27

* RELEASE FROM LOCATION 20 KM NORTHEAST OF BOWEN PLANT

Table B.1 (continued)

RELEASE TIME (EST)													
		0825			1002			1307			1600*		
DATE	HEIGHT A.G.	DIR	SPEED		DIR	SPEED		DIR	SPEED		DIR	SPEED	
DEC	M	DEG	M/S	MPH	DEG	M/S	MPH	DEG	M/S	MPH	DEG	M/S	MPH
13.	210	210	5	11	260	6	13	260	4	9	RAIN. INTO CLOUDS.		
	300	210	8	18	250	7	16						
	400	215	12	27	240	9	20						
	500	220	15	35	235	10	22						
	600	220	19	43	230	12	27						
	800	225	22	49	235	16	36						
	1000	225	20	45	CLOUDS AT								
	1200	230	16	36	1000 M.								
	1400	240	15	34									
	1600	245	18	40									
1800	CLOUDS AT												
		1700 M.											
		0830			0957			1253			1556*		
14	210	360	7	15	360	5	11	355	5	7	005	6	13
	300	005	9	20	005	7	16	020	4	9	010	5	11
	400	010	9	20	015	8	18	050	5	11	030	5	11
	500	020	9	20	030	9	20	080	5	11	060	5	11
	600	030	9	20	045	9	20	100	6	13	090	5	11
	900	040	8	18	080	6	13	125	5	11	120	5	11
	1000	045	5	13	110	5	11	150	3	7	155	3	7
	1200	010	5	11	075	3	7	LOW CLOUDS.			175	3	7
	1400	335	5	11	350	4	9				205	2	4
	1600	330	5	11	320	5	11				300	2	4
1800	325	5	11	310	4	9				325	4	9	
		0822			1007			1255			1555*		
15	210	105	10	22	105	12	27	110	9	20	115	5	11
	300	105	12	27	100	12	27	115	8	18	120	5	11
	400	105	14	31	105	12	27	120	7	16	125	5	11
	500	110	15	34	105	14	31	120	7	16	130	6	13
	600	110	15	35	105	16	36	125	7	16	140	7	16
	800	130	12	27	130	14	31	145	8	18	170	8	18
	1000	190	7	16	195	7	16	170	9	20	200	9	20
	1200	225	6	13	225	7	16	205	7	16	CLOUD BASE AT 940 M.		
	1400	240	5	11	240	6	13	240	5	13			
	1600	260	4	9	250	4	9	245	4	9			
1800	275	4	9	265	3	7	235	5	11				

* RELEASE FROM LOCATION 20 KM NORTHEAST OF BOWEN PLANT

Table B.1 (continued)

		RELEASE TIME (EST)											
		0827			1007			1137			1308		
DATE	HEIGHT A.G.	DIR	SPEED		DIR	SPEED		DIR	SPEED		DIR	SPEED	
DEC	M	DEG	M/S	MPH	DEG	M/S	MPH	DEG	M/S	MPH	DEG	M/S	MPH
16	210	145	3	7	145	4	9	325	1	2	315	4	9
	300	135	4	9	150	4	9	280	1	2	310	4	9
	400	125	5	11	155	4	9	245	1	2	305	5	11
	500	LOW CLOUDS.			160	3	7	240	1	2	295	5	11
	600				165	3	7	245	2	4	290	6	13
	800				245	1	2	260	3	7	INTO CLOUDS		
	1000				310	3	7	305	4	9			
	1200				330	7	16						
	1400				INTO CLOUDS								
		1558*											
16	210	360	4	9									
	300	355	5	11									
	400	345	5	13									
	500	340	6	13									
	600	330	6	13									
	800	305	6	13									
	1000	290	7	16									
	1200	290	8	13									
	1400	300	10	22									
	1500	300	11	25									
	1800	CLOUDS.											

* RELEASE FROM LOCATION 20 KM NORTHEAST OF BOWEN PLANT

Table B.2. Winds and temperatures at PNL station at site 24

		WIND*							WIND				
DAY	START TIME	TEMP *		DIR	SPEED		DAY	START TIME	TEMP		DIR	SPEED	
DEC	EST	C	F	DEG	M/S	MPH	DEC	FST	C	F	DEG	M/S	MPH
07	0910	2.6	37	051	0.4	1	08	0830	5.9	43	296	4.2	9
07	0920	2.8	37	061	0.5	1	08	0840	6.2	43	304	4.2	9
07	0930	6.1	43	103	0.5	1	08	0850	6.6	44	312	3.9	9
07	0940	7.9	46	158	0.5	1	08	0900	6.8	44	316	4.1	9
07	0950	9.4	49	098	0.3	1	08	0910	7.0	45	318	4.3	10
07	1000	7.5	46	022	0.4	1	08	0920	7.2	45	320	5.1	11
07	1010	9.5	49	307	0.2	1	08	0930	7.2	45	323	5.7	13
07	1020	9.8	50	295	0.8	2	08	0940	7.4	45	328	5.2	12
07	1030	11.3	52	274	0.4	1	08	0950	8.0	46	332	4.5	10
07	1040	12.5	55	242	0.8	2	08	1000	8.1	47	329	5.1	11
07	1050	13.7	57	265	0.7	2	08	1010	8.4	47	331	5.3	12
07	1100	13.9	57	203	0.7	2	08	1020	8.7	48	345	6.2	14
07	1110	12.8	55	299	1.1	2	08	1030	8.5	47	340	6.7	15
07	1120	12.2	54	232	1.0	2	08	1040	8.8	48	338	7.0	16
07	1130	13.0	55	238	0.5	1	08	1050	8.9	48	339	6.5	15
07	1140	13.6	56	267	1.7	4	08	1100	9.1	48	339	6.0	13
07	1150	13.0	55	291	2.0	4	08	1110	9.2	49	325	6.4	14
07	1200	12.7	55	285	1.3	3	08	1120	9.0	48	342	7.2	16
07	1210	13.7	57	232	2.1	5	08	1130	9.2	49	344	6.6	15
07	1220	14.1	57	261	2.9	6	08	1140	9.6	49	354	5.0	13
07	1230	13.8	57	292	3.2	7	08	1150	9.5	49	358	5.6	13
07	1240	13.7	57	278	2.1	5	08	1200	9.9	50	352	4.9	11
07	1250	14.2	58	313	1.7	4	08	1210	10.1	50	320	5.5	12
07	1300	13.9	57	314	1.5	3	08	1220	10.0	50	328	6.9	15
07	1310	14.0	57	320	1.5	3	08	1230	10.2	50	344	5.7	13
07	1320	14.6	58	276	0.9	2	08	1240	10.3	51	336	5.0	13
07	1330	14.5	58	245	0.8	2	08	1250	10.3	51	334	6.8	15
07	1340	15.1	59	327	0.7	2	08	1300	10.4	51	339	5.6	13
07	1350	14.9	59	223	1.1	2	08	1310	10.6	51	340	5.0	11
07	1400	14.9	59	222	1.1	2	08	1320	10.5	51	340	6.0	13
07	1410	14.9	59	269	0.5	1	08	1330	10.5	51	352	5.6	13
07	1420	15.4	60	209	1.2	3	08	1340	10.9	52	344	4.8	11
07	1430	15.3	60	208	1.8	4							
07	1440	15.2	59	228	1.8	4							
07	1450	15.1	59	260	2.2	5							
07	1500	15.2	59	268	2.1	5							
07	1510	15.2	59	240	3.1	7							
07	1520	15.3	60	277	2.3	5							
07	1530	15.3	60	255	2.6	5							
07	1540	15.5	60	259	2.7	5							

* Measured at 10-meter elevation.

Table B.2 (continued)

		WIND							WIND				
DAY	START TIME	TEMP		DIR	SPEED		DAY	START TIME	TEMP		DIR	SPEED	
DEC	EST	C	F	DEG	M/S	MPH	DEC	EST	C	F	DEG	M/S	MPH
09	0830	-1.9	29	MSG	MSG	MSG	10	0830	-1.1	30	207	0.5	1
09	0840	-1.4	29	166	0.1	0	10	0840	-0.2	32	204	0.7	2
09	0850	-1.1	30	023	0.2	0	10	0850	-0.2	32	154	0.2	0
09	0900	-0.6	31	017	0.3	1	10	0900	0.1	32	116	0.2	0
09	0910	0.0	32	084	0.6	1	10	0910	0.9	34	155	0.2	0
09	0920	0.2	32	075	0.3	1	10	0920	1.4	35	022	0.3	1
09	0930	1.0	34	112	0.1	0	10	0930	2.0	36	342	0.2	0
09	0940	1.5	35	223	0.3	1	10	0940	2.3	36	358	0.6	1
09	0950	1.6	35	341	0.5	1	10	0950	3.2	38	008	0.6	1
09	1000	2.9	37	077	0.7	2	10	1000	4.1	39	042	0.5	1
09	1010	4.1	39	094	2.5	5	10	1010	5.2	41	038	0.5	1
09	1020	5.0	41	103	2.9	6	10	1020	6.1	43	005	0.8	2
09	1030	5.6	42	111	3.4	8	10	1030	6.8	44	033	0.7	2
09	1040	6.7	44	097	4.0	9	10	1040	7.3	45	001	0.5	1
09	1050	6.6	44	085	4.4	10	10	1050	8.0	46	329	0.7	2
09	1100	7.0	45	078	3.9	9	10	1100	9.3	49	052	0.4	1
09	1110	7.7	46	105	3.2	7	10	1110	9.8	50	034	0.5	1
09	1120	7.9	46	100	3.8	9	10	1120	10.4	51	010	0.6	1
09	1130	8.3	47	121	4.4	10	10	1130	10.8	51	007	0.9	2
09	1140	9.1	48	118	3.4	8	10	1140	11.3	52	015	1.2	3
09	1150	9.9	50	103	3.1	7	10	1150	11.9	53	010	1.1	2
09	1200	10.1	50	120	2.6	5	10	1200	12.3	54	008	1.4	3
09	1210	10.1	50	117	3.3	7	10	1210	12.9	55	002	1.2	3
09	1220	10.1	50	111	2.4	5	10	1220	13.5	56	336	1.2	3
09	1230	10.5	51	103	2.8	6	10	1230	14.0	57	345	0.8	2
09	1240	10.9	52	089	1.1	2	10	1240	14.5	58	358	0.7	2
09	1250	11.1	52	094	2.8	6	10	1250	15.0	59	324	0.7	2
09	1300	11.1	52	084	1.2	3	10	1300	15.2	59	024	0.8	2
09	1310	11.7	53	122	1.9	4	10	1310	15.7	60	307	0.3	1
09	1320	11.8	53	090	1.2	3	10	1320	15.9	61	009	1.1	2
09	1330	12.0	54	065	0.9	2	10	1330	16.3	61	338	0.4	1
09	1340	12.4	54	MSG	MSG	MSG							

Table B.2 (continued)

WIND							WIND						
START		TEMP		-----			START		TEMP		-----		
DAY	TIME			DIR	SPEED		DAY	TIME			DIR	SPEED	
LFC	EST	C	F	DEG	M/S	MPH	LFC	EST	C	F	DEG	M/S	MPH
---	---	---	---	---	---	---	---	---	---	---	---	---	---
11	0840	5.3	42	MSG	MSG	MSG	12	0850	13.5	56	108	1.2	3
11	0850	5.5	42	MSG	MSG	MSG	12	0900	14.0	57	109	1.7	4
11	0900	6.1	43	071	1.3	3	12	0910	14.4	58	110	1.7	4
11	0910	6.8	44	090	1.4	3	12	0920	14.9	59	117	2.3	5
11	0920	7.4	45	092	1.5	3	12	0930	15.1	59	117	2.5	6
11	0930	8.7	48	094	2.3	5	12	0940	16.0	61	124	2.3	5
11	0940	9.0	48	091	2.8	5	12	0950	16.6	62	141	2.3	5
11	0950	9.4	49	099	2.3	5	12	1000	17.2	63	165	2.0	4
11	1000	10.1	50	110	2.4	5	12	1010	17.2	63	132	2.6	6
11	1010	10.7	51	104	2.5	6	12	1020	17.5	64	131	3.4	8
11	1020	11.5	53	110	2.6	6	12	1030	17.6	64	137	3.2	7
11	1030	12.1	54	119	1.5	3	12	1040	18.0	64	141	3.1	7
11	1040	13.1	56	112	2.2	5	12	1050	18.6	65	138	3.0	7
11	1050	13.4	56	119	2.3	5	12	1100	19.2	67	145	2.6	6
11	1100	14.1	57	127	2.3	5	12	1110	20.5	69	169	2.5	6
11	1110	14.9	59	129	2.7	6	12	1120	20.5	69	162	3.0	7
11	1120	15.1	59	130	3.1	7	12	1130	20.9	70	172	2.8	6
11	1130	16.0	61	150	2.3	5	12	1140	21.2	70	176	2.7	6
11	1140	16.3	61	142	2.6	5	12	1150	21.3	70	167	3.0	7
11	1150	16.5	62	129	2.5	5	12	1200	22.2	72	181	2.7	6
11	1200	16.8	62	132	2.6	6	12	1210	22.5	72	183	2.8	6
11	1210	17.7	64	148	4.0	9	12	1220	22.6	72	206	3.4	8
11	1220	18.2	65	167	3.3	7	12	1230	22.0	72	185	3.2	7
11	1230	18.2	65	165	3.2	7	12	1240	22.7	73	189	4.6	10
11	1240	18.2	65	160	2.2	5	12	1250	22.5	73	193	3.4	8
11	1250	18.7	66	129	2.1	5	12	1300	22.4	72	190	3.3	7
11	1300	19.3	67	149	3.3	7	12	1310	22.4	72	210	3.8	9
11	1310	19.4	67	158	3.6	8	12	1320	22.1	72	196	2.4	8
11	1320	19.7	67	167	2.4	5	12	1330	22.4	72	202	3.6	8
11	1330	20.2	68	164	2.4	5	12	1340	22.2	72	195	5.5	12
11	1340	20.8	69	161	2.4	5	12	1350	22.7	73	195	3.8	9
11	1350	21.1	70	193	3.3	7	12	1400	22.9	73	200	4.0	9
11	1400	21.3	70	183	3.3	7	12	1410	22.9	73	MSG	MSG	MSG
11	1410	21.0	70	206	3.5	8							

Table B.2 (continued)

		WIND							WIND				
DAY	START TIME	TEMP		DIR	SPEED		DAY	START TIME	TEMP		DIR	SPEED	
DEC	FST	C	F	DEG	M/S	MPH	DEC	FST	C	F	DEG	M/S	MPH
13	0810	16.9	62	MSG	MSG	MSG	13	1600	16.2	61	323	3.5	8
13	0820	17.0	63	182	0.4	1	13	1610	15.3	60	335	4.3	10
13	0830	17.0	63	185	0.9	2	13	1620	14.9	59	347	2.1	7
13	0840	17.3	63	184	2.1	5	13	1630	14.8	59	351	2.6	6
13	0850	17.4	63	183	2.5	6	13	1640	14.7	58	353	2.3	6
13	0900	17.5	64	186	2.9	6	13	1650	14.5	58	346	2.2	5
13	0910	17.7	64	183	3.2	7	13	1700	14.3	58	346	2.4	5
13	0920	17.4	63	185	2.1	5	13	1710	14.2	58	339	2.4	5
13	0930	17.5	64	185	1.8	4	13	1720	14.0	57	334	2.8	9
13	0940	17.4	63	235	1.2	3	13	1730	13.9	57	323	1.8	4
13	0950	17.3	63	309	1.2	3	13	1740	13.9	57	317	1.9	4
13	1000	17.3	63	275	1.3	4	13	1750	13.7	57	351	3.0	7
13	1010	17.3	63	275	2.4	5	13	1800	13.5	56	329	1.9	4
13	1020	17.3	63	261	2.2	5	13	1810	13.3	56	341	2.1	7
13	1030	17.0	63	252	2.4	5	13	1820	13.3	56	325	2.3	5
13	1040	16.7	62	243	2.2	5	13	1830	13.1	56	323	2.4	5
13	1050	16.4	62	262	1.4	3	13	1840	12.9	55	323	2.7	6
13	1100	16.2	61	271	1.5	4	13	1850	12.8	55	328	3.6	8
13	1110	16.2	61	283	2.6	6	13	1900	12.7	55	321	2.4	5
13	1120	16.2	61	267	2.6	6	13	1910	12.5	55	341	3.2	7
13	1130	16.1	61	272	1.9	4	13	1920	12.4	54	344	3.0	7
13	1140	16.1	61	316	1.2	3	13	1930	12.3	54	339	3.1	7
13	1150	15.9	61	351	1.5	3	13	1940	12.2	54	342	2.7	6
13	1200	15.9	61	336	0.7	2	13	1950	12.2	54	341	2.3	5
13	1210	16.0	61	202	0.6	1	13	2000	12.1	54	347	3.0	7
13	1220	16.2	61	184	1.9	4	13	2010	12.1	54	347	2.2	7
13	1230	16.3	61	242	0.9	2	13	2020	12.1	54	340	2.7	6
13	1240	16.3	61	272	1.1	2	13	2030	12.0	54	341	3.5	8
13	1250	16.5	62	257	1.1	2							
13	1300	16.5	62	273	0.9	2							
13	1310	16.5	62	268	1.8	4							
13	1320	16.6	62	252	2.2	5							
13	1330	16.6	62	257	1.7	4							
13	1340	16.7	62	296	1.8	4							
13	1350	16.6	62	284	2.4	5							
13	1400	16.7	62	270	2.4	5							
13	1410	16.7	62	276	2.0	4							
13	1420	16.7	62	274	2.4	5							
13	1430	16.7	62	289	2.2	5							
13	1440	16.7	62	290	2.3	5							
13	1450	16.5	62	277	2.1	5							
13	1500	16.4	62	275	2.3	5							
13	1510	16.3	61	267	2.1	5							
13	1520	16.2	61	264	2.0	4							
13	1530	16.2	61	272	1.5	2							
13	1540	16.2	61	289	1.5	3							
13	1550	16.2	61	285	1.3	3							

Table B.2 (continued)

		WIND							WIND				
DAY	START TIME	TEMP		DIR	SPEED		DAY	START TIME	TEMP		DIR	SPEED	
DEC	EST	C	F	DEG	M/S	MPH	DEC	EST	C	F	DEG	M/S	MPH
14	0910	4.0	39	MSG	MSG	MSG	15	0820	3.8	39	MSG	MSG	MSG
14	0920	4.2	40	350	2.9	6	15	0930	4.0	39	128	3.5	8
14	0930	4.8	41	349	2.9	6	15	0940	MSG	MSG	130	3.5	8
14	0940	4.9	41	338	3.0	7	15	0950	MSG	MSG	126	4.0	9
14	0950	5.2	41	350	2.6	6	15	0900	MSG	MSG	126	4.2	9
14	1000	5.4	42	324	3.2	7	15	0910	MSG	MSG	123	4.1	9
14	1010	5.7	42	348	2.3	5	15	0920	MSG	MSG	121	4.0	9
14	1020	6.0	42	341	2.2	5	15	0930	MSG	MSG	119	4.1	9
14	1030	6.2	43	345	1.4	3	15	0940	MSG	MSG	114	4.4	10
14	1040	6.1	43	025	1.0	2	15	0950	MSG	MSG	122	4.9	11
14	1050	6.3	43	016	0.8	2	15	1000	MSG	MSG	122	5.6	13
14	1100	6.5	44	349	1.6	4	15	1010	MSG	MSG	115	4.6	10
14	1110	6.7	44	349	1.8	4	15	1020	MSG	MSG	119	4.8	11
14	1120	6.6	44	356	2.1	5	15	1030	MSG	MSG	112	5.3	12
14	1130	6.8	44	343	2.1	5	15	1040	MSG	MSG	113	7.9	18
14	1140	7.0	45	354	1.9	4	15	1050	MSG	MSG	118	7.2	16
14	1150	7.2	45	352	2.0	4	15	1100	MSG	MSG	111	7.3	16
14	1200	7.9	46	341	2.4	5	15	1110	MSG	MSG	125	5.5	12
14	1210	8.0	46	336	2.2	5	15	1120	MSG	MSG	123	6.7	15
14	1220	8.0	46	301	1.3	3	15	1130	MSG	MSG	118	6.0	13
14	1230	8.4	47	213	1.5	3	15	1140	MSG	MSG	108	5.1	11
14	1240	8.6	47	344	1.8	4	15	1150	MSG	MSG	118	5.0	11
14	1250	8.8	48	357	1.5	3	15	1200	MSG	MSG	115	4.5	10
14	1300	9.0	48	343	2.1	5	15	1210	MSG	MSG	116	5.0	11
14	1310	9.1	48	359	1.6	4	15	1220	MSG	MSG	120	4.3	10
14	1320	9.4	49	007	1.5	3	15	1230	MSG	MSG	121	4.6	10
14	1330	9.4	49	002	1.2	3	15	1240	MSG	MSG	119	4.9	11
14	1340	9.5	49	001	1.2	3	15	1250	MSG	MSG	122	4.3	10
14	1350	9.8	50	352	2.0	4	15	1300	MSG	MSG	112	3.7	8
14	1400	9.9	50	000	1.3	3	15	1310	MSG	MSG	108	3.5	8
14	1410	10.0	50	350	1.8	4							
14	1420	10.2	50	002	0.8	2							
14	1430	10.1	50	239	0.7	2							
14	1440	10.3	51	357	1.7	4							
14	1450	10.2	50	348	1.3	3							

Table B.2 (continued)

DAY	START TIME	TEMP		WIND		
				DIR	SPEED	
	EST	C	F	DEG	M/S	KPH
16	0820	6.2	43	193	1.3	3
16	0830	6.3	43	155	1.7	4
16	0840	6.4	44	130	2.2	5
16	0850	6.5	44	123	2.1	5
16	0900	6.6	44	131	1.9	4
16	0910	6.9	44	158	1.0	2
16	0920	7.4	45	161	1.1	2
16	0930	7.3	45	173	1.0	2
16	0940	7.5	46	137	2.0	4
16	0950	7.5	46	140	1.9	4
16	1000	7.7	46	155	1.3	3
16	1010	7.9	46	137	1.5	3
16	1020	8.2	47	139	0.8	2
16	1030	8.3	47	132	0.7	2
16	1040	8.3	47	048	0.8	2
16	1050	8.3	47	026	1.2	3
16	1100	8.6	47	316	1.2	3
16	1110	8.8	48	335	1.2	3
16	1120	9.1	48	347	0.5	1
16	1130	9.0	48	355	0.7	2
16	1140	9.6	49	348	0.0	0
16	1150	10.1	50	189	0.7	2
16	1200	10.2	50	191	1.0	2
16	1210	10.4	51	228	0.6	1
16	1220	10.0	50	358	1.0	2
16	1230	10.2	50	327	0.7	2
16	1240	10.2	50	334	1.4	3
16	1250	10.2	50	345	1.4	3
16	1300	10.3	51	339	1.5	3
16	1310	10.7	51	337	1.5	3
16	1320	10.7	51	308	1.1	2
16	1330	10.9	52	309	1.2	3
16	1340	10.6	51	318	1.6	4
16	1350	10.8	51	330	2.1	5
16	1400	10.3	51	312	1.3	3
16	1410	MSG	MSG	319	1.8	4

Table B.3. Hodge Mountain meteorology and ORNL wind station observations

GA. POWER HODGE MT. STATION							ORNL WIND STATIONS								
START		DEL	DEW	SOLAR	WIND		BJWEN 1		BJWEN 2		SITE 17		SITE 24		
DAY	TIME	TEMP	TEMP	PT	RAD	DIR	SPD	DIR	SPD	DIR	SPD	DIR	SPD	DIR	SPD
DEC	EST	°F	F°	°F	LPM*	DEG	MPH	DEG	MPH	DEG	MPH	DEG	MPH	DEG	MPH
03	0000	47	3.3	28	.	295	26	CLM	0	CLM	0	MSG	MSG	2	
08	0100	47	3.4	28	.	300	25	CLM	0	CLM	0	MSG	MSG	2	
08	0200	46	3.0	29	.	310	25	030	1	050	1	MSG	MSG	2	
08	0300	44	2.7	29	.	320	23	CLM	0	050	1	MSG	MSG	1	
03	0400	44	2.5	29	.	350	27	CLM	0	CLM	0	MSG	MSG	2	
03	0500	44	0.9	23	.	355	21	290	4	280	4	MSG	MSG	3	
08	0600	43	1.8	27	0.00	345	20	340	2	330	1	MSG	MSG	3	
08	0700	42	2.5	26	0.01	340	23	330	3	330	2	MSG	MSG	3	
08	0800	41	1.5	26	0.28	335	21	310	4	300	5	MSG	MSG	5	
03	0900	43	0.3	25	0.43	340	21	330	5	320	5	MSG	MSG	6	
08	0910	43	-0.2	27	0.54	345	20								
08	0920	44	-0.3	28	0.61	350	21								
08	0930	45	-0.3	28	0.66	355	22								
08	0940	46	-0.8	29	0.72	350	33								
03	0950	46	-1.1	29	0.75	355	26								
03	1000	47	-1.2	29	0.81	350	30	350	8	330	7	MSG	MSG	8	
08	1010	47	-1.2	29	0.85	355	24								
08	1020	47	-1.4	29	0.90	355	22								
08	1030	48	-1.5	29	0.94	360	20								
08	1040	48	-1.7	29	0.98	355	23								
03	1050	48	-1.3	29	1.02	350	22								
03	1100	49	-1.9	29	1.05	360	19	350	9	340	7	MSG	MSG	7	
08	1110	49	-1.9	30	1.07	360	23								
08	1120	49	-2.2	30	1.09	005	23								
08	1130	49	-2.1	30	1.11	355	23								
08	1140	50	-2.0	30	1.12	350	22								
03	1150	50	-2.3	30	1.13	345	17								
03	1200	50	-2.3	31	1.14	340	18	340	8	340	7	MSG	MSG	8	
08	1210	50	-2.2	30	1.15	355	17								
08	1220	51	-2.2	30	1.15	350	21								
08	1230	51	-2.5	30	1.15	005	15								
08	1240	51	-2.2	30	1.15	350	19								
03	1250	52	-2.3	30	1.14	345	20								
03	1300	52	-2.5	30	1.13	360	17	350	9	350	7	MSG	MSG		
08	1320	52	-2.8	29	1.10	355	20								
08	1330	52	-2.3	28	1.08	355	21								
08	1340	52	-2.2	27	1.06	355	20								
08	1350	52	-2.2	26	1.03	350	20								

* LANGLEYS PER MIN OR (GRAM-CALORIES/SQUARE CM)/MIN

TEMP AND DEW POINT AT 1.0M

DEL TEMP IS TEMP AT 35M MINUS TEMP AT 10M

SOLAR RADIATION AT APPROXIMATELY 1.5M

HODGE MOUNTAIN WIND SPEED AND DIRECTION AT 35M

ORNL WIND SPEEDS AND DIRECTIONS AT APPROXIMATELY 5M

Table B.3 (continued)

GA. POWER HODGE MT. STATION						ORVL WIND STATIONS									
						WIND		BOWEN 1		BOWEN 2		SITE 17		SITE 24	
START	DEL	DEW	SOLAR												
DAY	TIME	TEMP	TEMP	PT	RAD	DIR	SPD	DIR	SPD	DIR	SPD	DIR	SPD	DIR	SPD
DEC	EST	°F	F°	°F	LMH	DEG	MPH	DEG	MPH	DEG	MPH	DEG	MPH	DEG	MPH
08	1400	52	-2.0	25	0.90	355	19	360	8	340	5	MSG	MSG	MSG	M
08	1500	52	-1.8	20	0.63	355	18	360	7	340	5	MSG	MSG	MSG	6
08	1600	51	-0.6	17	0.21	360	21	010	7	350	4	MSG	MSG	MSG	6
08	1700	48	0.2	16	0.01	355	19	350	4	340	1	MSG	MSG	MSG	3
03	1800	46	0.6	17	0.00	345	19	350	3	330	1	MSG	MSG	MSG	3
08	1900	44	1.0	17	.	350	24	340	3	320	2	MSG	MSG	MSG	3
08	2000	42	0.6	17	.	355	23	330	3	310	2	MSG	MSG	MSG	3
08	2100	41	0.2	17	.	360	20	340	2	320	1	MSG	MSG	MSG	3
08	2200	39	0.1	17	.	360	20	340	2	320	1	MSG	MSG	MSG	2
08	2300	38	0.3	17	.	005	21	340	2	330	1	MSG	MSG	MSG	0

Table B.3 (continued)

GA. POWER HODGE MT. STATION							ORNL WIND STATIONS								
START		DEL	DEW	SOLAR	WIND		BOWEN 1		BOWEN 2		SITE 17		SITE 24		
DAY	TIME				TEMP	TEMP	PT	RAD	DIR	SPD	DIR	SPD	DIR	SPD	DIR
DEC	EST	°F	°F	°F	LM*	DEG	MPH	DEG	MPH	DEG	MPH	DEG	MPH	DEG	MPH
09	0000	37	0.2	17	.	005	22	350	3	350	2	MSG	MSG	2	
09	0100	36	0.0	17	.	015	17	330	1	330	1	MSG	MSG	2	
09	0200	35	0.1	17	.	025	13	320	1	310	2	MSG	MSG	2	
09	0300	34	0.2	17	.	015	13	110	1	110	1	MSG	MSG	0	
09	0400	33	0.7	17	.	035	16	CLM	0	CLM	0	MSG	MSG	0	
09	0500	32	2.4	17	.	040	19	CLM	0	CLM	0	MSG	MSG	1	
09	0600	32	3.2	17	0.00	050	17	CLM	0	CLM	0	MSG	MSG	1	
09	0700	31	4.2	16	0.02	070	17	CLM	0	CLM	0	MSG	MSG	1	
09	0800	34	1.9	17	0.25	110	16	CLM	0	CLM	0	MSG	MSG	1	
09	0900	37	-0.1	18	0.47	115	15	120	2	110	2	MSG	MSG	1	
09	0910	38	-0.6	18	0.53	125	14								
09	0920	38	-0.7	19	0.58	130	12								
09	0930	39	-0.9	19	0.53	125	12								
09	0940	40	-1.1	20	0.69	125	13								
09	0950	40	-1.1	20	0.74	125	14								
09	1000	41	-1.0	20	0.79	130	16	100	11	090	8	MSG	MSG	4	
09	1010	42	-1.1	20	0.84	125	16								
09	1020	42	-1.5	21	0.88	125	14								
09	1030	44	-2.0	21	0.93	130	15								
09	1040	45	-1.5	21	0.97	130	17								
09	1050	46	-2.2	20	1.00	130	19								
09	1100	46	-2.5	21	1.03	130	18	110	9	100	8	MSG	MSG	4	
09	1110	46	-1.3	20	1.06	130	19								
09	1120	47	-1.3	20	1.08	130	18								
09	1130	48	-2.0	21	1.10	130	17								
09	1140	49	-1.2	21	1.11	135	18								
09	1150	49	-0.9	20	1.12	135	18								
09	1200	49	-1.4	20	1.13	130	16	110	7	100	5	MSG	MSG	3	
09	1210	50	-1.4	20	1.13	135	15								
09	1220	50	-0.9	20	1.14	135	12								
09	1230	51	-1.3	21	1.13	130	13								
09	1240	51	-0.5	20	1.13	140	13								
09	1250	52	-0.8	20	1.12	150	12								
09	1300	52	-1.6	20	1.11	125	11	140	6	130	4	MSG	MSG	2	
09	1310	52	0.5	20	1.10	135	9								
09	1320	54	-1.2	21	1.08	125	10								
09	1330	54	0.7	21	1.05	150	8								
09	1340	54	0.5	21	1.03	120	6								
09	1350	54	-0.8	21	1.00	120	9								
09	1400	54	0.2	21	0.97	120	6	110	4	100	3	MSG	MSG	2	
09	1410	54	0.7	21	0.94	140	5								
09	1420	55	1.0	22	0.90	205	3								
09	1430	55	0.9	22	0.85	135	4								
09	1440	55	2.1	22	0.83	140	5								
09	1450	56	1.3	22	0.77	145	4								

Table B.3 (continued)

GA. POWER HODGE MT. STATION							ORNL WIND STATIONS								
START		DEL		DEW	SOLAR	WIND		BOWEN 1		BOWEN 2		SITE 17		SITE 24	
DAY	TIME	TEMP	TEMP	PT	RAD	DIR	SPD	DIR	SPD	DIR	SPD	DIR	SPD	DIR	SPD
DEC	EST	°F	°F	°F	LPM*	DEG	MPH	DEG	MPH	DEG	MPH	DEG	MPH	DEG	MPH
09	1500	56	0.3	22	0.58	125	5	080	3	100	3	MSG	MSG	1	
09	1600	56	-0.3	22	0.21	110	3	050	2	CLM	0	MSG	MSG	2	
09	1700	54	-1.1	21	0.01	080	7	CLM	0	CLM	0	MSG	MSG	0	
09	1800	53	0.1	22	0.00	110	9	CLM	0	CLM	0	MSG	MSG	0	
09	1900	52	3.6	22	.	140	10	CLM	0	CLM	0	MSG	MSG	0	
09	2000	50	3.0	22	.	140	8	CLM	0	CLM	0	MSG	MSG	0	
09	2100	50	3.9	22	.	135	8	CLM	0	CLM	0	MSG	MSG	0	
09	2200	49	4.5	23	.	145	9	CLM	0	CLM	0	MSG	MSG	0	
09	2300	46	7.1	24	.	145	11	130	2	140	2	MSG	MSG	0	

Table B.3 (continued)

GA. POWER HODGE MT. STATION							ORNL WIND STATIONS							
START		DEL		DEW	SOLAR	WIND	BOWEN 1		BOWEN 2		SITE 17		SITE 24	
DAY	TIME	TEMP	TEMP	PT	RAD	DIR SPD	DIR	SPD	DIR	SPD	DIR	SPD	DIR	SPD
DEC	EST	°F	°F	°F	LPM*	DEG MPH	DEG	MPH	DEG	MPH	DEG	MPH	DEG	MPH
10	0000	44	3.0	25	.	150 15	130	3	120	2	MSG	MSG	0	
10	0100	41	7.3	24	.	165 14	110	2	100	2	MSG	MSG	0	
10	0200	42	7.4	24	.	180 14	CLM	0	CLM	0	MSG	MSG	2	
10	0300	42	5.8	24	.	170 10	140	1	110	2	MSG	MSG	2	
10	0400	40	5.5	24	.	165 11	160	1	150	2	MSG	MSG	2	
10	0500	40	5.3	23	.	170 11	120	2	110	2	MSG	MSG	2	
10	0600	40	5.0	23	0.00	175 11	130	1	130	1	MSG	MSG		
10	0700	40	5.0	23	0.01	185 8	CLM	0	CLM	0	MSG	MSG		
10	0800	42	5.7	23	0.26	175 7	120	1	110	1	MSG	MSG		
10	0900	42	5.2	24	0.46	160 8	100	1	080	2	MSG	MSG		
10	0910	42	5.3	24	0.52	155 7								
10	0920	43	5.9	24	0.57	150 7								
10	0930	43	4.9	25	0.62	145 8								
10	0940	43	4.7	25	0.68	150 8								
10	0950	44	4.3	26	0.73	150 8								
10	1000	45	3.4	26	0.77	155 7	130	3	110	2	MSG	MSG		
10	1010	46	3.1	27	0.81	160 6								
10	1020	48	2.4	28	0.86	170 5								
10	1030	50	2.3	29	0.90	185 6								
10	1040	50	2.0	29	0.93	190 4								
10	1050	51	2.1	30	0.97	190 4								
10	1100	52	2.4	31	1.01	175 4	VAR	2	260	2	MSG	MSG		
10	1110	53	2.2	31	1.03	175 4								
10	1120	54	2.4	31	1.05	155 4								
10	1130	54	2.0	32	1.07	140 5								
10	1140	55	2.4	32	1.08	160 5								
10	1150	56	2.4	32	1.10	175 5								
10	1200	57	2.3	32	1.11	160 5	VAR	3	320	2	MSG	MSG		
10	1210	58	2.2	31	1.12	165 5								
10	1220	58	1.7	30	1.12	135 5								
10	1230	59	1.1	31	1.12	150 4								
10	1240	60	1.8	31	1.12	165 6								
10	1250	60	2.0	30	1.11	150 5								
10	1300	60	2.5	30	1.10	145 5	VAR	3	VAR	2	MSG	MSG		
10	1310	61	0.4	31	1.08	125 6								
10	1320	61	-0.1	30	1.06	120 5								
10	1330	61	1.7	30	1.04	180 6								
10	1340	62	1.8	30	1.02	150 5								
10	1350	62	1.3	30	0.98	125 5								
10	1400	63	1.6	30	0.96	165 4	220	2	210	2	MSG	MSG		
10	1410	64	1.4	30	0.92	135 6								
10	1420	64	2.1	30	0.89	175 6								
10	1430	64	1.0	30	0.85	145 6								
10	1440	64	1.8	30	0.81	170 7								
10	1450	64	2.1	30	0.77	170 5								

Table B.3 (continued)

GA. POWER HODGE MT. STATION							ORNL WIND STATIONS								
START		DEL		DEW	SOLAR	WIND		BOWEN 1		BOWEN 2		SITE 17		SITE 24	
DAY	TIME	TEMP	TEMP	PT	RAD	DIR	SPD	DIR	SPD	DIR	SPD	DIR	SPD	DIR	SPD
DEC	EST	°F	°F	°F	LPM*	DEG	MPH	DEG	MPH	DEG	MPH	DEG	MPH	DEG	MPH
10	1500	64	1.5	29	0.72	125	4	350	1	360	1	MSG		MSG	
10	1510	65	0.0	30	0.67	VAR	4								
10	1520	65	0.2	30	0.62	230	4								
10	1530	65	0.8	29	0.57	160	3								
10	1540	65	0.7	28	0.51	140	4								
10	1550	65	2.4	27	0.45	150	7								
10	1600	64	2.4	27	0.20	145	6	050	1	CLM	0	MSG		MSG	
10	1700	61	3.9	27	0.02	140	12	120	4	110	3	MSG		MSG	
10	1800	59	4.0	27	0.00	155	17	120	5	110	4	MSG		MSG	
10	1900	57	5.6	27	.	160	20	110	5	100	4	MSG		MSG	
10	2000	56	4.6	28	.	165	20	CLM	0	CLM	0	MSG		MSG	
10	2100	55	5.1	28	.	165	18	CLM	0	CLM	0	MSG		MSG	
10	2200	53	4.2	28	.	160	21	100	3	090	3	MSG		MSG	
10	2300	53	4.0	30	.	170	17	110	4	100	3	MSG		MSG	

Table B.3 (continued)

GA. POWER HEDGE MT. STATION							ORNL WIND STATIONS							
START		DEL	DEW	SOLAR	WIND		BOWEN 1		BOWEN 2		SITE 17		SITE 24	
DAY	TIME				DIR	SPD	DIR	SPD	DIR	SPD	DIR	SPD	DIR	SPD
DEC	EST	°F	°F	°F LPM*	DEG	MPH	DEG	MPH	DEG	MPH	DEG	MPH	DEG	MPH
11	0000	50	4.4	31 .	170	15	120	1	140	1	MSG		MSG	
11	0100	49	3.9	32 .	155	17	100	7	100	5	MSG		MSG	
11	0200	48	4.1	34 .	155	20	100	7	090	7	MSG		MSG	
11	0300	47	4.2	35 .	150	21	100	5	080	4	MSG		MSG	
11	0400	48	4.2	36 .	140	22	100	4	090	3	MSG		MSG	
11	0500	46	5.4	34 .	140	23	100	2	080	2	MSG		MSG	
11	0600	46	5.4	34 .	145	21	090	3	080	2	MSG		MSG	
11	0700	46	5.2	35 0.00	145	21	100	2	090	1	MSG		MSG	
11	0800	47	3.9	36 0.03	145	20	100	4	080	4	MSG		MSG	
11	0900	48	3.0	38 0.14	145	17	110	6	090	5	MSG		MSG	
11	0910	48	3.0	38 0.21	140	16								
11	0920	48	2.5	38 0.17	140	15								
11	0930	49	2.5	38 0.19	135	15								
11	0940	49	2.5	39 0.40	135	17								
11	0950	50	2.6	39 0.57	135	18								
11	1000	50	2.3	39 0.45	135	17	140	7	120	6	140	3	MSG	
11	1010	51	1.3	40 0.88	140	16								
11	1020	53	1.2	41 0.53	145	15								
11	1030	54	1.0	42 1.01	140	14								
11	1040	56	0.3	43 0.95	140	10								
11	1050	57	0.8	44 0.73	150	9								
11	1100	57	1.1	45 0.83	160	10	150	8	150	8	140	5	MSG	
11	1110	58	0.7	45 1.03	160	8								
11	1120	59	0.5	46 1.03	150	9								
11	1130	61	0.9	47 1.04	170	9								
11	1140	61	1.2	48 1.05	185	9								
11	1150	62	1.2	48 1.04	170	9								
11	1200	62	1.1	49 0.98	185	8	160	10	140	9	150	5	MSG	
11	1210	62	1.5	49 0.77	175	10								
11	1220	63	0.3	48 1.08	155	14								
11	1230	64	0.9	49 0.80	150	14								
11	1240	64	1.0	49 0.62	155	13								
11	1250	65	0.6	49 1.00	165	12								
11	1300	67	0.4	50 1.10	150	12	170	12	150	11	160	5	MSG	
11	1310	67	0.4	51 1.07	180	15								
11	1320	68	0.4	52 0.93	180	14								
11	1330	68	0.3	52 1.07	160	13								
11	1340	68	0.5	52 0.98	170	12								
11	1350	68	0.7	52 0.69	165	13								

Table B.3 (continued)

GA. POWER RIDGE MT. STATION							ORNL WIND STATIONS								
START		DEL TEMP	DEW TEMP	SOLAR PT	RAD	WIND		BOWEN 1		BOWEN 2		SITE 17		SITE 24	
DAY	TIME					DIR	SPD	DIR	SPD	DIR	SPD	DIR	SPD	DIR	SPD
DEC	EST	°F	°F	°F	LPM*	DEG	MPH	DEG	MPH	DEG	MPH	DEG	MPH	DEG	MPH
11	1400	69	0.7	51	0.63	185	16	180	12	170	10	170	6	MSG	
11	1500	68	1.3	50	0.30	175	13	170	9	150	8	150	4	MSG	
11	1600	68	2.0	49	0.13	155	13	140	6	150	7	140	3	MSG	
11	1700	66	2.9	49	0.02	140	13	130	5	120	5	120	2	MSG	
11	1800	65	3.2	49	0.00	145	23	140	5	140	5	150	2	MSG	
11	1900	63	3.0	49	.	160	15	110	1	110	1	CLM	0	MSG	
11	2000	62	3.1	49	.	155	21	120	5	120	5	130	2	MSG	
11	2100	60	3.4	48	.	150	23	110	6	110	7	300	1	MSG	
11	2200	60	3.5	48	.	155	21	100	5	090	4	CLM	0	MSG	
11	2300	60	3.4	49	.	145	22	110	5	100	6	CLM	0	MSG	

Table B.3 (continued)

GA. POWER HODGE MT. STATION							ORNL WIND STATIONS							
START		DEL	DEW	SOLAR	WIND		BOWEN 1		BOWEN 2		SITE 17		SITE 24	
DAY	TIME				DIR	SPD	DIR	SPD	DIR	SPD	DIR	SPD	DIR	SPD
DEC	EST	°F	°F	°F LPM*	DEG	MPH	DEG	MPH	DEG	MPH	DEG	MPH	DEG	MPH
12	0000	60	3.5	49 .	145	22	110	6	110	5	CLM	0	MSG	
12	0100	59	3.9	49 .	140	21	110	5	100	5	200	1	MSG	
12	0200	59	3.9	48 .	140	22	110	7	110	7	120	1	MSG	
12	0300	58	3.4	48 .	145	22	110	7	100	7	140	1	MSG	
12	0400	57	2.9	48 .	155	10	110	6	100	6	100	1	MSG	
12	0500	56	2.9	48 .	150	17	110	6	090	6	120	2	MSG	
12	0600	56	2.8	48 .	145	17	100	5	090	5	110	3	MSG	
12	0700	57	1.9	49 0.00	170	15	130	3	120	3	130	3	MSG	
12	0800	58	1.5	50 0.02	170	12	140	7	140	7	130	3	MSG	
12	0810	58	1.5	50 0.02	170	13								
12	0820	58	1.5	50 0.03	165	13								
12	0830	58	1.5	51 0.05	160	14								
12	0840	58	1.5	51 0.09	160	13								
12	0850	59	1.5	51 0.11	170	10								
12	0900	58	1.6	52 0.13	160	10	130	8	130	8	140	3	MSG	
12	0910	58	1.7	52 0.16	155	12								
12	0920	58	1.8	52 0.17	160	14								
12	0930	58	1.8	52 0.18	155	15								
12	0940	59	1.5	52 0.21	155	17								
12	0950	60	1.4	53 0.25	160	15								
12	1000	60	1.4	53 0.32	160	13	160	9	160	11	140	3	MSG	
12	1010	60	1.3	54 0.40	170	13								
12	1020	60	1.5	54 0.43	170	12								
12	1030	61	1.5	54 0.75	165	10								
12	1040	62	1.3	55 0.92	165	11								
12	1050	63	0.5	55 0.92	160	11								
12	1100	65	-0.1	55 0.95	165	12	160	11	150	11	150	4	MSG	
12	1110	66	-0.3	56 0.99	165	12								
12	1120	67	0.2	56 0.99	165	13								
12	1130	68	-0.1	56 1.08	170	13								
12	1140	69	0.2	56 1.07	175	12								
12	1150	70	0.0	56 1.06	170	12								
12	1200	71	0.1	57 1.13	180	14	170	15	180	14	180	5	MSG	
12	1210	71	0.2	57 0.90	185	14								
12	1220	71	0.3	56 0.90	170	13								
12	1230	73	0.0	56 0.90	185	15								
12	1240	73	0.0	56 0.90	185	16								
12	1250	74	-0.4	55 1.07	185	19								

Table B.3 (continued)

GA. POWER LODGE MT. STATION						ORNL WIND STATIONS									
START						WIND		BOWEN 1		BOWEN 2		SITE 17		SITE 24	
DAY	TIME	TEMP	DEL TEMP	DEW PT	SOLAR RAD	DIR	SPD	DIR	SPD	DIR	SPD	DIR	SPD	DIR	SPD
DEC	EST	°F	°F	°F	LPM*	DEG	MPH	DEG	MPH	DEG	MPH	DEG	MPH	DEG	MPH
12	1300	74	-0.1	54	0.65	190	21	210	13	200	12	190	7	MSG	
12	1400	73	0.4	52	0.44	190	19	210	8	210	8	190	7	MSG	
12	1500	72	0.8	52	0.26	195	18	210	8	200	7	200	6	MSG	
12	1600	71	1.7	51	0.12	180	13	150	6	150	6	180	4	MSG	
12	1700	69	2.4	50	0.01	165	13	140	7	120	7	160	3	MSG	
12	1800	68	2.9	50	0.00	155	17	130	6	120	6	140	2	MSG	
12	1900	67	2.8	50	.	170	11	120	1	120	1	CLM	0	MSG	
12	2000	66	3.2	50	.	175	11	150	1	190	1	140	1	MSG	
12	2100	65	3.6	50	.	155	15	110	4	110	3	110	1	MSG	
12	2200	64	3.6	50	.	170	18	130	7	130	7	190	1	MSG	
12	2300	63	3.2	50	.	165	20	140	8	140	8	160	2	MSG	

Table B.3 (continued)

GA. POWER HODGE MT. STATION							ORNL WIND STATIONS							
START		DEL	DEW	SOLAR	WIND		BOWEN 1		BOWEN 2		SITE 17		SITE 24	
DAY	TIME				DIR	SPD	DIR	SPD	DIR	SPD	DIR	SPD	DIR	SPD
DEC	EST	°F	°F	°F	°F	MPH	°F	MPH	°F	MPH	°F	MPH	°F	MPH
13	0000	62	3.3	50	.	165 20	140	8	140	8	170	3	MSG	
13	0100	62	2.8	50	.	160 19	140	7	130	7	140	2	MSG	
13	0200	62	2.9	50	.	160 20	120	5	110	4	120	2	MSG	
13	0300	62	2.4	51	.	165 19	140	5	140	7	140	4	MSG	
13	0400	62	2.2	52	.	165 17	150	8	140	7	150	5	MSG	
13	0500	63	2.1	52	.	180 14	160	8	150	8	160	3	MSG	
13	0600	62	2.3	52	.	185 15	170	6	160	5	150	3	MSG	
13	0700	62	2.3	52	0.00	190 18	180	5	170	5	150	2	MSG	
13	0800	62	2.5	52	0.01	195 18	130	5	130	5	170	3	MSG	
13	0810	62	2.5	53	0.02	195 17								
13	0820	62	2.5	53	0.03	195 17								
13	0830	62	2.5	53	0.09	190 16								
13	0840	63	2.4	54	0.07	190 16								
13	0850	63	2.3	54	0.03	185 17								
13	0900	64	2.2	54	0.04	195 16	200	7	200	7	210	3	MSG	
13	0910	64	2.1	54	0.06	195 17	200	7	200	8	190	3	MSG	
13	0920	64	1.9	54	0.09	195 17	190	8	180	7	200	3	MSG	
13	0930	64	1.6	54	0.16	195 14	210	7	210	7	310	4	MSG	
13	0940	64	1.0	54	0.09	235 14	250	7	260	8	300	4	MSG	
13	0950	64	0.3	54	0.09	280 14	310	6	300	7	320	3	MSG	
13	1000	64	-0.1	54	0.07	285 15	310	3	300	5	350	2	MSG	
13	1010	64	0.2	54	0.08	275 13	290	5	280	5	350	1	MSG	
13	1020	64	1.0	54	0.08	270 12	300	4	290	5	290	1	MSG	
13	1030	63	0.8	54	0.08	275 13	300	4	290	5	260	1	MSG	
13	1040	63	0.5	54	0.06	275 12	290	5	280	5	220	1	MSG	
13	1050	63	1.8	54	0.04	260 14	230	5	270	5	230	1	MSG	
13	1100	62	2.0	55	0.04	260 15	230	5	280	5	340	2	MSG	
13	1110	62	1.3	56	0.05	265 17	310	3	310	4	350	2	MSG	
13	1120	62	1.2	55	0.06	270 16	300	4	310	4	350	2	MSG	
13	1130	62	-0.1	55	0.07	305 12	310	4	310	6	360	2	MSG	
13	1140	62	-0.5	55	0.11	330 10	340	2	340	3	350	2	MSG	
13	1150	62	-0.5	55	0.18	320 11	350	2	350	2	340	2	MSG	
13	1200	62	-0.5	56	0.23	315 11	340	2	340	2	270	1	MSG	
13	1210	62	-0.5	56	0.24	310 9	320	2	290	2	200	2	MSG	
13	1220	62	0.2	56	0.21	275 8	230	3	240	3	220	2	MSG	
13	1230	62	0.9	56	0.16	240 8	260	4	270	5	300	2	MSG	
13	1240	62	0.4	56	0.21	285 6	330	4	300	4	340	2	MSG	
13	1250	62	-0.4	56	0.18	300 9	290	3	290	4	310	2	MSG	
13	1300	62	-0.3	56	0.12	290 7	310	1	290	2	330	3	MSG	
13	1310	62	-0.3	56	0.13	300 8	290	3	290	4	320	3	MSG	
13	1320	62	-0.4	56	0.11	300 9	290	4	290	5	310	3	MSG	
13	1330	62	-0.4	56	0.09	300 10	290	4	300	5	330	3	MSG	
13	1340	62	-0.4	56	0.08	300 10	320	2	310	3	330	3	MSG	
13	1350	62	-0.4	56	0.06	310 11	320	4	320	5	330	3	MSG	

Table B.3 (continued)

GA. POWER HODGE MT. STATION							ORNL WIND STATIONS							
START		DEL TEMP	DEW PT	SOLAR RAD	WIND		BJWEN 1		BJWEN 2		SITE 17		SITE 24	
DAY	TIME				DIR	SPD	DIR	SPD	DIR	SPD	DIR	SPD	DIR	SPD
DEC	EST	°F	°F	°F LPM*	DEG	MPH	DEG	MPH	DEG	MPH	DEG	MPH	DEG	MPH
13	1400	62	-0.4	56 0.13	310	12	310	4	310	5	320	3	MSG	
13	1410	62	-0.5	56 0.18	310	10	310	5	300	6	320	3	MSG	
13	1420	62	-0.5	56 0.13	305	11	300	6	300	7	320	4	MSG	
13	1430	62	-0.5	56 0.07	305	10	310	5	310	7	320	3	MSG	3
13	1440	62	-0.5	56 0.03	310	11	310	5	310	7	330	3	MSG	3
13	1450	62	-0.5	56 0.04	310	12	300	5	310	7	320	3	MSG	3
13	1500	62	-0.5	56 0.04	305	12	300	5	300	7	320	3	MSG	3
13	1510	62	-0.5	57 0.05	305	13	290	6	290	7	320	3	MSG	3
13	1520	62	-0.5	56 0.04	305	12	290	5	290	6	320	3	MSG	3
13	1530	62	-0.5	57 0.05	310	11	300	5	300	5	330	3	MSG	3
13	1540	62	-0.5	57 0.06	315	11	320	3	310	4	350	7	MSG	2
13	1550	62	-0.5	57 0.07	325	11	300	4	300	6	360	6	MSG	2
13	1600	61	-0.6	57 0.03	335	16	360	5	340	4	350	3	MSG	4
13	1610	59	-0.5	55 0.04	005	16								
13	1620	59	-0.5	54 0.05	005	14								
13	1630	58	-0.5	53 0.04	360	12								
13	1640	58	-0.5	53 0.04	350	11								
13	1650	58	-0.5	53 0.03	355	11								
13	1700	58	-0.5	52 0.03	355	13	350	3	350	5	350	5	MSG	5
13	1710	58	-0.5	52 0.02	355	15								
13	1720	58	-0.5	52 0.01	360	19								
13	1730	57	-0.5	52 0.00	350	19								
13	1740	57	-0.5	51 .	355	22								
13	1750	56	-0.5	51 .	355	24								
13	1800	55	-0.6	49 .	360	21	350	7	340	6	350	6	MSG	7
13	1900	54	-0.6	48 .	360	19	360	7	340	5	350	5	MSG	4
13	2000	53	-0.5	46 .	360	24	350	7	340	5	350	5	MSG	5
13	2100	52	-0.4	44 .	355	22	350	7	340	5	350	7	MSG	5
13	2200	50	-0.4	43 .	355	23	350	7	340	7	350	7	MSG	7
13	2300	49	-0.4	40 .	350	23	350	8	340	5	340	7	MSG	7

Table B.3 (continued)

GA. POWER HOOGE MT. STATION							ORNL WIND STATIONS							
START		DEL	DEW	SOLAR	WIND		BOWEN 1		BOWEN 2		SITE 17		SITE 24	
DAY	TIME				DIR	SPD	DIR	SPD	DIR	SPD	DIR	SPD	DIR	SPD
DEC	EST	F	F	F	PM*	DEG	MPH	DEG	MPH	DEG	MPH	DEG	MPH	MPH
14	0000	47	-0.6	39	.	355	22	360	7	340	5	350	6	MSG 7
14	0100	46	-0.6	37	.	355	19	360	7	340	5	350	6	MSG 6
14	0200	45	-0.5	36	.	355	21	350	5	340	5	350	6	MSG 7
14	0300	44	-0.5	35	.	350	22	350	7	340	5	350	6	MSG 7
14	0400	43	-0.5	33	.	355	22	360	7	340	5	350	7	MSG 7
14	0500	41	-0.4	31	.	360	20	350	5	340	4	350	8	MSG 6
14	0600	40	-0.5	30	.	005	18	350	7	340	4	360	7	MSG 5
14	0700	39	-0.2	29	0.00	355	16	350	5	340	4	350	5	MSG 4
14	0800	38	-0.4	29	0.19	360	18	350	4	340	3	350	6	MSG 4
14	0900	41	-0.9	30	0.50	360	13	010	6	340	5	350	5	MSG 5
14	1000	43	-1.3	31	0.73	010	13	010	5	340	5	010	6	MSG 6
14	1100	46	-1.4	32	0.68	010	12	360	5	340	4	010	5	MSG 5
14	1200	49	-1.9	34	0.88	005	12	350	6	340	5	360	6	MSG 5
14	1300	50	-1.8	33	0.75	015	12	350	5	340	5	010	5	MSG 4
14	1400	52	-1.9	34	0.75	360	11	350	6	340	5	020	5	MSG 4
14	1500	52	-1.5	34	0.50	010	13	350	4	340	4	020	5	MSG 4
14	1600	50	-0.7	32	0.13	010	13	350	3	340	3	010	4	MSG 4
14	1700	49	-0.4	32	0.01	010	16	010	3	350	3	010	3	MSG 3
14	1800	47	-0.2	30	0.00	015	20	010	3	360	3	010	3	MSG 3
14	1900	46	-0.1	30	.	020	19	CLM	0	CLM	0	010	3	MSG 2
14	2000	45	-0.4	29	.	025	16	CLM	0	CLM	0	010	3	MSG 0
14	2100	45	-0.5	29	.	030	13	CLM	0	CLM	0	020	2	MSG 0
14	2200	44	-0.1	29	.	035	15	CLM	0	CLM	0	020	2	MSG 0
14	2300	42	2.8	28	.	065	15	CLM	0	CLM	0	CLM	0	MSG 2
15	0000	43	3.3	28	.	105	15	CLM	0	CLM	0	CLM	0	MSG 1
15	0100	43	1.0	30	.	115	17	060	1	MSG	3	070	1	MSG 1
15	0200	43	0.4	29	.	125	20	130	1	MSG	1	CLM	0	MSG 2
15	0300	42	0.2	27	.	120	24	080	2	MSG	2	CLM	0	MSG 2
15	0400	42	0.1	25	.	120	24	110	4	MSG	4	CLM	0	MSG 2
15	0500	40	0.6	24	.	120	21	110	5	MSG	5	100	2	MSG 2
15	0600	41	0.1	24	0.00	120	22	110	7	MSG	7	110	1	MSG 3
15	0700	40	0.3	24	0.01	125	20	120	8	MSG	9	150	1	MSG 3
15	0800	40	0.1	26	0.24	135	24	120	10	MSG	11	140	2	MSG 4
15	0900	43	-0.8	27	0.48	130	32	110	13	MSG	12	130	4	MSG 7
15	1000	46	-1.1	28	0.78	130	31	110	15	MSG	14	110	4	MSG 8
15	1100	50	-2.2	28	1.19	130	29	110	15	MSG	14	130	5	MSG 9
15	1200	52	-2.1	27	1.10	130	26	120	12	MSG	12	130	6	MSG 8
15	1300	52	-1.5	27	1.03	135	25	120	14	MSG	12	110	5	MSG 7
15	1400	53	-0.2	28	0.62	135	20	110	11	MSG	9	140	5	MSG 7
15	1500	52	0.3	28	0.19	135	17	120	8	MSG	8	130	4	MSG 5
15	1600	51	0.3	27	0.14	135	19	120	9	MSG	9	130	4	MSG 5
15	1700	50	0.4	26	0.00	130	20	120	7	MSG	8	130	4	MSG 5
15	1800	49	0.3	26	.	130	20	110	7	MSG	8	130	4	MSG 4
15	1900	48	0.7	26	.	130	22	130	9	MSG	10	120	3	MSG 5
15	2000	48	1.5	26	.	140	18	130	9	MSG	9	140	3	MSG 5
15	2100	47	1.1	27	.	135	21	130	10	MSG	10	140	3	MSG 5
15	2200	47	1.5	29	.	140	19	140	9	MSG	11	130	4	MSG 5
15	2300	46	0.3	30	.	130	21	120	11	MSG	10	120	3	MSG 6

Table B.3 (continued)

GA. POWER HODGE MT. STATION							ORNL WIND STATIONS								
START		TEMP	DEL	DEW	SOLAR	WIND		BJWEN 1		BJWEN 2		SITE 17		SITE 24	
DAY	TIME					DIR	SPD	DIR	SPD	DIR	SPD	DIR	SPD	DIR	SPD
DEC	EST	°F	°F	°F	LMH	DEG	MPH	DEG	MPH	DEG	MPH	DEG	MPH	DEG	MPH
16	0000	45	0.8	31	.	135	18	120	9	MSG	8	130	3	MSG	5
16	0100	44	1.0	31	.	135	17	120	7	MSG	8	140	4	MSG	4
16	0200	44	0.9	30	.	135	16	120	7	MSG	7	130	3	MSG	5
16	0300	44	0.7	30	.	135	15	120	5	MSG	7	130	3	MSG	4
16	0400	44	0.1	30	.	130	15	110	6	MSG	7	130	2	MSG	4
16	0500	44	-0.4	30	.	120	17	120	7	MSG	6	140	2	MSG	4
16	0600	44	1.9	30	.	175	10	200	7	MSG	6	200	2	MSG	3
16	0700	44	2.0	31	0.00	165	7	170	4	MSG	4	170	2	MSG	2
16	0800	44	1.9	32	0.09	155	9	170	5	MSG	6	150	2	MSG	3
16	0900	45	1.2	32	0.11	130	13	120	7	MSG	7	120	3	MSG	4
16	0910	45	1.0	32	0.19	130	13								
16	0920	45	-0.4	32	0.39	125	12								
16	0930	46	-1.7	33	0.60	125	16								
16	0940	47	0.0	34	0.33	130	13								
16	0950	47	-0.8	34	0.32	120	15								
16	1000	47	0.0	34	0.35	130	14	110	5	MSG	3	120	2	MSG	3
16	1010	47	0.6	34	0.29	145	12								
16	1020	47	0.4	35	0.48	135	9								
16	1030	48	1.0	35	0.62	155	6								
16	1040	48	0.7	36	0.52	125	7								
16	1050	48	1.0	36	0.40	130	5								
16	1100	49	0.4	36	0.41	115	4	340	3	MSG	3	230	2	MSG	2
16	1110	49	0.6	36	0.54	120	3								
16	1120	49	1.4	36	0.58	VAR	2								
16	1130	50	0.8	37	0.53	035	3								
16	1140	50	1.0	37	0.56	VAR	2								
16	1150	50	2.1	37	0.79	195	2								
16	1200	50	2.7	38	0.57	270	2	VAR	3	MSG	3	330	2	MSG	3
16	1210	51	0.4	38	0.70	295	6								
16	1220	51	-0.5	38	0.69	305	6								
16	1230	52	-0.9	38	0.58	310	6								
16	1240	52	-1.1	38	0.41	320	7								
16	1250	52	-1.4	38	0.33	315	9								
16	1300	52	-1.6	38	0.32	325	12	340	5	MSG	5	340	4	MSG	5
16	1400	51	-1.4	38	0.16	330	15	330	6	MSG	5	340	5	MSG	6
16	1500	51	-1.4	39	0.25	344	12	340	3	MSG	3	330	4	MSG	5
16	1600	51	-1.0	39	0.15	315	5	330	3	MSG	4	320	3	MSG	3
16	1700	50	-0.8	38	0.00	315	13	320	4	MSG	5	320	3	MSG	4
16	1800	49	-0.2	38	.	320	15	320	3	MSG	5	330	3	MSG	2
16	1900	49	0.6	38	.	310	16	290	5	MSG	5	310	2	MSG	3
16	2000	48	0.6	37	.	325	19	320	4	MSG	6	340	5	MSG	3
16	2100	47	0.9	37	.	335	23	320	4	MSG	5	340	5	MSG	4
16	2200	46	0.1	33	.	350	27	340	7	MSG	7	350	8	MSG	5
16	2300	43	-0.3	30	.	340	27	340	7	MSG	8	340	8	MSG	9

Table B.4. National Weather Service observations at three-hour intervals

ATHENS, GEORGIA

OBSERVATIONS AT 3-HOUR INTERVALS

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06	0	UNL	15			53	38	15	29	30	6	0	UNL	15			61	44	24	26	21	8	10	100	15			64	54	54	96	10	5
07	0	UNL	15			56	40	14	19	28	6	0	UNL	15			59	44	24	26	21	8	10	100	15			64	54	54	96	10	5
08	0	UNL	15			47	35	13	25	31	4	0	UNL	15			53	40	24	29	18	7	10	100	15			57	57	57	100	26	6
09	0	UNL	15			41	34	21	45	26	6	0	UNL	15			50	39	24	36	16	4	10	100	15			55	54	54	96	31	9
DAY 06																				DAY 07													
01	10	10	7			49	47	46	93	32	10	0	UNL	20			42	37	30	63	28	9	0	UNL	20			35	30	20	54	34	8
02	0	UNL	7			42	42	41	96	31	5	0	UNL	20			41	36	29	58	27	9	0	UNL	20			33	29	20	59	34	8
03	0	UNL	7			37	37	37	100	30	11	0	UNL	20			41	36	29	58	27	9	0	UNL	20			36	30	20	52	08	11
04	0	UNL	8			44	41	37	76	30	11	0	UNL	20			47	39	28	68	32	15	0	UNL	20			42	34	19	40	08	11
05	0	UNL				55	43	26	33	31	11	0	UNL	20			53	41	26	38	32	15	0	UNL	20			51	38	18	47	07	6
06	0	UNL				54	44	25	27	23	10	0	UNL	20			55	42	23	29	33	13	0	UNL	20			58	43	24	27	15	5
07	0	UNL				50	40	26	37	25	8	0	UNL	20			50	40	26	37	25	8	0	UNL	20			57	47	27	19	14	1
08	0	UNL	20			46	39	29	52	27	8	0	UNL	20			40	33	20	45	31	13	0	UNL	20			44	37	27	51	07	3
DAY 07																				DAY 08													
01	10	10	7			49	47	46	93	32	10	0	UNL	20			42	37	30	63	28	9	0	UNL	20			35	30	20	54	34	8
02	0	UNL	7			42	42	41	96	31	5	0	UNL	20			41	36	29	58	27	9	0	UNL	20			33	29	20	59	34	8
03	0	UNL	7			37	37	37	100	30	11	0	UNL	20			41	36	29	58	27	9	0	UNL	20			36	30	20	52	08	11
04	0	UNL	8			44	41	37	76	30	11	0	UNL	20			47	39	28	68	32	15	0	UNL	20			42	34	19	40	08	11
05	0	UNL				55	43	26	33	31	11	0	UNL	20			53	41	26	38	32	15	0	UNL	20			51	38	18	47	07	6
06	0	UNL				54	44	25	27	23	10	0	UNL	20			55	42	23	29	33	13	0	UNL	20			58	43	24	27	15	5
07	0	UNL				50	40	26	37	25	8	0	UNL	20			50	40	26	37	25	8	0	UNL	20			57	47	27	19	14	1
08	0	UNL	20			46	39	29	52	27	8	0	UNL	20			40	33	20	45	31	13	0	UNL	20			44	37	27	51	07	3
DAY 08																				DAY 09													
01	0	UNL	20			42	36	27	55	16	5	0	UNL	15			47	44	40	77	18	4	6	40	10			57	56	55	93	12	7
02	0	UNL	20			38	34	27	65	00	0	0	UNL	15			45	44	42	89	12	4	8	40	7			56	55	55	95	14	6
03	0	UNL	20			36	33	27	70	32	3	0	UNL	15			42	41	40	93	11	5	8	45	4		F	54	54	54	100	15	6
04	0	UNL	20			52	42	28	42	20	6	0	UNL	15			53	47	46	77	16	10	10	2	1		F	57	56	56	106	15	6
05	0	UNL	15			60	46	29	31	23	4	0	UNL	15			55	48	50	63	30	10	10	30			F	70	62	64	119	13	
06	0	UNL	15			66	49	30	26	19	5	0	UNL	25			70	61	55	59	20	8	10	100	10			72	61	54	53	18	0
07	0	UNL	20			59	45	29	32	18	6	0	UNL	20			62	58	55	78	12	8	10	180	25			67	60	55	66	16	5
08	0	UNL	20			51	43	33	50	14	5	0	UNL	15			60	57	55	84	13	5	10	180	25			65	59	54	68	17	5
DAY 10																				DAY 11													
01	0	UNL	20			42	36	27	55	16	5	0	UNL	15			47	44	40	77	18	4	6	40	10			57	56	55	93	12	7
02	0	UNL	20			38	34	27	65	00	0	0	UNL	15			45	44	42	89	12	4	8	40	7			56	55	55	95	14	6
03	0	UNL	20			36	33	27	70	32	3	0	UNL	15			42	41	40	93	11	5	8	45	4		F	54	54	54	100	15	6
04	0	UNL	20			52	42	28	42	20	6	0	UNL	15			53	47	46	77	16	10	10	2	1		F	57	56	56	106	15	6
05	0	UNL	15			60	46	29	31	23	4	0	UNL	15			55	48	50	63	30	10	10	30			F	70	62	64	119	13	
06	0	UNL	15			66	49	30	26	19	5	0	UNL	25			70	61	55	59	20	8	10	100	10			72	61	54	53	18	0
07	0	UNL	20			59	45	29	32	18	6	0	UNL	20			62	58	55	78	12	8	10	180	25			67	60	55	66	16	5
08	0	UNL	20			51	43	33	50	14	5	0	UNL	15			60	57	55	84	13	5	10	180	25			65	59	54	68	17	5
DAY 11																				DAY 12													
01	10	70	20			62	58	55	78	14	10	5	10	5	10		52	50	49	90	32	11	4	UNL	20			44	38	31	60	09	1
02	10	80	15			61	59	55	79	18	10	5	10	32	10		44	43	44	94	32	11	4	UNL	20			48	40	33	62	07	12
03	10	80	10			62	60	59	90	17	8	0	8	120	12		44	43	38	83	32	8	3	UNL	20			39	34	27	65	07	13
04	10	20	7			65	62	61	87	19	8	0	5	15	12		44	41	38	80	34	8	2	UNL	15			43	38	31	63	08	17
05	10	20	7			69	63	60	73	23	10	0	10	250	15		57	50	43	60	35	5	5	33	25			50	41	29	44	07	13
06	10	14	3			63	62	62	97	25	10	0	10	25	15		59	52	45	60	34	5	10	21	25			58	48	36	61	09	11
07	10	8	6			61	61	61	100	32	5	0	5	850	20		51	47	42	71	32	6	10	21	20			46	38	27	48	08	12
08	10	3	6			56	55	55	96	31	10	0	8	UNL	20		50	43	34	54	07	7	10	19	15			42	39	35	76	09	12
DAY 13																				DAY 14													
01	10	70	20			62	58	55	78	14	10	5	10	5	10		52	50	49	90	32	11	4	UNL	20			44	38	31	60	09	1
02	10	80	15			61	59	55	79	18	10	5	10	32	10		44	43	44	94	32	11	4	UNL	20			48	40	33	62	07	12
03	10	80	10			62	60	59	90	17	8	0	8	120	12		44	43	38	83	32	8	3	UNL	20			39	34	27	65	07	13
04	10	20	7			65	62	61	87	19	8	0	5	15	12		44	41	38	80	34	8	2	UNL	15			43	38	31	63	08	17

Table. B.4 (continued)

BIRMINGHAM, ALABAMA

OBSERVATIONS AT 3-HOUR INTERVALS

HOUR	VISI-BILITY				TEMPERATURE				WIND				SEA COVER				VISI-BILITY				TEMPERATURE				WIND				SEA COVER				VISI-BILITY				TEMPERATURE				WIND																																																						
	SAT	CEL	WIND	WIND	AIR	WET	DEW	REL	DIR	SAT	CEL	WIND	WIND	AIR	WET	DEW	REL	DIR	SAT	CEL	WIND	WIND	AIR	WET	DEW	REL	DIR	SAT	CEL	WIND	WIND	AIR	WET	DEW	REL	DIR																																																											
00	0	UNL	10	15	26	26	18	63	00	0	0	UNL	8	32	30	26	79	00	0	0	45	7	56	50	44	64	16	8	55	52	49	60	17	8																																																													
03	0	UNL	10	15	26	24	19	75	00	0	0	UNL	8	31	29	26	82	00	0	0	10	30	7	55	50	49	60	17	8	55	52	49	60	17	8																																																												
06	0	UNL	10	15	25	24	20	81	00	0	0	UNL	8	29	28	26	89	00	0	0	10	30	7	55	53	51	66	16	8	55	53	51	66	16	8																																																												
09	0	UNL	10	15	25	24	20	81	00	0	0	UNL	8	29	28	26	89	00	0	0	10	30	7	55	53	51	66	16	8	55	53	51	66	16	8																																																												
12	0	UNL	10	15	25	24	20	81	00	0	0	UNL	8	29	28	26	89	00	0	0	10	30	7	55	53	51	66	16	8	55	53	51	66	16	8																																																												
15	0	UNL	10	15	25	24	20	81	00	0	0	UNL	8	29	28	26	89	00	0	0	10	30	7	55	53	51	66	16	8	55	53	51	66	16	8																																																												
18	0	UNL	10	15	25	24	20	81	00	0	0	UNL	8	29	28	26	89	00	0	0	10	30	7	55	53	51	66	16	8	55	53	51	66	16	8																																																												
21	0	UNL	10	15	25	24	20	81	00	0	0	UNL	8	29	28	26	89	00	0	0	10	30	7	55	53	51	66	16	8	55	53	51	66	16	8																																																												
DAY 04																																DAY 05																																DAY 06																															
00	0	UNL	10	15	26	26	18	63	00	0	0	UNL	8	32	30	26	79	00	0	0	45	7	56	50	44	64	16	8	55	52	49	60	17	8																																																													
03	0	UNL	10	15	26	24	19	75	00	0	0	UNL	8	31	29	26	82	00	0	0	10	30	7	55	50	49	60	17	8	55	52	49	60	17	8																																																												
06	0	UNL	10	15	25	24	20	81	00	0	0	UNL	8	29	28	26	89	00	0	0	10	30	7	55	53	51	66	16	8	55	53	51	66	16	8																																																												
09	0	UNL	10	15	25	24	20	81	00	0	0	UNL	8	29	28	26	89	00	0	0	10	30	7	55	53	51	66	16	8	55	53	51	66	16	8																																																												
12	0	UNL	10	15	25	24	20	81	00	0	0	UNL	8	29	28	26	89	00	0	0	10	30	7	55	53	51	66	16	8	55	53	51	66	16	8																																																												
15	0	UNL	10	15	25	24	20	81	00	0	0	UNL	8	29	28	26	89	00	0	0	10	30	7	55	53	51	66	16	8	55	53	51	66	16	8																																																												
18	0	UNL	10	15	25	24	20	81	00	0	0	UNL	8	29	28	26	89	00	0	0	10	30	7	55	53	51	66	16	8	55	53	51	66	16	8																																																												
21	0	UNL	10	15	25	24	20	81	00	0	0	UNL	8	29	28	26	89	00	0	0	10	30	7	55	53	51	66	16	8	55	53	51	66	16	8																																																												
DAY 07																																DAY 08																																DAY 09																															
00	0	UNL	10	15	26	26	18	63	00	0	0	UNL	8	32	30	26	79	00	0	0	45	7	56	50	44	64	16	8	55	52	49	60	17	8																																																													
03	0	UNL	10	15	26	24	19	75	00	0	0	UNL	8	31	29	26	82	00	0	0	10	30	7	55	50	49	60	17	8	55	52	49	60	17	8																																																												
06	0	UNL	10	15	25	24	20	81	00	0	0	UNL	8	29	28	26	89	00	0	0	10	30	7	55	53	51	66	16	8	55	53	51	66	16	8																																																												
09	0	UNL	10	15	25	24	20	81	00	0	0	UNL	8	29	28	26	89	00	0	0	10	30	7	55	53	51	66	16	8	55	53	51	66	16	8																																																												
12	0	UNL	10	15	25	24	20	81	00	0	0	UNL	8	29	28	26	89	00	0	0	10	30	7	55	53	51	66	16	8	55	53	51	66	16	8																																																												
15	0	UNL	10	15	25	24	20	81	00	0	0	UNL	8	29	28	26	89	00	0	0	10	30	7	55	53	51	66	16	8	55	53	51	66	16	8																																																												
18	0	UNL	10	15	25	24	20	81	00	0	0	UNL	8	29	28	26	89	00	0	0	10	30	7	55	53	51	66	16	8	55	53	51	66	16	8																																																												
21	0	UNL	10	15	25	24	20	81	00	0	0	UNL	8	29	28	26	89	00	0	0	10	30	7	55	53	51	66	16	8	55	53	51	66	16	8																																																												
DAY 10																																DAY 11																																DAY 12																															
00	0	UNL	10	15	26	26	18	63	00	0	0	UNL	8	32	30	26	79	00	0	0	45	7	56	50	44	64	16	8	55	52	49	60	17	8																																																													
03	0	UNL	10	15	26	24	19	75	00	0	0	UNL	8	31	29	26	82	00	0	0	10	30	7	55	50	49	60	17	8	55	52	49	60	17	8																																																												
06	0	UNL	10	15	25	24	20	81	00	0	0	UNL	8	29	28	26	89	00	0	0	10	30	7	55	53	51	66	16	8	55	53	51	66	16	8																																																												
09	0	UNL	10	15	25	24	20	81	00	0	0	UNL	8	29	28	26	89	00	0	0	10	30	7	55	53	51	66	16	8	55	53	51	66	16	8																																																												
12	0	UNL	10	15	25	24	20	81	00	0	0	UNL	8	29	28	26	89	00	0	0	10	30	7	55	53	51	66	16	8	55	53	51	66	16	8																																																												
15	0	UNL	10	15	25	24	20	81	00	0	0	UNL	8	29	28	26	89	00	0	0	10	30	7	55	53	51	66	16	8	55	53	51	66	16	8																																																												
18	0	UNL	10	15	25	24	20	81	00	0	0	UNL	8	29	28	26	89	00	0	0	10	30	7	55	53	51	66	16	8	55	53	51	66	16	8																																																												
21	0	UNL	10	15	25	24	20	81	00	0	0	UNL	8	29	28	26	89	00	0	0	10	30	7	55	53	51	66	16	8	55	53	51	66	16	8																																																												
DAY 13																																DAY 14																																DAY 15																															
00	8	75	7	6	65	60	56	73	21	8	8	11	7	44	42	30	86	36	7	6	30	7	56	50	44	64	16	8	55	52	49	60	17	8																																																													
03	10	75	12	7	65	60	56	73	21	10	10	7	7	44	42	30	86	36	7	6	30	7	56	50	44	64	16	8	55	52	49	60	17	8																																																													
06	10	28	12	7	64	60	57	78	19	10	10	7	7	38	36	33	82	26	8	10	UNL	11	46	40	32	58	08	12	47	37	30	68	08	12																																																													
09	10	6	2	62	64	60	59	90	25	5	7	200	7	41	37	32	70	01	10	9	30	11	46	40	32	58	08	12	47	37	30	68	08	12																																																													
12	10	6	2	62	64	60	59	90	25	5	7	200	7	41	37	32	70	01	10	9	30	11	46	40	32	58	08	12	47	37	30	68	08	12																																																													
15	10	6	4	61	51	50	49	93	36	7	8	UNL	15	53	42	29	40	01	12	10	23	15	56	48	40	55	15	5	53	47	40	62	14	7																																																													
18	10	5	7	61	49	47	46	89	34	9	8	UNL	11	44	39	32	63	36	4	10	21	15	53	47	40	62	14	7	51	45	38	61	09	8																																																													
21	10	7	6	61	48	46	44	86	36	10	8	UNL	10	41	37	32	70	00	0	10	17	15	51	45	38	61	09	8	51	45	38	61	09	8																																																													
DAY 16																																DAY 17																																DAY 18																															
00	10	16	7	49	43	42	37	63	13	8	10	19	7	23	23	20	64	30	15	0	UNL	15	23	22	17	74	00	0	20	22	17	74	00	0																																																													
03	10	16	7	46	39	42	39	80	05	5	10	19	11	25	23	16	29	76	10	0	UNL	15	20	21	17	84	00	0	20	22	17	84	00	0																																																													
06	10	28	7	47	45	43	46	86	36	5	4	UNL	12	27	23	13	55	35	12	5	UNL	5	29	27	21	72	00	0	20	22	17	84	00	0																																																													
09	10	9	5	51	48	46	46	83	32	6	5	UNL	12	27	23	16	48	36	13	5	UNL	7	42	32	14	72	00	0	20	22	17	84	00	0																																																													
12	10	9	5	51	48	46	46	83	32	6	5	UNL	12	27	23	16	48	36	13	5	UNL	7	48	35	11	22	23	11	22	23	11	22	23	11																																																													
15	9	21	7	51	48	46	46	83	30	4	4	UNL	12	29	25	16	58	35	6	0	UNL	8	36	31	22	57	04	3	30	27	21	69	00	0																																																													
18	1	UNL	8	46	41	35	66	74	15	4	4	UNL	15	27	24	16	63	36	3	0	UNL	7	30	27	21	69	00	0	30	27	21	69	00	0																																																													

CHATTANOOGA, TENNESSEE

OBSERVATIONS AT 3-HOUR INTERVALS

HOUR	SAT. COV. TEMPS			WINDS OF FT.	VISI- BILITY		TEMPERATURE				WIND				SAT. COV. TEMPS			WINDS OF FT.	VISI- BILITY		TEMPERATURE				WIND			
	SEA	CLD	WVLS		HEATH	AIR °F	WET BULB °F	DEW PT °F	REL. HUM %	SPEED KNOTS	DIR	AIR °F	WET BULB °F	DEW PT °F	REL. HUM %	SPEED KNOTS	DIR		AIR °F	WET BULB °F	DEW PT °F	REL. HUM %	SPEED KNOTS	DIR				
DAY 04																												
01	0	UNL	10		26	23	15	63	18	0	0	UNL	10		30	28	23	75	00	0	0	UNL	10					
04	0	UNL	10		22	21	15	74	00	0	0	UNL	10		27	26	24	88	00	0	0	UNL	10					
07	0	UNL	10		22	21	17	81	00	0	0	UNL	10		25	24	20	81	00	0	0	UNL	10					
10	0	UNL	10		21	21	22	69	00	0	0	UNL	10		26	26	25	30	12	0	0	UNL	10					
13	0	UNL	10		47	26	17	47	00	0	0	UNL	10		56	34	25	30	12	0	0	UNL	10					
16	0	UNL	12		54	40	19	25	17	3	0	UNL	15		60	44	21	22	22	0	0	UNL	15					
19	0	UNL	15		43	34	22	45	00	0	0	UNL	15		49	38	22	35	21	4	0	UNL	15					
22	0	UNL	12		32	30	25	75	00	0	0	UNL	15		46	37	23	40	03	0	0	UNL	15					
DAY 05																												
01	0	UNL	10		30	28	23	75	00	0	0	UNL	10		32	30	26	64	00	0	0	UNL	10					
04	0	UNL	10		27	26	22	81	00	0	0	UNL	10		32	30	25	75	07	0	0	UNL	10					
07	0	UNL	10		25	24	20	81	00	0	0	UNL	10		42	36	28	58	36	10	0	UNL	10					
10	0	UNL	10		36	32	25	30	12	0	0	UNL	10		47	36	16	29	05	12	0	UNL	10					
13	0	UNL	10		56	44	27	26	16	0	0	UNL	10		60	44	21	22	22	0	0	UNL	10					
16	0	UNL	15		49	38	22	35	21	4	0	UNL	15		43	33	18	49	03	0	0	UNL	15					
19	0	UNL	15		46	37	23	40	03	0	0	UNL	15		33	28	19	56	03	8	0	UNL	15					
DAY 06																												
01	0	UNL	15		32	31	20	82	07	3	0	UNL	30		32	31	20	82	07	3	0	UNL	30					
04	0	UNL	15		32	30	25	78	00	0	0	UNL	30		32	30	25	78	00	0	0	UNL	30					
07	0	UNL	10		35	33	29	79	18	3	0	UNL	15		42	36	28	58	36	10	0	UNL	15					
10	0	UNL	15		52	42	30	43	22	0	0	UNL	15		47	36	16	29	05	12	0	UNL	15					
13	0	UNL	10		33	31	27	76	00	0	0	UNL	15		42	36	28	58	36	10	0	UNL	15					
16	0	UNL	10		49	40	27	43	24	5	0	UNL	30		41	33	18	49	03	0	0	UNL	30					
19	0	UNL	20		42	36	28	58	25	5	0	UNL	30		33	28	19	56	03	8	0	UNL	30					
DAY 07																												
01	0	UNL	15		32	31	26	85	07	3	0	UNL	15		32	31	20	82	07	3	0	UNL	15					
04	0	UNL	15		32	30	25	78	00	0	0	UNL	15		32	30	25	78	00	0	0	UNL	15					
07	0	UNL	10		35	33	29	79	18	3	0	UNL	15		42	36	28	58	36	10	0	UNL	15					
10	0	UNL	15		52	42	30	43	22	0	0	UNL	15		47	36	16	29	05	12	0	UNL	15					
13	0	UNL	10		33	31	27	76	00	0	0	UNL	15		42	36	28	58	36	10	0	UNL	15					
16	0	UNL	10		49	40	27	43	24	5	0	UNL	30		41	33	18	49	03	0	0	UNL	30					
19	0	UNL	20		42	36	28	58	25	5	0	UNL	30		33	28	19	56	03	8	0	UNL	30					
DAY 08																												
01	0	UNL	15		32	31	20	82	07	3	0	UNL	15		32	31	20	82	07	3	0	UNL	15					
04	0	UNL	15		32	30	25	78	00	0	0	UNL	15		32	30	25	78	00	0	0	UNL	15					
07	0	UNL	10		35	33	29	79	18	3	0	UNL	15		42	36	28	58	36	10	0	UNL	15					
10	0	UNL	15		52	42	30	43	22	0	0	UNL	15		47	36	16	29	05	12	0	UNL	15					
13	0	UNL	10		33	31	27	76	00	0	0	UNL	15		42	36	28	58	36	10	0	UNL	15					
16	0	UNL	10		49	40	27	43	24	5	0	UNL	30		41	33	18	49	03	0	0	UNL	30					
19	0	UNL	20		42	36	28	58	25	5	0	UNL	30		33	28	19	56	03	8	0	UNL	30					
DAY 09																												
01	0	UNL	15		32	31	20	82	07	3	0	UNL	30		32	31	20	82	07	3	0	UNL	30					
04	0	UNL	15		32	30	25	78	00	0	0	UNL	30		32	30	25	78	00	0	0	UNL	30					
07	0	UNL	10		35	33	29	79	18	3	0	UNL	15		42	36	28	58	36	10	0	UNL	15					
10	0	UNL	15		52	42	30	43	22	0	0	UNL	15		47	36	16	29	05	12	0	UNL	15					
13	0	UNL	10		33	31	27	76	00	0	0	UNL	15		42	36	28	58	36	10	0	UNL	15					
16	0	UNL	10		49	40	27	43	24	5	0	UNL	30		41	33	18	49	03	0	0	UNL	30					
19	0	UNL	20		42	36	28	58	25	5	0	UNL	30		33	28	19	56	03	8	0	UNL	30					
DAY 10																												
01	0	UNL	10		31	29	26	82	00	0	0	UNL	10		33	31	28	82	00	0	0	UNL	10					
04	2	UNL	10		30	28	25	82	00	0	0	UNL	10		30	29	26	85	00	0	0	UNL	10					
07	0	UNL	10		28	27	24	85	00	0	0	UNL	10		30	29	26	85	00	0	0	UNL	10					
10	0	UNL	7		36	33	29	76	00	0	0	UNL	10		40	37	32	73	00	0	0	UNL	10					
13	0	UNL	6		54	44	31	42	23	3	0	UNL	8		53	51	49	86	23	9	0	UNL	8					
16	0	UNL	12		62	47	28	28	22	3	0	UNL	9		61	55	50	67	19	9	0	UNL	9					
19	0	UNL	12		47	39	29	50	00	0	0	UNL	12		47	36	28	58	00	0	0	UNL	12					
22	0	UNL	12		37	34	29	73	00	0	0	UNL	7		47	46	45	93	14	4	0	UNL	7					
DAY 11																												
01	0	UNL	10		33	31	28	82	00	0	0	UNL	10		33	31	28	82	00	0	0	UNL	10					
04	2	UNL	10		30	29	26	85	00	0	0	UNL	10		30	29	26	85	00	0	0	UNL	10					
07	0	UNL	10		28	27	25	88	00	0	0	UNL	10		30	29	26	85	00	0	0	UNL	10					
10	0	UNL	7		40	37	32	73	00	0	0	UNL	10		40	37	32	73	00	0	0	UNL	10					
13	0	UNL	6		54	44	31	42	23	3	0	UNL	8		53	51	49	86	23	9	0	UNL	8					
16	0	UNL	12		62	47	28	28	22	3	0	UNL	9		61	55	50	67	19	9	0	UNL	9					
19	0	UNL	12		47	39	29	50	00	0	0	UNL	12		47	36	28	58	00	0	0	UNL	12					
22	0	UNL	12		37	34	29	73	00	0	0	UNL	7		47	46	45	93	14	4	0	UNL	7					
DAY 12																												
01	10	41	10		57	55	53	87	21	5	10	14	12		44	39	32	63	03	0	0	UNL	30					
04	10	41	10		58	55	52	81	21	5	10	14	12		44	39	32	63	03	0	0	UNL	30					
07	10	26	10		58	55	53	84	25	6	10	14	12		44	39	32	63	03	0	0	UNL	30					
10	10	15	10		59	57	56	90	15	7	7	UNL	30		36	32	25	64	07	3	4	UNL	12					
13	10	21	12		60	57	55	87	03	5	3	UNL	30		35	31	25	67	04	3	4	UNL	12					
16	10	45	20		55	52	49	80	03	3	4	UNL	15		47	40	38	50	04	14	3	UNL	12					
19	10	80	20		51	48	45	80	03	8	4	UNL	30		49	40	27	43	05	10	0	UNL	15					
22	10	250	20		45	42	38	77	36	6	7	26	30		42	35	25	51	06	5	3	UNL	15					
DAY 13																												
01	10	41	10		57	55	53	87	21	5	10	14	12		44	39	32	63	03	0	0	UNL	30					
04	10	41	10		58	55	52	81	21	5	10	14	12		44	39	32	63	03	0	0	UNL	30					
07	10	26	10		58	55	53	84	25	6	10	14	12		44	39	32	63	03	0	0	UNL	30					
10	10	15	10		59	57	56	90	15	7	7	UNL	30		36	32	25	64	07	3	4	UNL	12					
13	10	21	12		60	57	55	87	03	5	3	UNL	30		35	31	25	67	04	3	4	UNL	12					
16	10	45	20		55	52	49	80	03	3	4	UNL	15		47	40	38	50	04	14	3	UNL	12					
19	10	80	20		51	48	45	80	03	8	4	UNL	30		49													

Table B.4 (continued)

HUNTSVILLE, ALABAMA

OBSERVATIONS AT 3-HOUR INTERVALS

HOUR	SAT. DATE	TIME	MOON	VISI- BILITY	WEATHER	TEMPERATURE					WIND					VISI- BILITY	WEATHER	TEMPERATURE					WIND					VISI- BILITY	WEATHER	TEMPERATURE					WIND																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																			
						AIR °F	WET BULB °F	DEW PT °F	REL. HUM. %	DIR	SPEED KNOTS	DIR	CEILING FT.	MOON PHASE	MOON MILES			AIR °F	WET BULB °F	DEW PT °F	REL. HUM. %	DIR	SPEED KNOTS	DIR	CEILING FT.	MOON PHASE	MOON MILES			AIR °F	WET BULB °F	DEW PT °F	REL. HUM. %	DIR	SPEED KNOTS	DIR	CEILING FT.	MOON PHASE	MOON MILES																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
DAY 04																																	DAY 05																																	DAY 06																																	DAY 07																																	DAY 08																																	DAY 09																																	DAY 10																																	DAY 11																																	DAY 12																																	DAY 13																																	DAY 14																																	DAY 15																																	DAY 16																																	DAY 17																																	DAY 18																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																								
00	1	UNL	20			25	23	19	78	00	0	0	UNL	10				30	28	24	78	06	4	10	29	15			54	47	39	57	16	12																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				

ROME, GEORGIA

OBSERVATIONS AT 3-HOUR INTERVALS

TIME		MOON		DATE		MOON		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE		WIND		TEMPERATURE	
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