The Vermont Monitoring Cooperative Data Integration Pilot Project

VMC Research Report 7
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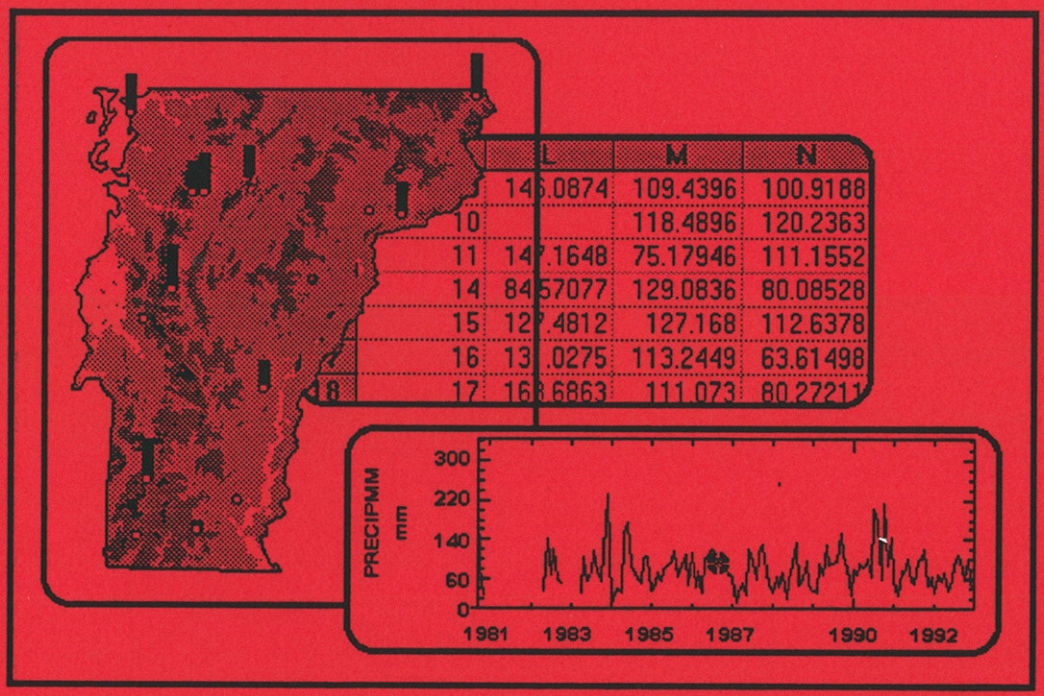

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Abstract

Current trends in research and management of forested ecosystems encourage the development of a holistic understanding of ecosystem structure and function. Arriving at such an understanding can only result from an effective synthesis of knowledge on ecosystems at various spatial scales and across disciplines. This is best accomplished through integrated research, monitoring, and assessment activities which are supported by systematically archived multi-disciplinary data. A highly structured and easily accessible data-base is needed to: a) provide ready access to disparate data sets, b) allow for comparison and correlation of data across disciplines and scales, and c) facilitate descriptive and predictive modeling of ecosystem response to environmental change. We believe that these goals can be met and that an effective and useful degree of data integration can be achieved using a PC-based software package, the Voyager Data Exploration System (Version 3.1, Lantern Corporation, Clayton MO). This software was developed for facilitating the graphical examination of large, complex data sets and visualizing relationships within them. A total of 15 data sets containing meteorological, wet deposition, air quality, aquatic chemistry and forest health data were processed and formatted for use in Voyager. In addition, three integrated Voyager workbooks were prepared to demonstrate and examine inter-relationships among several independent but functionally related data sets. This report describes the rationale, methods and products of our initial efforts to investigate and formalize data integration for multi-disciplinary environmental and ecological data sets.

Acknowledgments

We would like to thank Rudolf Husar, Todd Oberman, Aleksander Juric, and the other staff of Lantern Corp for their collaboration in this project and for their support, patience and advice on the technical aspects of informatics. Additional thanks are extended to the various project managers, principle investigators, and others within the Vermont Monitoring Cooperative who's cooperation and data have made this project possible. We also gratefully acknowledge financial support from the Vermont Monitoring Cooperative, the Vermont Department of Forests, Parks and Recreation, the Vermont Air Pollution Control Division, and the US Forest Service (cooperative agreement # USDA 23-758).

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THE VERMONT MONITORING COOPERATIVE
DATA INTEGRATION PILOT PROJECT

TABLE OF CONTENTS

I. INTRODUCTION

A. Background

Current trends in research and management of forested ecosystems encourage the development of a holistic understanding of ecosystem structure and function. Arriving at such an understanding can only result from an effective synthesis of knowledge on ecosystems at various spatial scales and across disciplines. This integrated approach has become increasingly urgent as we become aware of the profound changes that are taking place in our global environment. In response to this trend "Ecosystem Management" has appropriately become a goal of federal, state and private resource managers. Effective ecosystem management requires an improved understanding of the dynamic interactions among complex physical, chemical, and biological components of an ecosystem's structure and function. This improved understanding will demand greater coordination of environmental monitoring and research, and improved methods for the integration and exchange of complex environmental and ecological data from many disciplines.

We at the Vermont Monitoring Cooperative (VMC) believe that data integration is a fundamental requirement for any study or management plan following an ecological approach to ecosystem management and research. This report describes our efforts to develop effective tools for the integration and exchange of multi-disciplinary ecosystem information.

B. The Vermont Monitoring Cooperative

A number of government and research organizations concerned with the effects of environmental change on forested ecosystems in Vermont have joined together to form the Vermont Monitoring Cooperative, Vermont's intensive forest ecosystem monitoring and research program. Together these organizations are conducting environmental and ecological research and monitoring to gain a stronger understanding of the factors which influence the condition and sustainability of forested ecosystems. These studies address long-term forest health, forest management impacts, wet and dry deposition of atmospheric pollutants, photochemical oxidants, meteorology, stream biogeochemistry, organismal demographics including insects, birds, amphibians, aquatic invertebrates, and others.

The primary goals of the VMC are to:

1. Generate long-term data sets describing environmental and ecological conditions and changes in forested ecosystems.

2. Improve the understanding of processes affecting forest ecosystem development and responses to environmental change.

3. Determine the consequences of management practices under known environmental and ecological conditions.

4. Facilitate cooperative research and monitoring of environmental change effects on forested ecosystems.

The ultimate goal of the VMC is to strengthen our understanding of forested ecosystems throughout Vermont. Many statewide data sets are included in the VMC database, but intensive research and monitoring is centered on two sites within the state, Mount Mansfield and Lye Brook Wilderness. Mount Mansfield, included in the US Forest Service's Intensive Site Ecosystem Monitoring (ISEM) Program, was the initial site for these long term studies. This site comprises multiple-use forests (recreation, forest management, timber production, research) along a 1000 meter elevational gradient. The Lye Brook Wilderness site, located in the southern Green Mountain National Forest, was added in 1993. Currently the VMC is extending many of the studies underway at Mount Mansfield to the Lye Brook Wilderness site, as well as additional activities of local importance. It is noteworthy that both of these study sites are located within a region having one of the highest population densities in North America, subjecting them to intensive use and environmental pressures.

C. The Data Integration Pilot Project

The VMC recognizes that contemporary ecosystem management and research requires access to complex data sets generated by numerous ecological and environmental research and monitoring activities. Efficient access to these data is essential in order to understand and evaluate the complex interactions among the biotic and abiotic components of an ecosystem. It is necessary, therefore, to systematically archive multi-disciplinary data in a highly structured and easily accessible data-base in order to: a) provide ready access to disparate data sets, b) allow for comparison and correlation of data across disciplines, and c) facilitate descriptive and predictive modeling of ecosystem processes and responses to environmental change. The goal of the VMC Data Integration Pilot Project was to develop and demonstrate a data integration system that would facilitate these three activities within the VMC.

The specific objectives of the project were to:

1. Compile a selection of data sets from VMC cooperators and other sources representing a variety of environmental and ecological disciplines (e.g., forest health, precipitation chemistry, lake water quality, etc.).

2. Process the data sets to facilitate inter-comparisons and provide greater relevance to a variety of users (e.g., convert daily and weekly precipitation data into monthly averages to enhance comparison of measurements between programs and with ecological data).

3. Convert the data sets into common formats to enhance accessibility and analysis (e.g., Voyager files and workbooks, as well as ASCII text and spreadsheet formats).

4. Illustrate the usefulness of the data integration system by providing models of integrated Voyager workbooks (e.g., linked precipitation and lake chemistry data files to characterize the relationship between precipitation pH, lake pH and lake buffering capacity [see Appendix II]).

5. Prepare and distribute a final printed report and the data products described in this report along with the Voyager Viewer (a shareware version of the Voyager software; see Appendix V).

To accomplish these objectives, the VMC, with technical assistance from Lantern Corporation, initiated the Data Integration Pilot Project. We believed that our goals could be met and an effective and useful degree of data integration would be achieved using a PC-based software package, the Voyager Data Exploration System (Version 3.1, Lantern Corporation, Clayton MO). Voyager was created by Rudolf Husar, Todd Oberman and Edward Hutchins of Lantern Corporation. The software was developed for the primary purposes of facilitating the graphical examination of large, complex data sets and visualizing relationships within them.

The Voyager program was selected as the primary data integration system in this project for several reasons: a) it is user friendly, providing fast and easy browsing of very large data sets in a Windows environment, b) it provides simultaneous, linked views of data in time, space, variable and relational views, facilitating evaluation and interpretation of patterns existing within complex environmental and ecological data, and c) the ASCII files generated in the process of formatting data for Voyager can be easily imported to word processing, spreadsheet, or statistical programs (for more information on Voyager see Appendix V).

II. METHODS

A. Data Selection

Data sets were selected for inclusion in this project based on the following criteria:

1. They included a site at or near the VMC sites at Mount Mansfield and Lye Brook.
2. They were considered relevant to VMC goals and objectives.
3. They contained rich spatial and/or temporal domains.

Selected data sets were obtained from a variety of sources including:

1. National Climatic Data Center (NCDC)
2. National Weather Service (NWS)

3. Carbon Dioxide Information Analysis Center (CDIAC)
4. Interagency Monitoring of Protected Visual Environments (IMPROVE)
5. National Atmospheric Deposition Program (NADP)
6. US Environmental Protection Agency (US EPA)
7. Northeastern States for Coordinated Air Use Management (NESCAUM)
8. Vermont Department of Forests Parks and Recreation (VT FPR)
9. Vermont Department of Environmental Conservation Water Quality Division (VT DEC WQD)
10. Vermont Department of Environmental Conservation Air Pollution Control Division (VT DEC APCD)

B. Data Processing

Data processing was conducted by staff at Lantern Corporation and the University of Vermont School of Natural Resources (SNR). Data were converted into comparable spatial, temporal, and quantitative units and arranged in fixed format ASCII files. These ASCII files were used for compilation into Voyager and were saved to produce an archived database. At SNR, data processing was conducted on a desktop PC with a 486SX processor operating at 33 MHz. Various software packages were employed including Microsoft Windows 3.1, Excel 4.0, Quatro-Pro 4.0, SAS 604, and several custom Pascal programs. Colorado Memory Systems (Loveland, CO) tape drives, DT 250 mini data cartridges, and Tape Backup Software (Version 3.03) were used for data back-up and archiving. Similar procedures were used for data processing by Lantern Corporation.

All data sets were compiled from ASCII to individual Voyager files using the data compiler provided with the Voyager Data Exploration Software. These files were then incorporated into individual workbooks which allow for simultaneous spatial, temporal and variable views. Workbooks and Voyager files can be easily accessed and manipulated with the public-domain shareware Voyager Viewer (see Appendix V for more information on the Voyager Viewer).

Several integrated Voyager workbooks were also prepared to initiate and demonstrate the process of data integration by combining multiple data sets into a common data environment. These integrated workbooks represent a preliminary investigation and interpretation of the inter-relationships between independently generated environmental and ecological data sets. They also represent data integration "tools" which can be exchanged among, and enhanced by the usage of, other data users with an interest in exploring these relationships in additional detail. They are also intended to serve as useful examples, to encourage similar inter-comparisons among other currently accessible or yet to be acquired VMC data sets.

III. RESULTS

A. Data Sets

The following data sets have been compiled into Voyager workbooks and fixed format ASCII files. Graphic views and more information on these files are in Appendix I. In the following list, the data source is given in parentheses.

1. Meteorology:

- 1 pm Climatological Data from Burlington, VT Airport, 1985-91 (NCDC)
- Hourly Climatological Data from Burlington, VT, Airport, 1985-91 (NCDC)
- Northeastern Long-Term Temperature and Precipitation Records, 1890-1980 (NWS,CDIAC)
- Underhill State Park Meteorology Station, 1991-92 (VT FPR)
- Vermont Cooperative Weather Stations Meteorological Data, period of record through 1990 for over 100 sites (NWS)

2. Deposition:

- Vermont Acid Precipitation Monitoring Program (VAPMP), 1980-92 (VT DEC WQD)
- NADP Precipitation Chemistry Monthly Averages, 1978-92 (NADP)

3. Air Quality:

- NESCAUM Regional Particle Monitoring Networking (NEPART), 1988-92 (NESCAUM)
- NEPART and IMPROVE Aerosol Composition as Monthly Means, 1988-91 (NESCAUM)
- Hourly Ozone Concentrations for the Northeastern US, 1987-92 (NESCAUM, US EPA)
- Daily Ozone Maximum in the Northeastern US, 1987-92 (NESCAUM, US EPA)
- Monthly Biological Ozone Indices for the Northeastern US, 1987-92 (NESCAUM, US EPA)
- NESCAUM Daily Ozone Maximums and Times of Occurrence, Preliminary Data, 1991-93 (NESCAUM)

4. Surface Waters:

- Vermont Long Term Lake Study (LTLM), 1980-90 (VT DEC WQD, US EPA)

5. Forest Health:

- North American Maple Project, Vermont Data, 1988-92 (VT FPR)

B. Integrated Voyager Workbooks

Three integrated workbooks have also been completed. Graphic Views and more information on these are in Appendix II.

1. Comparison of monthly mean aerosol and precipitation chemistry

   This workbook combines data on monthly mean aerosol chemistry and monthly mean precipitation chemistry provided by NESCAUM, IMPROVE and NADP. The workbook allows for a detailed examination of the spatial, temporal and relational aspects of the individual aerosol and precipitation data sets.

2. Comparisons of monthly mean precipitation and aquatic chemistry

   VAPMP precipitation chemistry data and aquatic chemistry from the Vermont Long-Term Lake Monitoring Program are combined in this workbook. The workbook explores the relationship between lake and precipitation pH in both northern and southern Vermont.

3. Contrast of precipitation chemistry measurements between NADP and VAPMP

   This workbook contains both NADP and VAPMP data on precipitation chemistry. It provides a comparative look at measurements made by both programs at the Proctor Maple Research Center in Underhill, VT over the same time period.

C. Supporting Geographical Information

A number of Vermont-specific GIS Map layers (obtained from The VT ANR Geographic Information System Office) have been converted to Voyager compatible format for use by the VMC. Various combinations of these map layers (illustrated in Appendix III) can be employed in Voyager to underlie any of the individual or integrated environmental data sets.
These map layers include:

1. Vermont Roadways
2. Vermont Railroads
3. Vermont Counties
4. Vermont Population
5. Vermont Water Bodies
6. Vermont Streams
7. Vermont Elevation
8. Vermont Census Locations

In addition, work is underway to use existing GIS data to create detailed maps of the VMC study areas on Mount Mansfield and in Lye Brook Wilderness. This work involves translating GIS map layers into Voyager format, providing topographic, land-use and other information to enhance the data for these areas. This is an example of how Voyager can be adapted for use at various scales or for different locations.

D. Related Projects

Several VMC projects have been supported with technical or financial support from the Northeast States for Coordinated Air Use Management (NESCAUM). In turn, several NESCAUM projects benefit from the participation of VMC cooperators, specifically from efforts undertaken as part of the VMC Data Integration Pilot Project.

The ***NESCAUM/VMC Ozone Data Exchange Network*** was initiated in 1990 to provide rapid distribution of preliminary ozone data among northeastern US and Canadian air quality monitoring programs and forestry professionals. This network employs an electronic bulletin board to transfer and integrate the preceding day's maximum ozone values for all monitoring sites in the region in ASCII, spreadsheet and Voyager format.

The ***AIRS/Voyager Data Delivery System*** (DDS) was developed in 1993 with support from NESCAUM and EPA's Office of Air Quality Planning and Standards (OAQPS). This system, running on a users computer, provides for extraction, in Voyager format, of any current or historical air quality data from the vast EPA Aerometric Information and Retrieval System (AIRS).

In an effort to test and exercise the new AIRS/Voyager DDS, NESCAUM developed an extensive assessment of 1992 regional ozone concentrations in the northeastern United States [*1992 Regional Ozone Concentrations in the Northeastern United States* (Nescaum, 1993, Boston MA)]. Several of the data files developed for this NESCAUM project have been incorporated into the VMC Data Integration Pilot Project (for example, hourly ozone and daily fine particle data). In turn, a number of the VMC data files were employed in the NESCAUM regional ozone summary (e.g, various short and long-term climatological data sets and biological ozone indexes).

These opportunities to integrate and share disparate data sets of common interest and in common format among different organizations provide an excellent example of the kind of productive cooperation that the VMC Data Integration Pilot Project was intended to foster. Several examples from the NESCAUM publication are included in Appendix IV, and help illustrate the practical benefits of these data integration efforts across institutional boundaries.

IV. DISCUSSION: CAN WE REALLY COMPARE APPLES AND ORANGES?

How can we best use disparate environmental and ecological data to better understand ecosystems? Can we meaningfully combine some of these very different kinds of data? Can we really compare apples and oranges? If so, can we actually learn something from this comparison? In conducting ecosystem studies we are often faced with interpreting and using many different types of data (e.g., air quality and forest health) at differing temporal and spatial scales (e.g., seasonal vs. hourly, regional vs. local). These are the apples and oranges of ecosystem analysis, which despite their very different qualities, together determine the underlying structure and function of our forested ecosystems.

Our challenge in the VMC Data Integration Pilot Project has been to demonstrate that through the development of new integrative tools to manage data and facilitate its analysis, we can improve our understanding of ecosystems. To do this a broad range of independently generated data sets were collected, processed, compared, interpreted and shared among VMC cooperators. The project has successfully met this challenge in many respects. A number of data sets representing a multiplicity of scientific disciplines have been gathered and processed into a readily available and easily accessible common format. Data on meteorology, wet and dry deposition, air quality, water quality and forest health, representing hundreds of megabytes of data, previously available only in coded numeric formats, have been transformed and rendered accessible to anyone with a personal computer who can point and click a mouse. These compiled data sets can be loaded into Voyager and viewed individually or in combination with any other. This approach essentially adds value to data by a) providing easy access to the data by users, b) presenting the data visually as well as numerically, c) combining the data with other comparable data, and d) expressing the data in relevant units. The concept of "value-added data," and particularly activities such as (c) and (d) above, are critical to our working definition of data integration.

The Data Integration Pilot Project has demonstrated that it is possible to "compare apples and oranges." However, another and perhaps more difficult part of the question remains: can we meaningfully compare and interrelate these various types of data (the apples and oranges) in a way that will increase our knowledge and understanding of ecosystems?

The three integrated Voyager workbooks illustrated in this report (see Appendix II) show that meaningful comparisons are, in fact, possible utilizing our approach. It is important to realize, however, that these comparisons transcend the technology which makes them possible. Human curiosity and imagination are ultimately the driving forces behind this aspect of integration. Given the tools that this integrated data base supplies, it is up to researchers and managers to use them to further their understanding and knowledge by asking appropriate questions. It must be stressed that an integrated data base by itself does not answer questions; it raises them. It provides the means for researchers to explore complex data, probing for patterns and relationships in a visual environment, and to pose critical questions for further exploration. The thrust of these explorations should be towards the formulation of specific questions and hypotheses about ecosystem processes and relationships. These questions might address short-

term processes, such as seasonal variation or meteorological effects, or long-term processes such as succession or ecosystem responses to environmental change. Short-term and long-term research and monitoring should be designed to address these hypothesis and questions. Data from these studies should, in turn, be fed back into the data integration system, providing new views of the data and increasingly refined information about the status of our ecosystems. It is through this kind of process that the power of data integration, and the benefits of ecosystem management, will be realized.

V. FUTURE PLANS

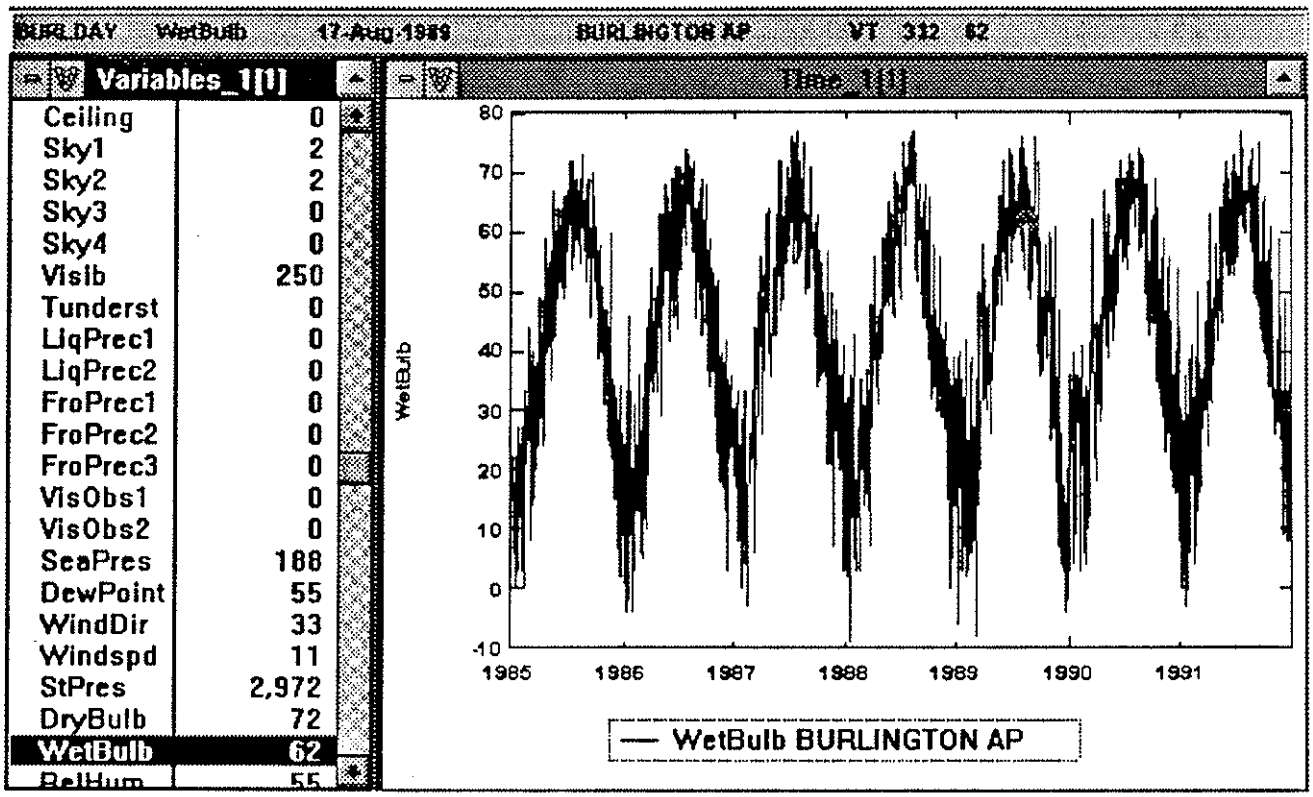
The VMC Data Integration Pilot Project is only Phase One of the VMC's efforts to develop an effective data integration infrastructure. This first phase has resulted in the compilation of various data sets into a centralized database and development of preliminary data integration concepts and products. Phases Two and Three will extend this work by updating and expanding the integrated database, furthering distribution of information and data sets, and providing a thorough analysis of the system's benefits and weaknesses.

In Phase Two, supervision, expansion, and further distribution of the VMC database will be facilitated by hiring a full time Data Manager within the VMC, this is scheduled for Summer 1994. Expansion of the database should proceed through: a) the inclusion of more data sets generated by VMC cooperators at the Mount Mansfield and Lye Brook Wilderness sites, b) the further acquisition of existing data sets relevant to the VMC mission, and c) annual updates of the existing database. Distribution of the materials produced in Phases One and Two will be accomplished through the circulation of this report and distribution of compiled data sets to user groups both within and outside the VMC. Database distribution will be primarily electronic (floppy disk or FTP) with the printed form used only as a secondary medium.

Phase Three will include pro-active data integration efforts. Workshops will identify the VMC's priority data integration needs and the procedures required to address them. These workshops will be directed towards expanding the participation of VMC collaborators in data integration efforts by inviting them to go beyond merely sharing data and actively use the VMC database to advance their research and management objectives. The goal of Phase Three will be to produce a truly integrated VMC report, supported by increased participation of VMC members in the data integration effort, in 1995. To help in this work and to capitalize on the growing success and popularity of the Voyager Data Exploration System, we will continue a close collaborative relationship with Lantern Corporation.

The success of a continuing VMC data integration program will be measured by the response of the community of users. Those who actively utilize the integrated data base will provide the critical tests of both the usefulness and value of the VMC's data integration efforts. We believe that this approach, and the use of the Voyager Data Exploration System, will prove to be an increasingly important and successful component of our work to understand and wisely manage our forested ecosystems.

APPENDIX I: WORKBOOK SUMMARIES



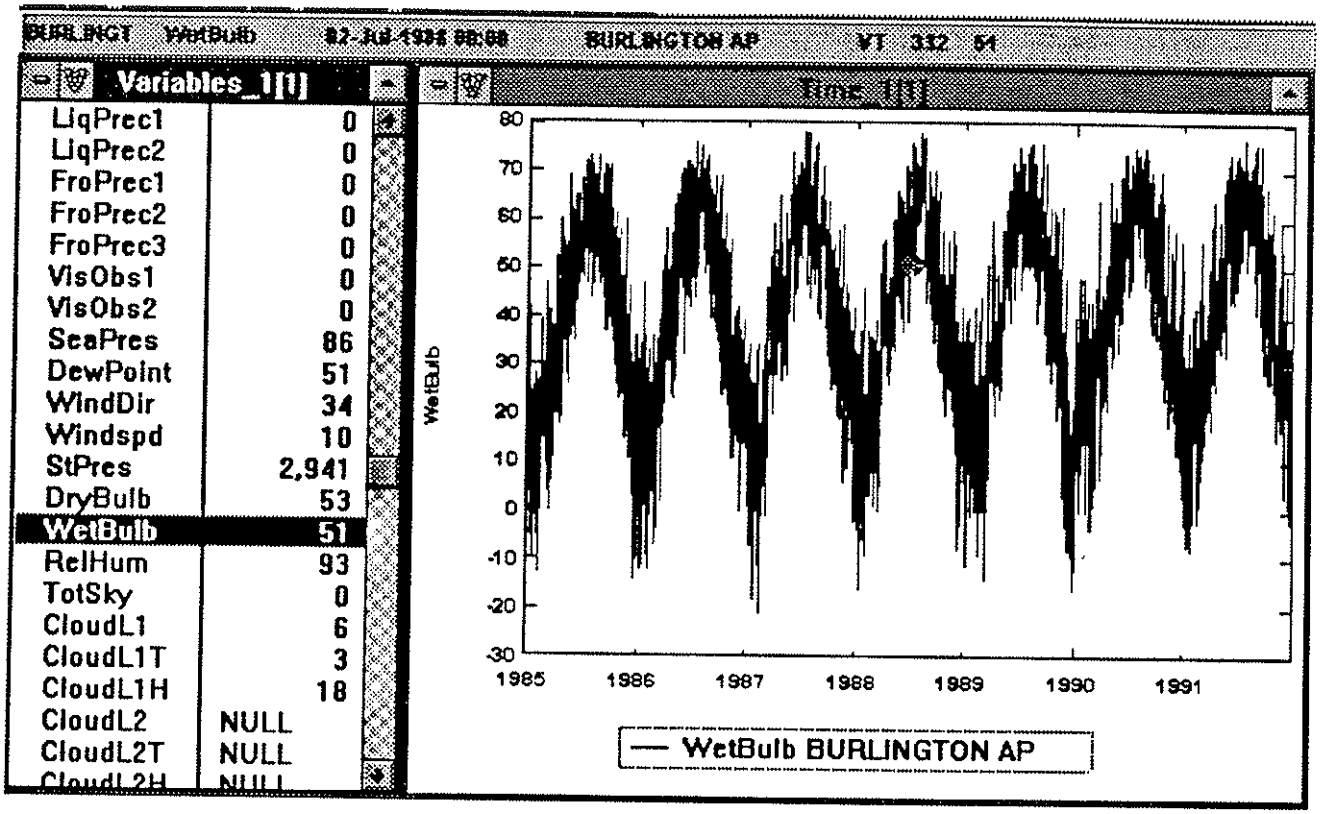
1 PM CLIMATOLOGICAL DATA FROM BURLINGTON, VT AIRPORT, 1985-91

Contributors: National Climatic Data Center, Lantern Corp.
Compiled: September 13, 1992 by Lantern Corp.

This data set contains the 1:00 PM EST climatological observations from the Burlington, VT Airport for the period 1/1/85 - 12/31/91. The data are also available in ASCII.

Variables: ceiling (100s of ft.); sky cover (10ths); visibility (10ths of miles); thunderstorms (yes/no); liquid precip. (inches); frozen precip. (inches); visible observations (weather type); sea level pressure (10ths of inches at MSL); dew point (degrees F); wind direction (0 - 360 degrees); wind speed (knots); station pressure (inches at 340 ft. above MSL); dry bulb temp. (degrees F); wet bulb temp. (degrees F); relative humidity (%); cloud layer 1, 2, 3, 4: cover (10ths), type (0-9), hieght (100s of ft.); total open sky (10ths).

Workbook Name: BURLDAY.WKB
Required Files: BURLDAY.VOY, NAM.MAP, US.LAY
Package Size: 85 kB
Related Files: BURLINGT.VOY, NEMINMAX.VOY, NEPREC.VOY



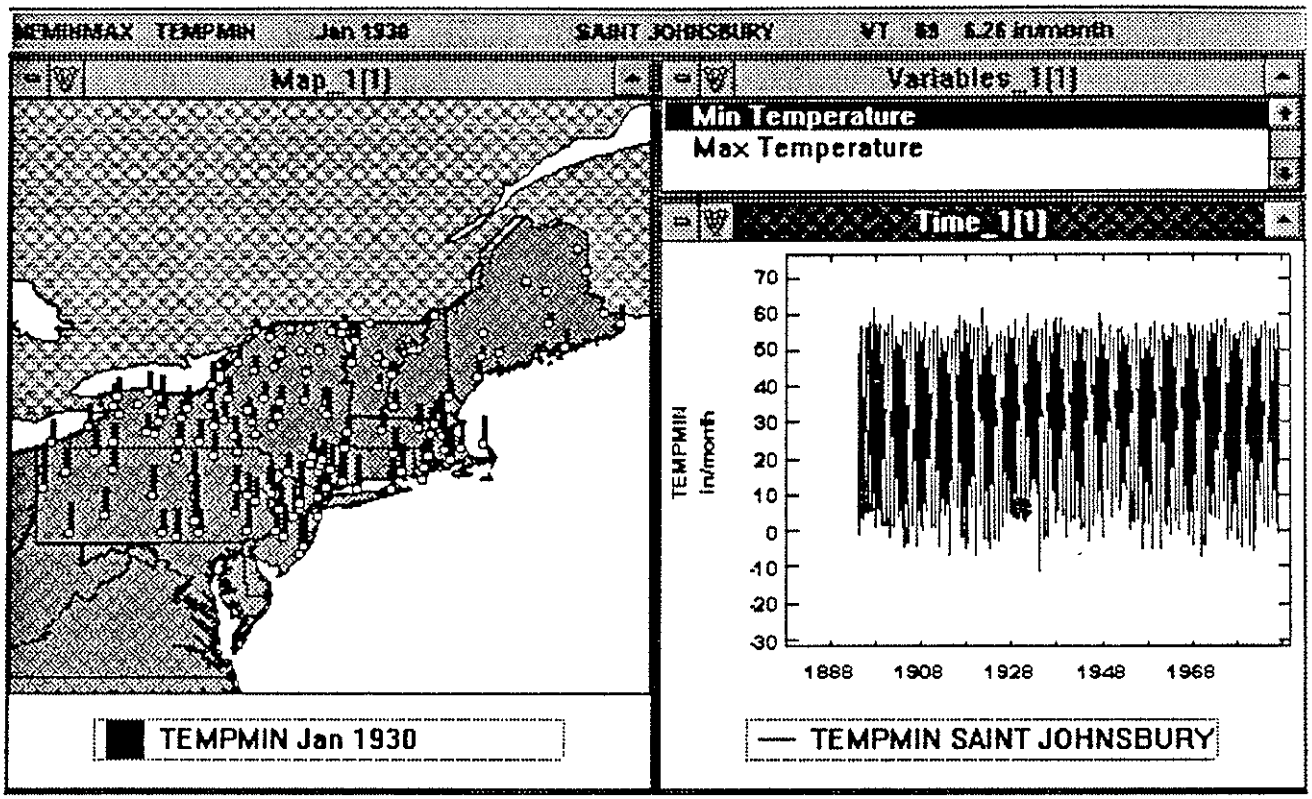
HOURLY CLIMATOLOGICAL DATA FROM BURLINGTON, VT AIRPORT, 1985-91

Contributors: National Climatic Data Center, Lantern Corp.
Compiled: September 13, 1992 by Lantern Corp.

This data set contains the hourly climatological observations from the Burlington, VT Airport for the period 1/1/85 - 12/31/91. The data are also available in ASCII.

Variables: ceiling (100s of ft.); sky cover (10ths); visibility (10ths of miles); thunderstorms (yes/no); liquid precip. (inches); frozen precip. (inches); visible observations (weather type); sea level pressure (10ths of inches at MSL); dew point (degrees F); wind direction (0 - 360 degrees); wind speed (knots); station pressure (inches at 340 ft. above MSL); dry bulb temp. (degrees F); wet bulb temp. (degrees F); relative humidity (%); cloud layer 1, 2, 3, 4: cover (10ths), type (0-9), hieght (100s of ft.); total open sky (10ths).

Workbook Name: BURLINGT.WKB
Required Files: BURLINGT.VOY, NAM.MAP, US.LAY
Package Size: 1.93 MB
Related Files: BURLDAY.VOY, NEMINMAX.VOY, NEPREC.VOY



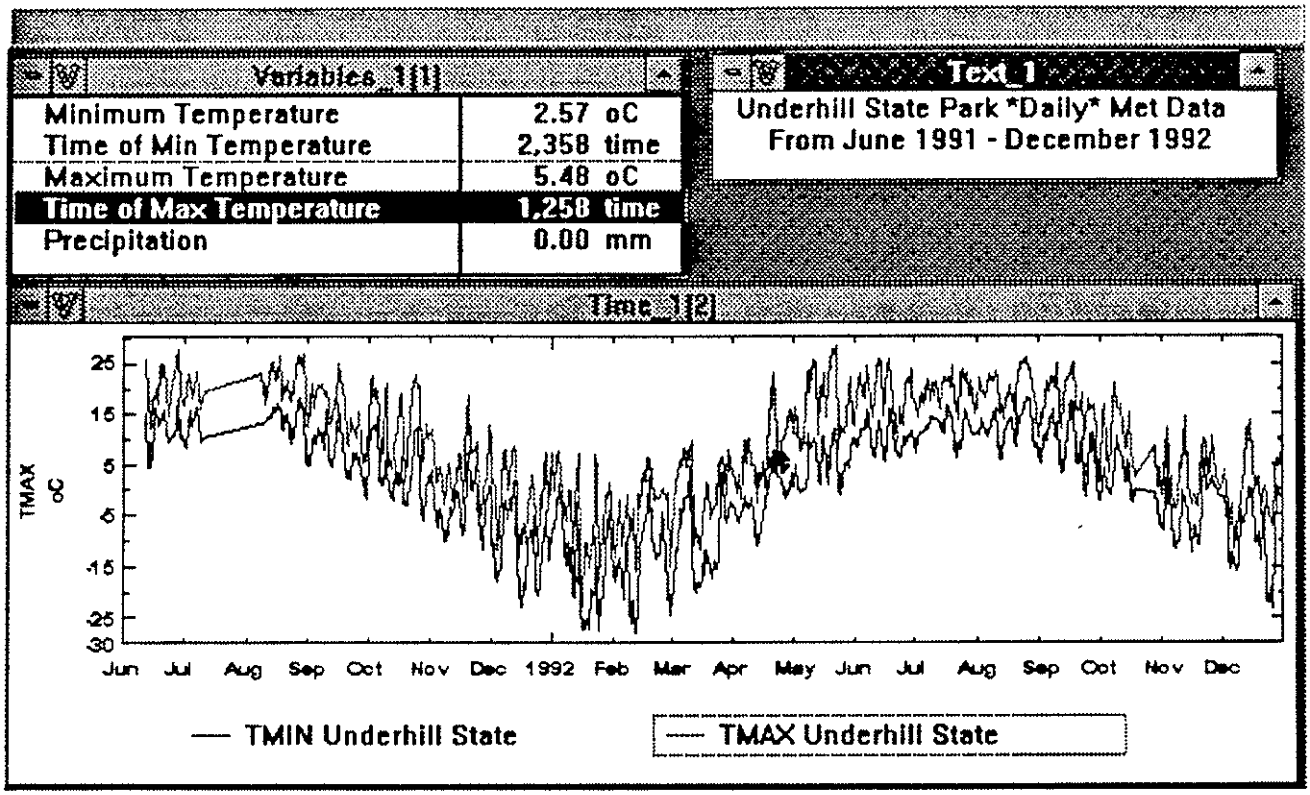
NORTHEASTERN LONG-TERM TEMPERATURE AND PRECIPITATION RECORDS

Contributors: National Weather Service, Carbon Dioxide Information Analysis Center
Compiled: September 15, 1992 by Lantern Corp.

This data set contains monthly averaged data from a set of long-term weather stations (Historical Climate Network) having at least 80 years of quality-approved data in the northeastern US. The data set does have a few obvious errors in the form of unreasonable extreme values. This is a 3-page workbook, accessing 2 VOY files.

Variables: maximum and minimum temperature and precipitation amount.

Workbook name: NEMETLON.WKB
Required files: NEMINMAX.VOY, NEPREC.VOY, NAM.MAP, US.LAY
Package size: 1,059 kb
Related files: VTMET3.VOY, BURLDAY.VOY, BURLINGT.VOY



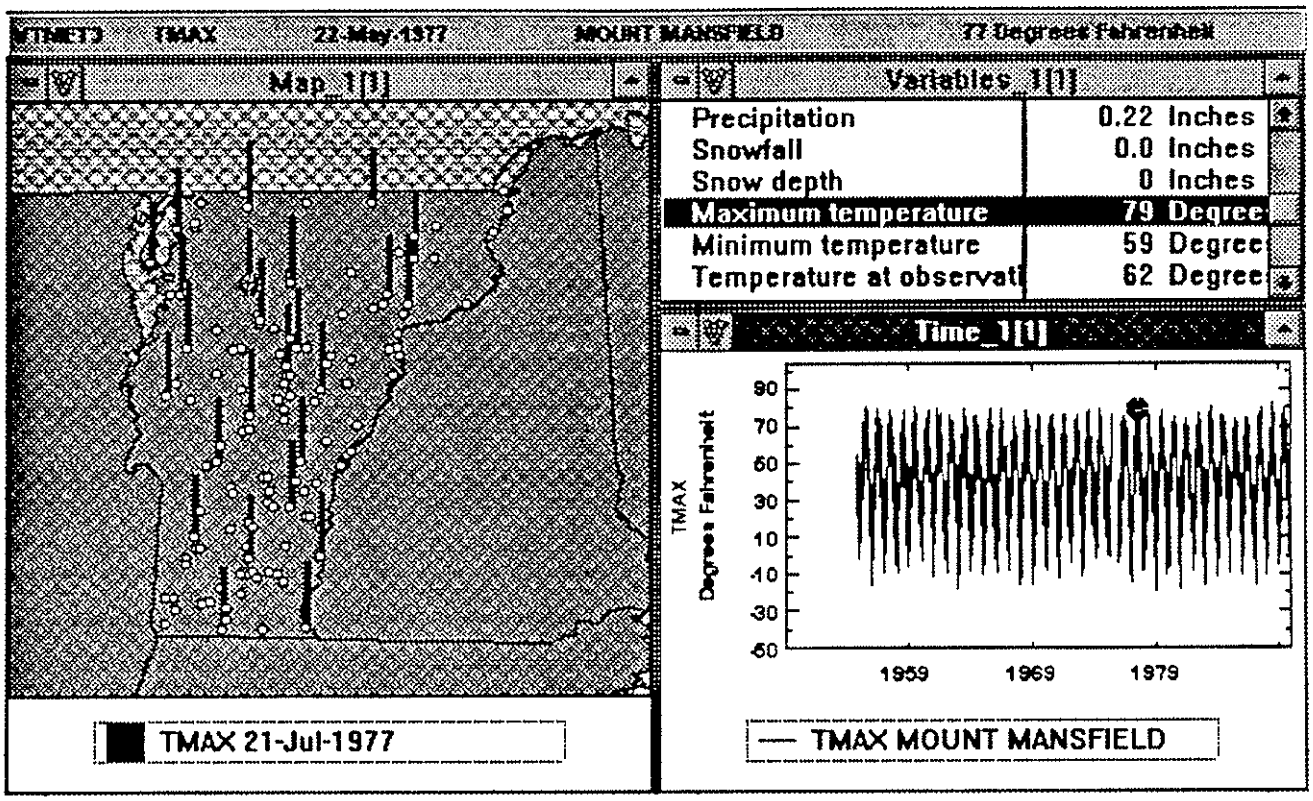
UNDERHILL STATE PARK METEOROLOGY STATION, JUNE 1991 - DECEMBER 1992

Contributors: Vermont State Department of Forests Parks and Recreation
Compiled: June 3, 1993 by Ian Martin

This data set contains hourly and daily meteorology data collected in Underhill State Park from June, 1991 - December, 1992. The data set is also available in either in ASCII or Lotus files (hourly 1.3 MB, daily 0.5 MB).

Variables: Daily maximum and minimum temperature (oC), daily precipitation depth (mm), hourly mean temperature (oC), hourly mean relative humidity (%), hourly mean wind speed (ms-1), hourly wind direction (deg), hourly precipitation depth (mm).

Workbook Name:	UNDER1.WKB
Required Files:	UNDERHR.VOY, UNDERDAY.VOY
Package Size:	70 kB
Related Files:	VTMETDAT.VOY, BURLDAY.VOY, BURLINGT.VOY, NEMINMAX.VOY, VTPREC.VOY, VAPMPMO2.VOY



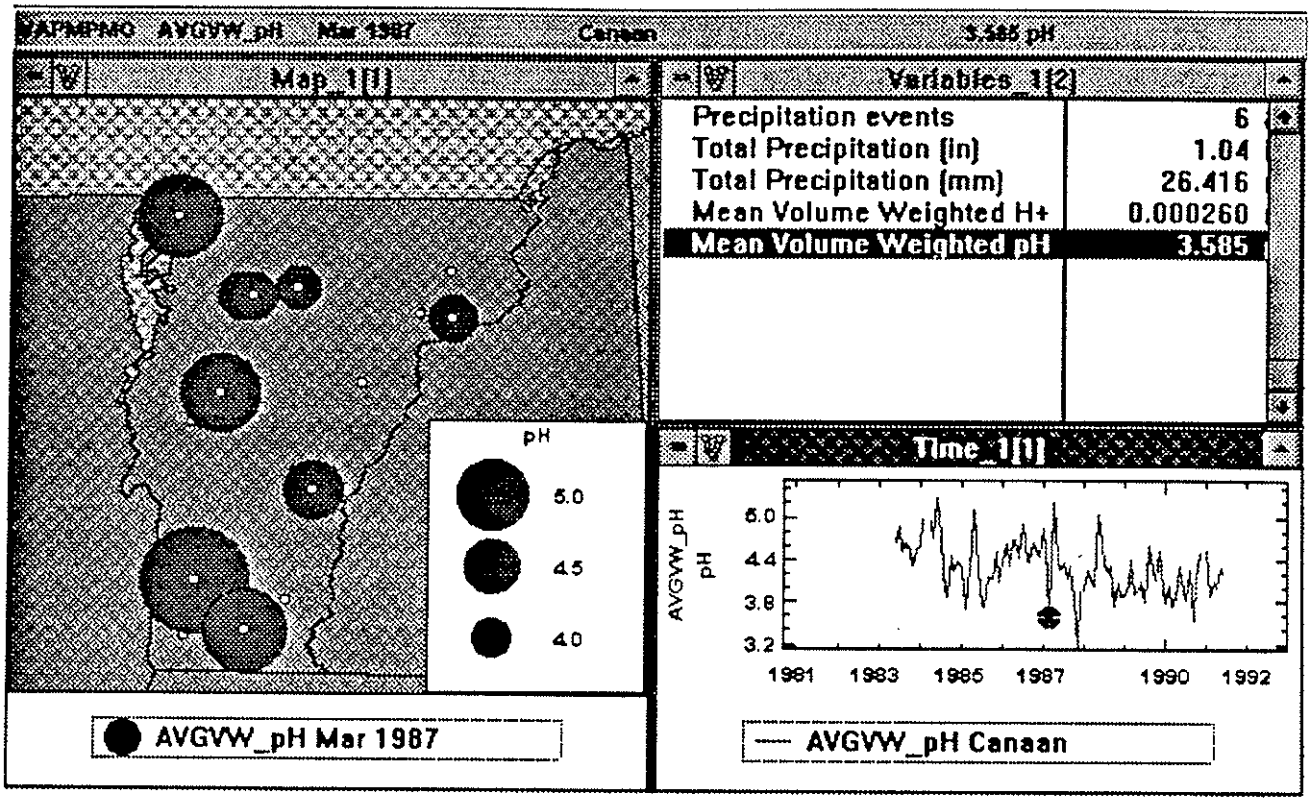
VERMONT METEOROLOGICAL DATA

Contributors: National Weather Service
Compiled: October 10, 1993 by Don Hay, Carl Slenk and Ian Martin

This data set contains daily weather data from all National Weather Service cooperating weather stations in Vermont for their entire period of record. The most recent data available is through December 1990, at which time there were 45 active stations. Due to the large size of this database, it is only available as a Voyager file and workbook, or as an ASCII file of variable (40 Mb) or fixed (90 Mb) length records. The only known problem with these data may be an erroneous extreme value (easy to identify) for at least one station for temperature (e.g., 500 deg F) and precipitation (e.g., 1,000 inches).

Variables: Daily precipitation amount (inches), snowfall (inches), snow-depth (inches), maximum, minimum and time-of-observation temperature (deg. F), and numerous categories of weather conditions (sleet, blowing snow, lightning, dust, etc.).

Workbook names: VTMET3.WKB
Required files: VTMET3.VOY, NAM.MAP, US.LAY
Package size: 9.52 Mb
Related files: VAPMPMO2.VOY, VTPREC.VOY, UNDERDAY.VOY, UNDERHR.VOY, BURLDAY.VOY, BURLINGT.VOY, NEMINMAX.VOY, NEPREC.VOY



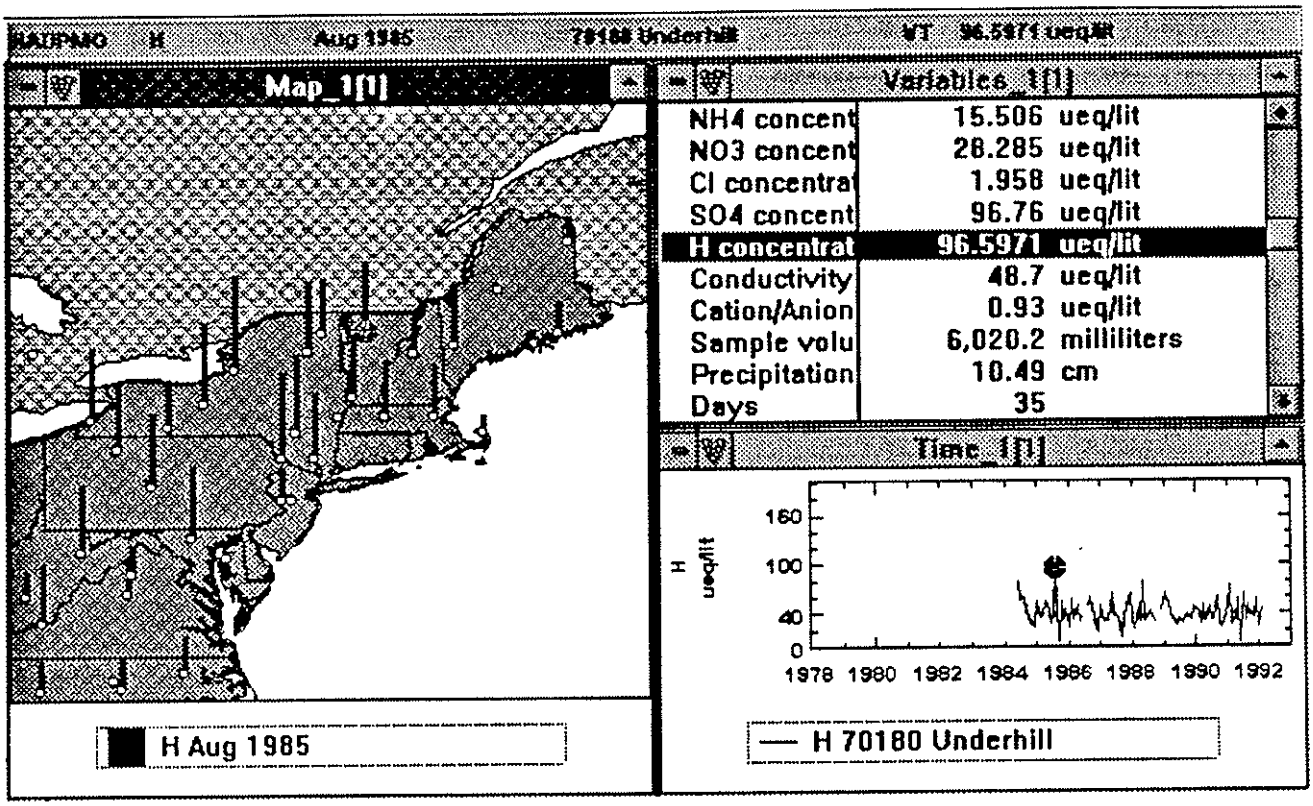
VERMONT ACID PRECIPITATION MONITORING PROGRAM (VAPMP).

Contributors: Vermont Water Quality Division
Compiled: September 10, 1993 by Ian Martin

This data set contains monthly aggregate data from 16 VAPMP stations from June 1980 - December 1992. The data set is also available in daily, weekly or monthly ASCII and Lotus files (daily ASCII 900 kB, weekly 400 kB, monthly 75 kB).

Variables: # precipitation events, monthly precipitation depth (in and mm), mean volume weighted H+, mean volume weighted pH.

Workbook Name: VAPMPMO2.WKB
Required Files: VAPMPMO2.VOY, NAM.MAP, US.LAY
Package Size: 45 kB
Related files: NADPAV.VOY, NADPMO.VOY



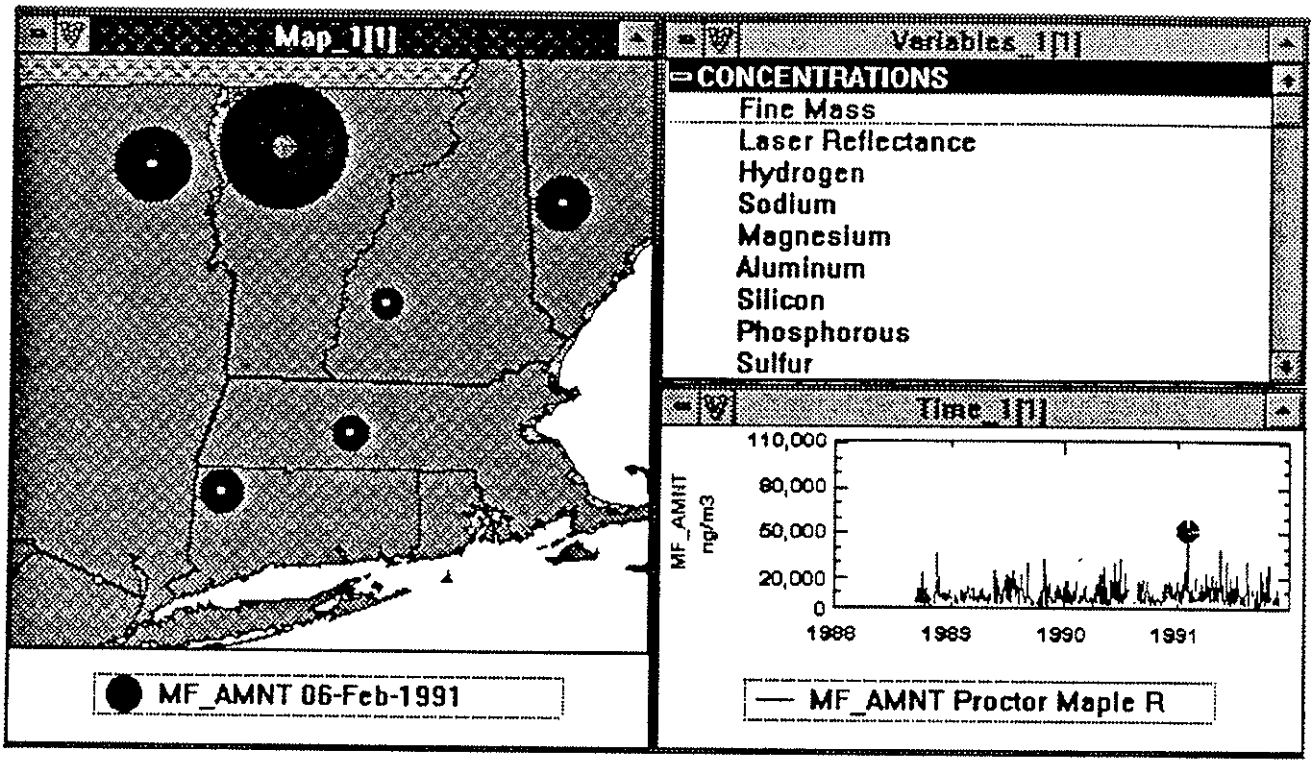
NADP PRECIPITATION CHEMISTRY MOTHLY AVERAGES

Contributors: National Atmospheric Deposition Program / National Trends Network
Compiled: September 11, 1992 by Lantern Corp.

This data set contains monthly averaged data from all U.S. NADP/NTN stations (206 sites in 47 states) from July 1978 through February 1992. There may be in the data at least one erroneous very extreme (easy to identify as erroneous) value for some variables; there are no other known problems.

Variables: Ca, Mg, K, Na, NH4, NO3, Cl, SO4, H, conductivity, cation/anion ratio, volume, precip amount, # days, # valid samples, date on, date off, and data completeness.

Workbook names: NADPMO.WKB
Required files: NADPMO.VOY, NAM.MAP, US.LAY
Package size: 1,199 kB
Related files: VAPMPMO2.VOY, VTPREC.VOY, NADPAV.VOY



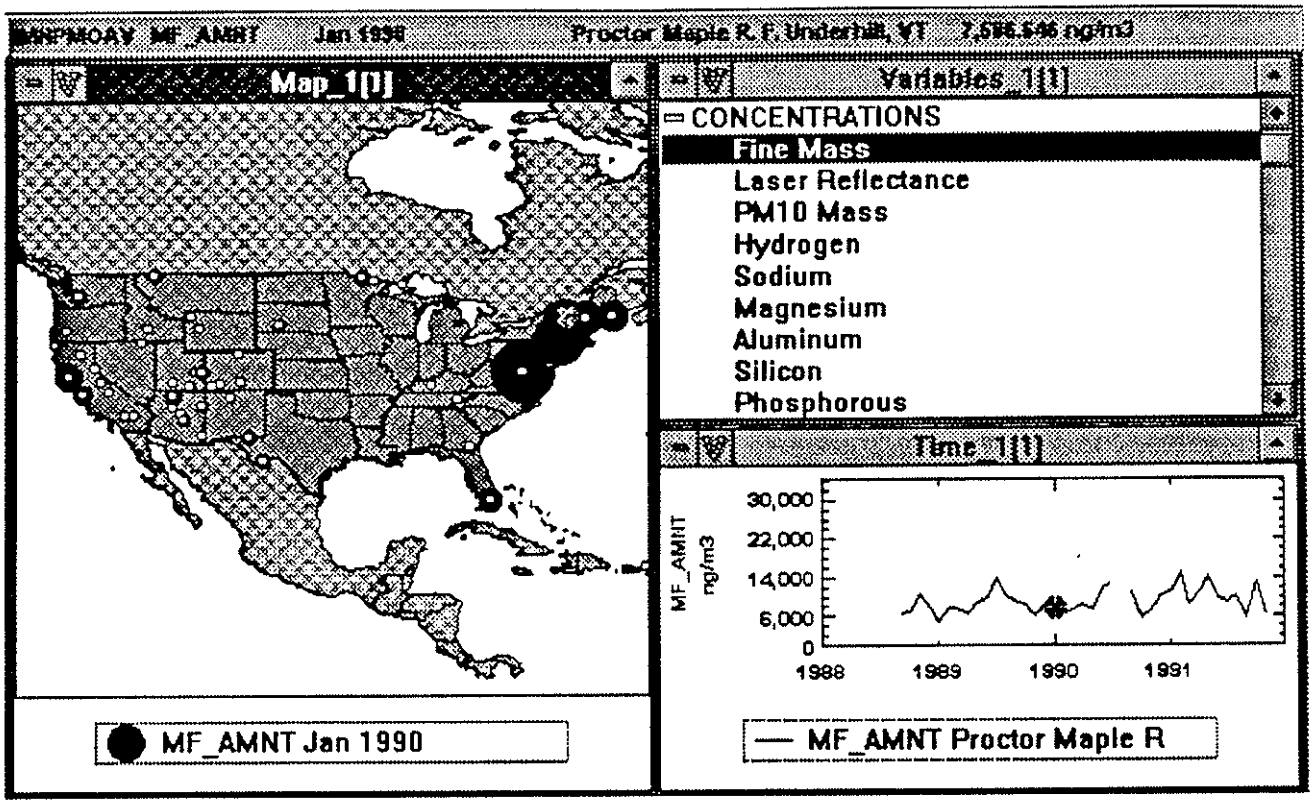
NESCAUM REGIONAL PARTICLE MONITORING NETWORK (NEPART), 1988-92

Contributors: Northeast States for Coordinated Air Use Management (NESCAUM)
Compiled: April 12, 1993 by Lantern Corp.

This data set contains results from the NESCAUM Regional Particle Monitoring Network (NEPART) for the period 9/14/88 - 11/30/92. Fine particle samples (<2.5 microns) were collected for 24 hours on Wednesdays, Saturdays and every 6th day at 7 rural sites in NJ, NY, CT, RI, MA, ME, NH, and VT. Filters were analyzed for mass, light absorption, and multiple trace elements at Crocker Nuclear Laboratory, University of California at Davis. A duplicate sampler was run at the VT site starting in 10/92. Two additional fine particle samplers were run at NY and MA sites through11/89, with analysis for elemental and organic carbon at Desert Research Institute, Reno, NV> Several "composite variables" (calculated from combinations of the raw data) are also provided. Results include measured variables, measurement error, detection limits, and QA species status codes. The data set is also available in ASCII.

Variables: fine mass, babs, H, Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, As, Pb, Se, Br, Rb, Sr, Zr, Mo; (low and high temperature organic and elemental carbon): OCLT, OCHT, ECLT, ECHT; (composite variables): NHSO, SOIL, KNON,OMH,OMC,LAC,RCMA,RCMC,REMM,RSMA,RSMC (ng/m3)

Workbook Name:	NEPART6.WKB
Required Files:	NEPART6.VOY, NAM.MAP, US.LAY
Package Size:	1.1 MB
Related Files:	NEP6MOAV.VOY, IMP_NESC.VOY, IMNPMOAV.VOY



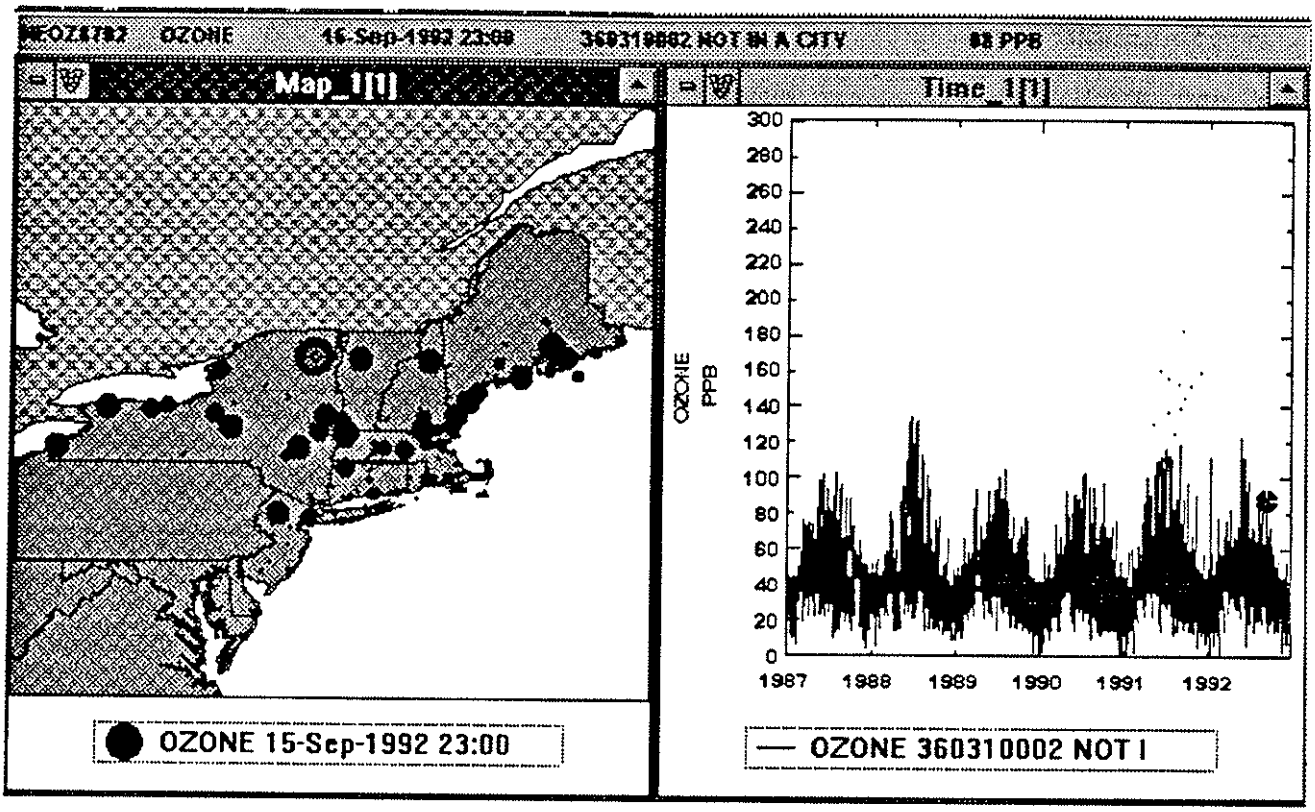
NEPART AND IMPROVE AEROSOL COMPOSITION AS MONTHLY MEANS, 1988-91.

Contributors: Northeast States for Coordinated Air Use Management (NESCAUM) and Interagency Monitoring of Protected Visual Environments (IMPROVE)
Compiled: September 13, 1992 by Lantern Corp.

This data set contains the combined results from the NESCAUM Regional Particle Monitoring Network (NEPART) and the Interagency Monitoring of Protected Environments (IMPROVE) aerosol monitoring programs, expressed as monthly means. NEPART monthly means are based on three 24-hour samples per week (Wednesday, Saturday and 6th day), while IMPROVE means are based on Wednesday and Saturday only. IMPROVE data include several variables not measured at NEPART sites. For values at or below Minimum Detection Limits a value of MDL/2 is employed in calculating the monthly means.

Variables: (All Sites) Fine Mass, Babs, H, Na, Mg, Al, Sl, P, S, CL, K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, As, Pb, Se, Br, Rb, Sr, Zr, Mo; (IMPROVE and 2 NEPART Sites Only): OCLT, OCHT, ECLT, ECHT (Low and High Temperature Organic and Elemental Carbon); (IMPROVE Only): PM-10 Mass, Nitrite, Nitrate, Sulfur Dioxide (ng/m3)

Workbook Name: IMNPMOAV. WKB
Required files: IMNPMOAV.VOY, NAM.MAP, US.LAY
Package Size: 252 kB
Related files: NEPART6.VOY, NEP6MOAV.VOY, IMP_NESC.VOY



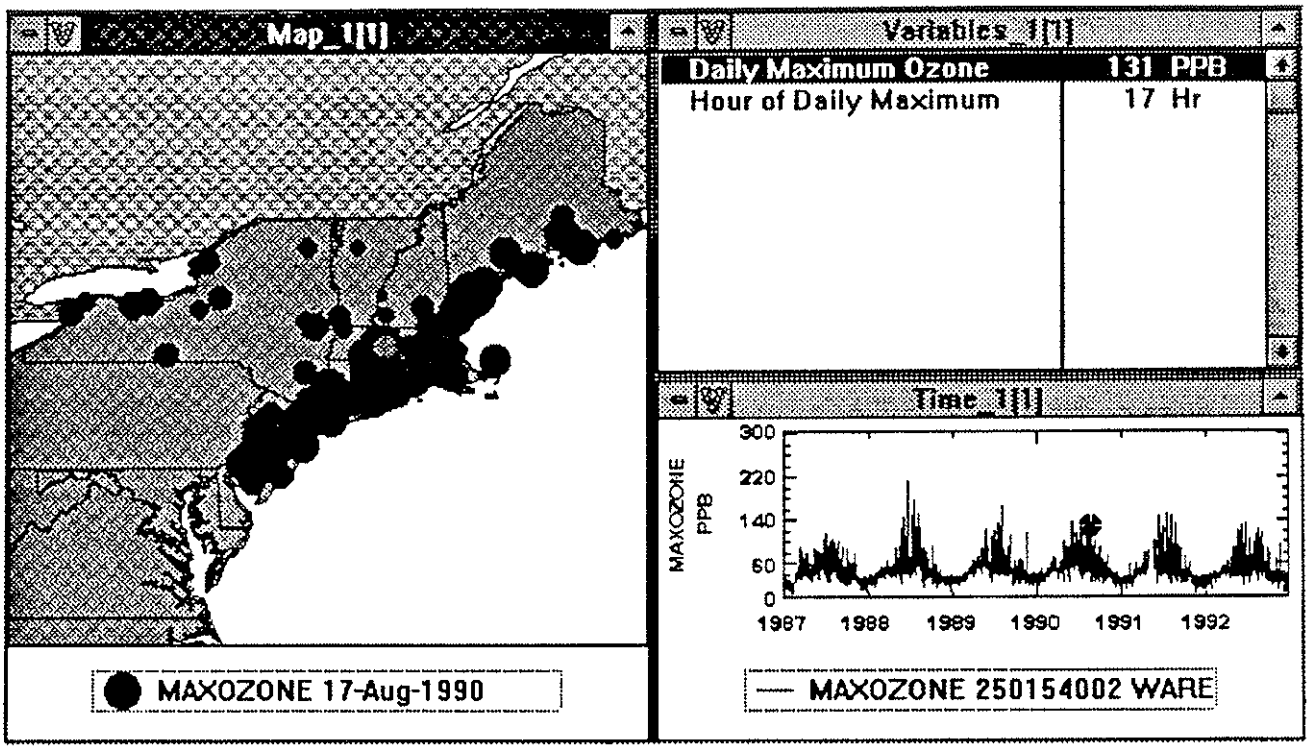
HOURLY OZONE CONCENTRATIONS FOR THE NORTHEASTERN U.S., 1987 - 92

Contributors: Northeast States for Coordinated Air Use Management (NESCAUM) and USEPA
Compiled: April 12, 1993 by Lantern Corp.

This data set contains hourly ozone concentrations from 1/1/87 through 12/31/92 from all sites in the northeastern states of NY, NJ, CT, RI, MA, ME, NH and VT which have been reported to the USEPA Aerometric Information and Retrieval System (AIRS). Data were extracted as an AMP350 file from AIRS by means of the AIRS/Voyager Data Delivery System. The data are also available in ASCII.

Variables: Hourly average ozone (ppb)

Workbook Name: NEOZ8792.WKB
Required Files: NEOZ8792.VOY, NAM.MAP, US.LAY
Package Size: 4.17 MB
Related Files: OZ8792QA.WKB, NEOZAGDA.VOY, NEOZMOAG.VOY, NEOZPERC.VOY, NEPM8792.VOY



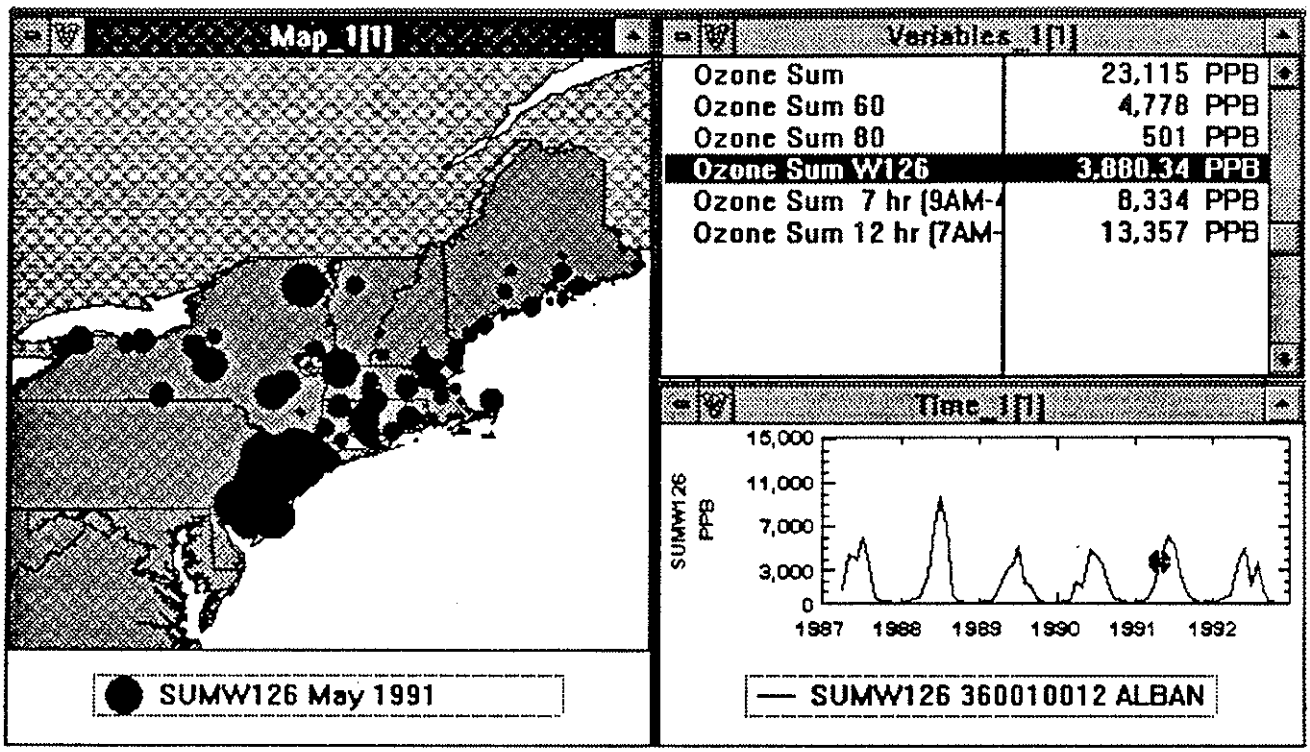
DAILY MAXIMUM OZONE IN THE NORTHEASTERN U.S., 1987 - 92

Contributors: Northeast States for Coordinated Air Use Management (NESCAUM) and USEPA
Compiled: April 12, 1993 by Lantern Corp.

This data set contains maximum daily one-hour ozone concentrations from 1/1/87 through 12/31/92 from all sites in the northeastern states of NY, NJ, CT, RI, MA, ME, NH and VT (NESCAUM) which have been reported to the USEPA Aerometric Information and Retrieval System (AIRS). Data were extracted as an AMP350 file (hourly data) from AIRS by means of the AIRS/Voyager Data Delivery System. The results were re-formated by Lantern Corp. to include only the maximum hourly concentrations (and hour of occurrence) for each day. The data are also available in ASCII.

Variables: Maximum daily ozone (ppb), hour of maximum (0 - 23)

Workbook Name: NEOZAGDA.WKB
Required Files: NEOZAGDA.VOY, NAM.MAP, US.LAY
Package Size: 563 kB
Related Files: NEOZ8792.VOY, OZ8792QA.WKB, NEOZMOAG.VOY, NEOZPERC.VOY, NEPM8792.VOY



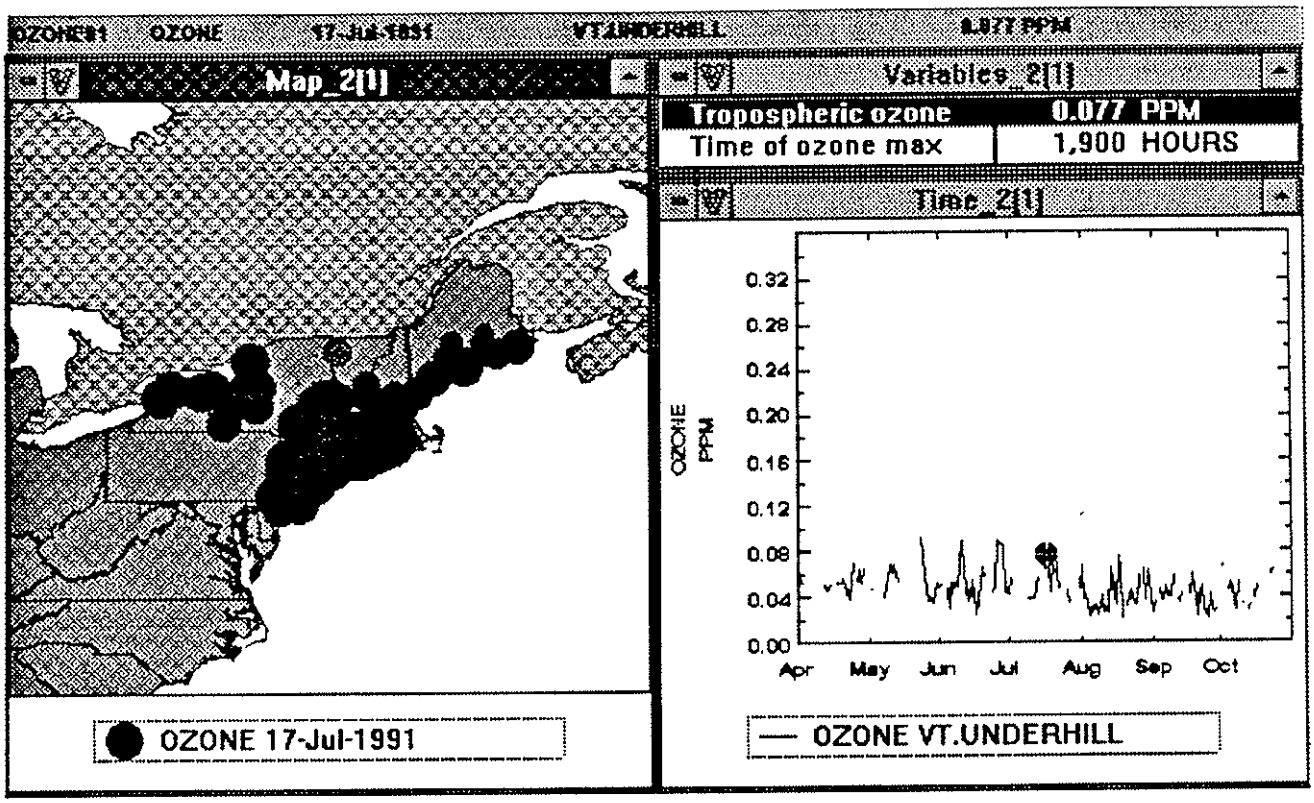
MONTHLY BIOLOGICAL OZONE INDICES FOR THE NORTHEASTERN U.S.,1987-92

Contributors: Northeast States for Coordinated Air Use Management (NESCAUM) and USEPA
Compiled: April 12, 1993 by Lantern Corp.

This data set contains monthly aggregated sums of various "biologically relevant" ozone indices from 1/1/87 through 12/31/92 for all sites in the northeastern states of NY, NJ, CT, RI, MA, ME, NH and VT, which have been reported to the USEPA Aerometric Information and Retrieval System (AIRS). Data were extracted as an AMP350 file (hourly data) from AIRS by means of the AIRS/Voyager Data Delivery System. The results were re-formated by Lantern Corp. to include the monthly sums of the indices indicated below. The data are also available in ASCII.

Variables: Sum of all hourly values, sum of all values >= 60 ppb, sum of all values >= 80 ppb, sum of W126 index, sum of 7 hour values (9 am - 4 pm), sum of 12 hour values (7 am - 7 pm) in ppb

Workbook Name: NEOZMOAG.WKB
Required Files: NEOZMOAG.VOY, NAM.MAP, US.LAY
Package Size: 152 kB
Related Files: NEOZ8792.VOY, OZ8792QA.WKB, NEOZAGDA.VOY, NEOZPERC.VOY, NEPM8792.VOY



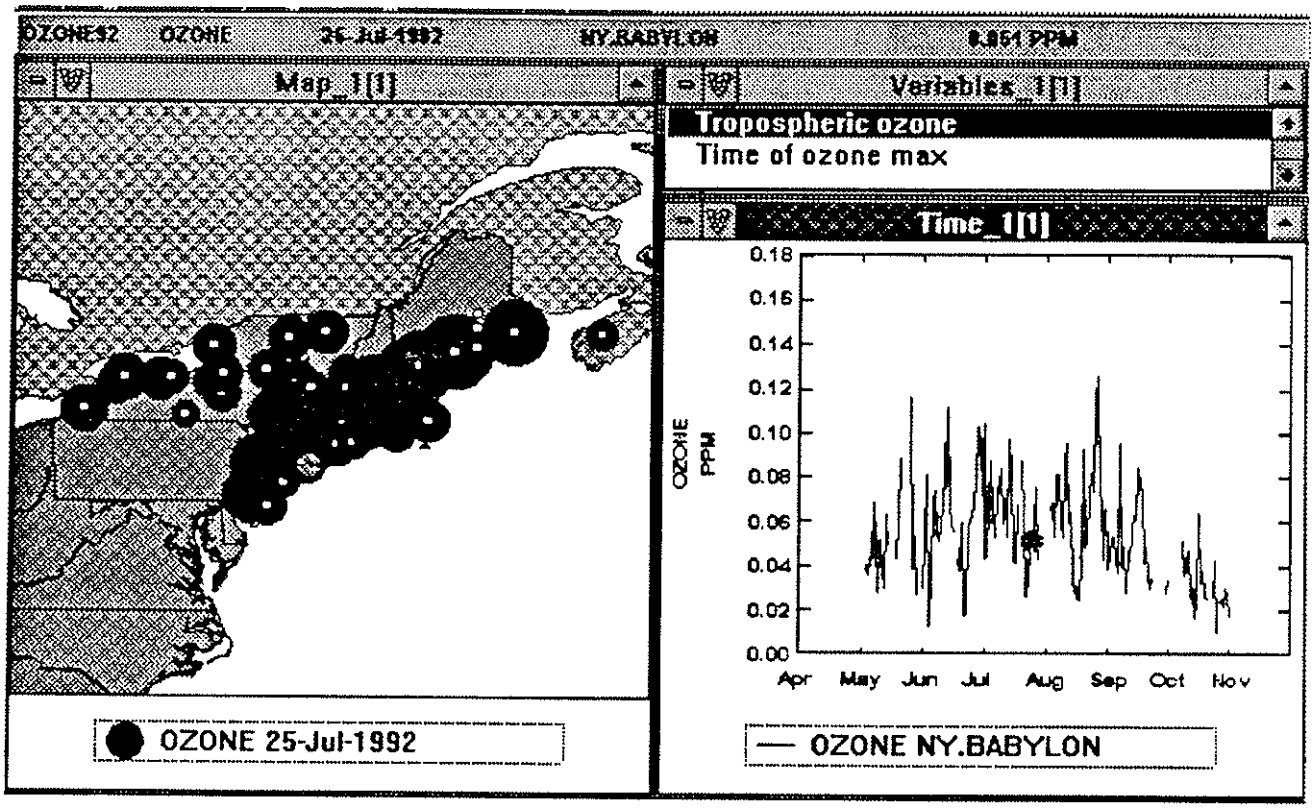
NESCAUM DAILY OZONE MAXIMUMS AND TIMES OF OCCURANCE, 1991. PRELIMINARY DATA.

Contributors: Northeastern States for Coordinated Air Use Management
Compiled: May 5, 1992 by Ian Martin

This data set contains preliminary daily ozone maximum values (ppm) and first recorded time of occurance (hours) reported by NESCAUM cooperators from April 1, 1991 - October 31, 1991. The data covers 97 monitoring stations in CT, ME, MA, NH, NY, RI, and VT. The data set is also available in weekly ASCII or Lotus files (complete set approx. 925 kB).

Variables: Daily maximum ozone (ppm), hour of occurance (hours)

Workbook Name: OZONE91.WKB
Required Files: OZONE91.VOY , NAM.MAP, US.LAY
Package Size: 70 kB
Related Files: OZONE92.VOY, NEOZ8792.VOY, NEOZAGDA.VOY, NEOZMOAG.VOY, NEOZPERC.VOY



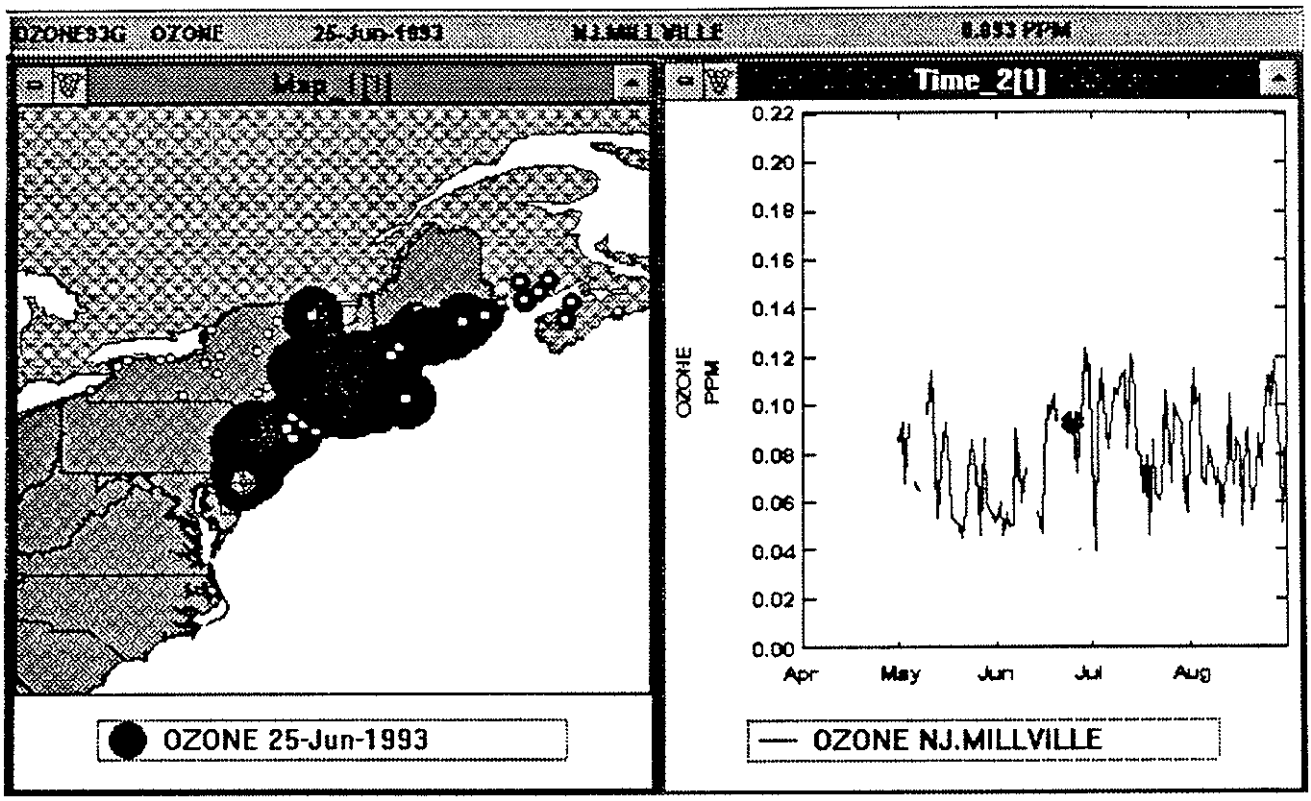
NESCAUM DAILY OZONE MAXIMUMS AND TIMES OF OCCURANCE , 1992. PRELIMINARY DATA

Contributors: Northeastern States for Coordinated Air Use Management
Compiled: February 25, 1993 by Ian Martin

This data set contains preliminary daily ozone maximum values (ppm) and first recorded time of occurance (hours) reported by NESCAUM cooperators from April 1, 1992 - October 31, 1992. The data covers 81 monitoring stations in CT, ME, MA, NH, NY, Nova Scotia (Can), RI, and VT. The data set is also available in weekly ASCII or Lotus files (complete set approx. 1.2 MB).

Variables: Daily maximum ozone (ppm), hour of occurance (hours)

Workbook Name: OZONE92.WKB
Required Files: OZONE92.VOY, NAM.MAP, US.LAY
Package Size: 80 kB
Related Files: OZONE91.VOY, NEOZ8792.VOY, NEOZAGDA.VOY, NEOZMOAG.VOY, NEOZPERC.VOY



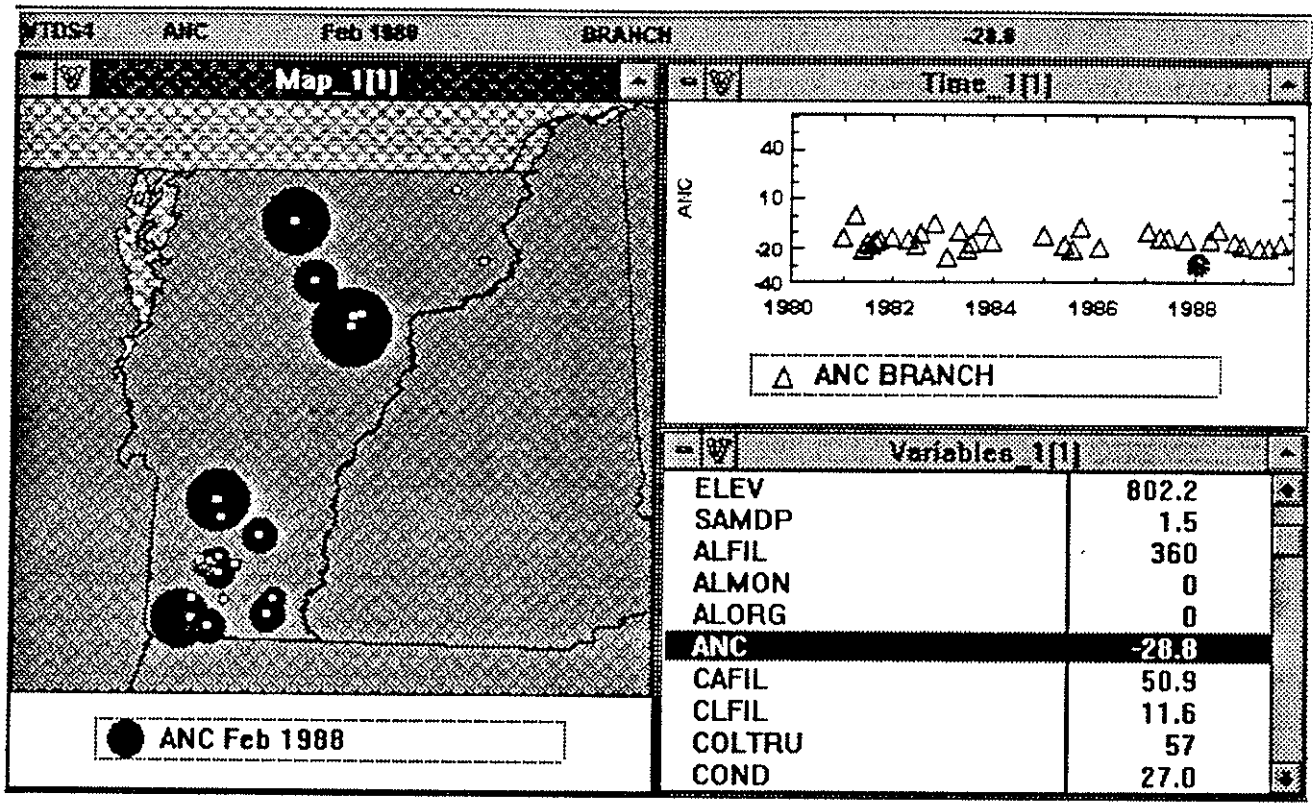
NESCAUM DAILY OZONE MAXIMUMS AND TIMES OF OCCURANCE, 1993. PRELIMINARY DATA

Contributors: Northeastern States for Coordinated Air Use Management
Compiled: December 10, 1993 by Ian Martin

Ozone93j.wkb is the sixth in a series of workbooks constructed for NESCAUM cooperators in 1993. This final edition contains data submited to the NESCAUM ozone network between the dates April 1, 1993 and November 30, 1993. The data covers 93 monitoring stations in CT, ME, MA, New Brunswick (Can), NH, NY, Nova Scotia (Can), RI, and VT. This data set is also available in ASCII (800 kB) or EXCEL files (1.3 MB).

Variables: Daily ozone maximum (ppm), Hour of occurance (hours)

Workbook Name:	OZONE93J.WKB
Required Files:	OZONE93G.VOY, NAM.MAP, US.LAY
Package Size:	163 kB
Related Files:	OZONE92.VOY, OZONE91.VOY, NEOZAGDA.VOY, NEOZMOAG.VOY, NEOZPERC.VOY



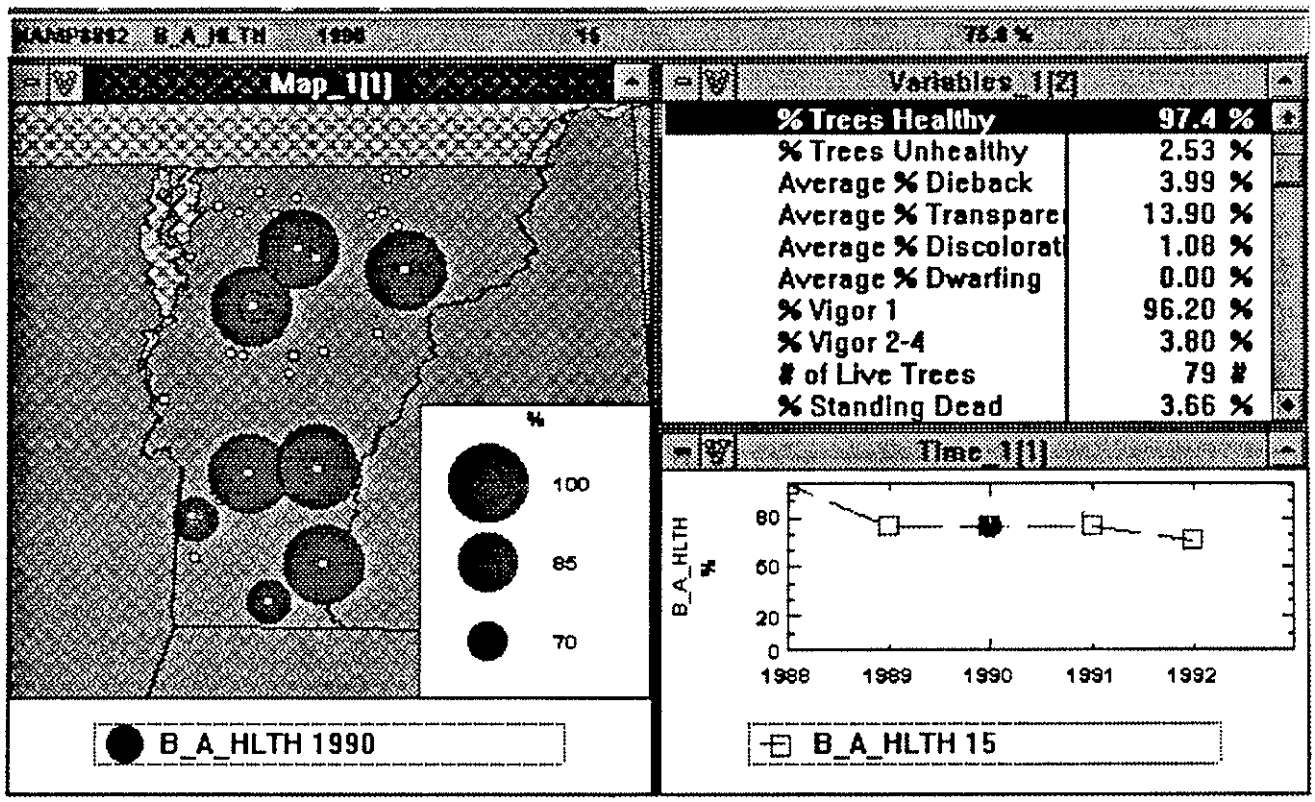
VERMONT LONG-TERM LAKE MONITORING PROGRAM (LTLM), 1980 - 90.

Contributors: VT DEC Water Quality Division and USEPA
Compiled: May 13, 1992 by Lantern Corp.

This data set contains aquatic chemistry measurements from the Vermont Long-Term Monitoring (LTM) program from 1980 - 1990. The LTLM program included physical and chemical measurements at approximately quarterly sampling frequency from 24 acid-sensitive lakes in VT. The data were obtained from the USEPA Environmental Research Laboratory in Corvalis, OR, and include several adjustments to the raw measurement values to account for changes in methods over time. The data are also available in ASCII.

Variables: Elevation (m), sample depth (m), total filtered Al (ug/l), acid neutralizing capacity (ueq/l), filtered Ca (ueq/l), filtered chloride (ueq/l), true color (PCU), conductivity (uS/cm), filtered potassium (ueq/l), lake size (ha), filtered magnesium (ueq/l), filtered sodium (ueq/l), filtered nitrate (ueq/l), estimated organic ion concentration (ueq/l), pH, lake retention time (years), secchi depth (m), filtered sulfate (ueq/l), lake watershed area (ha), water temp. at sample depth (degrees C), lake hydrological type, observation ID, water stratum sampled, season of sample, state, principal investigator, and quality assurance tags.

Workbook Name: VTDS4.WKB
Required files: VTDS4.VOY, NAM.MAP, US.LAY
Package Size: 737 kB
Related Files: VTPREC.VOY, NADPMO.VOY, NEPREC.VOY



NORTH AMERICAN MAPLE PROJECT, VERMONT DATA 1988 - 1992

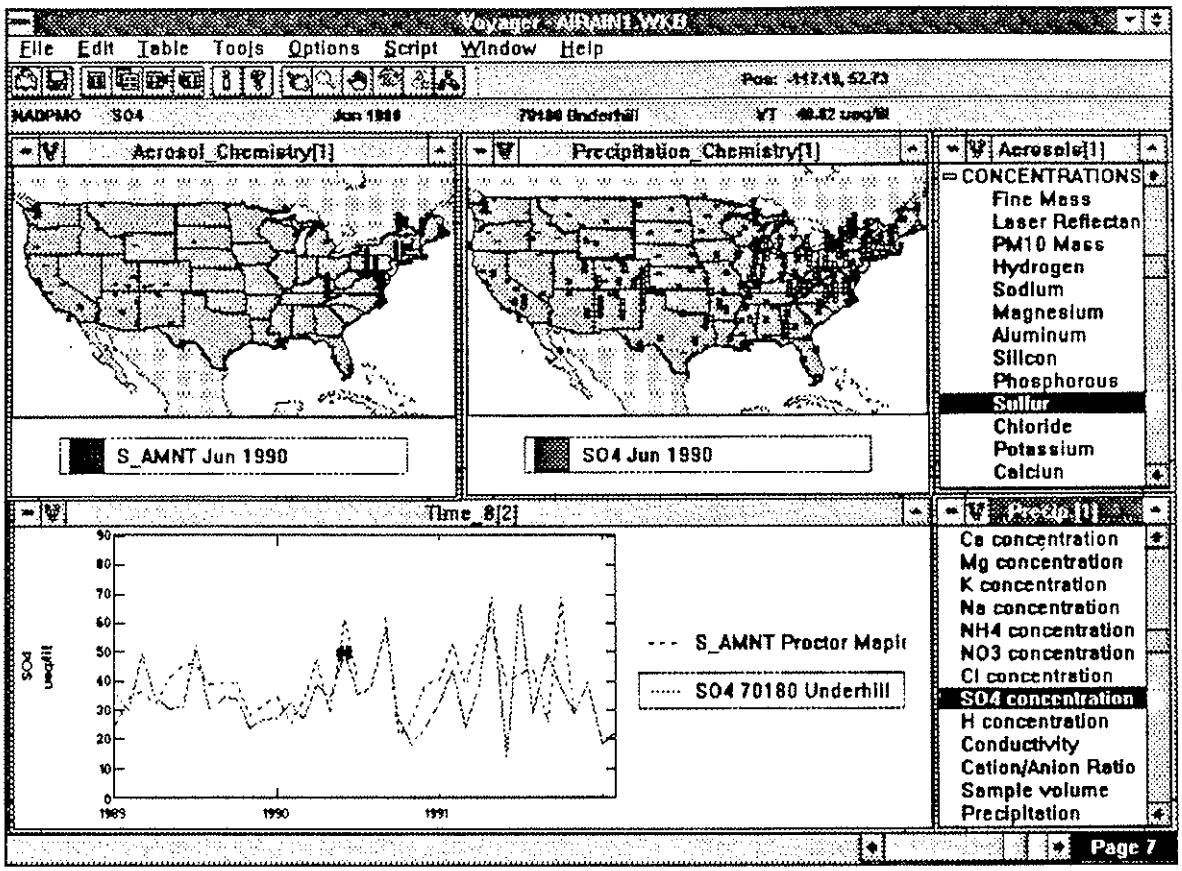
Contributors: VT Department of Forests Parks and Recreation
Compiled: September 3, 1993 by Ian Martin & Sandy Wilmot

This data represents a summary of data collected in Vermont under the NAMP program. In 1988, 26 plots were established. Additional plots were added in subsequent years so that by 1992, there were a total of 40 plots. Displayed here are data collected on trees greater than or equal to 10 cm. Initially, crown measurements were not collected on non-sugar maple species, but beginning in 1991 these measurements were taken on all hardwood species. Data displayed here have been stratified by both species and crown class, such that for each species, variables are displayed for all trees and for dominant/codominant trees. All sites contain data collected for sugar maples, but not necessarily other tree species. The data set is also available in an ASCII or Lotus file (ASCII 200 kB, Lotus 400 kB).

Variables: % trees healthy, % trees unhealthy, average % dieback, average % transparency, average % discoloration, % vigor 1, % vigor 2-4, # of live trees, % standing dead. % new mortality, % trees cut, average # tapped, average # open tapholes.

Workbook Name: NAMP8892.WKB
Required Files: NAMP8892.VOY, NAM.MAP, US.LAY
Package Size: 125 kB

APPENDIX II: INTEGRATED WORKBOOK SUMMARIES



COMPARISON OF MONTHLY MEAN AEROSOL AND PRECIPITATION CHEMISTRY

Contributors: Northeast States for Coordinated Air Use Management (NESCAUM), Interagency Monitoring of Protected Visual Environments (IMPROVE), and National Atmospheric Deposition Program (NADP)
Compiled: October 1, 1993 by Richard Poirot

This workbook provides for access to and comparison of Voyager Files of two national data sets (both of which include stations at the VMC Proctor Maple Research Center in Underhill, VT):

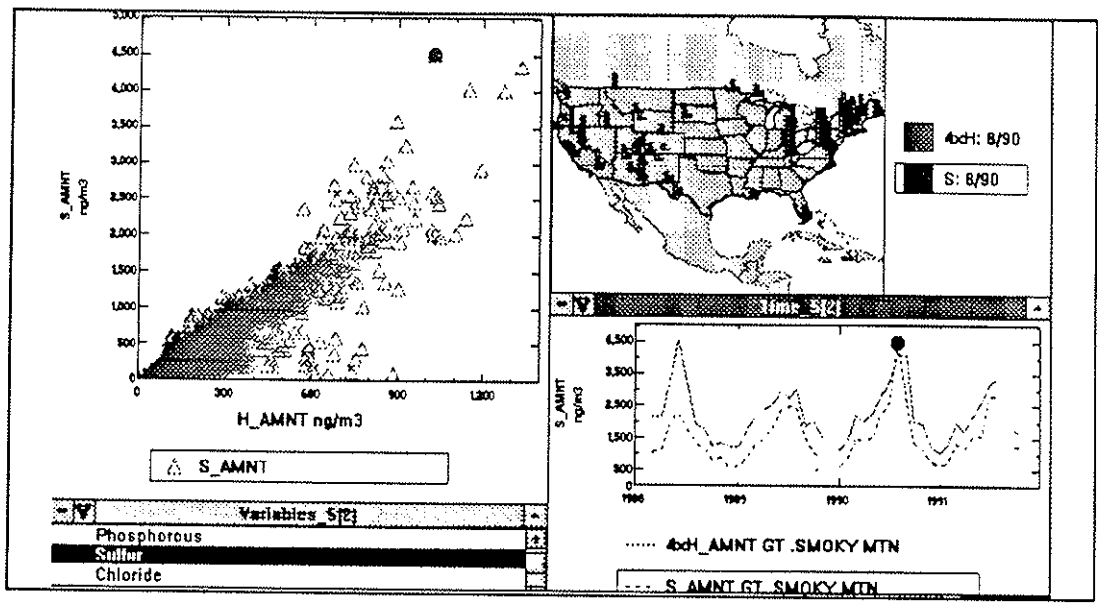
1. IMNPMOAV.VOY - monthly mean aerosol chemistry from IMPROVE and NESCAUM networks
2. NADPMO.VOY - monthly volume-weighted mean precipitation chemistry from NADP network

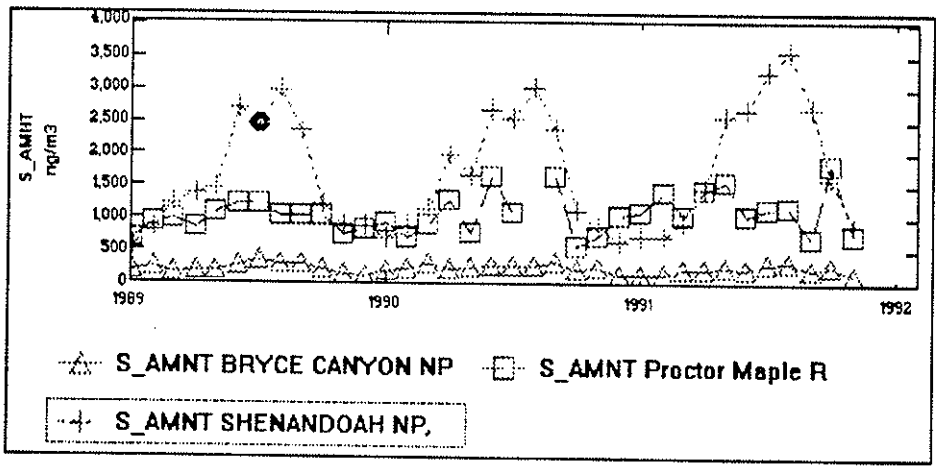
For additional details on these data files, see workbooks: IMNPMOAV.WKB & NADPMO.WKB

Workbook Name: AIRAINS.WKB
Required Files: IMNPMOAV.VOY, NADPMO.VOY, NAM.MAP, US.LAY
Package Size: 1.75 MB

The AIRAINS.WKB workbook allows for detailed examination of the spatial, temporal and relational aspect of the individual aerosol and precipitation chemistry data sets.

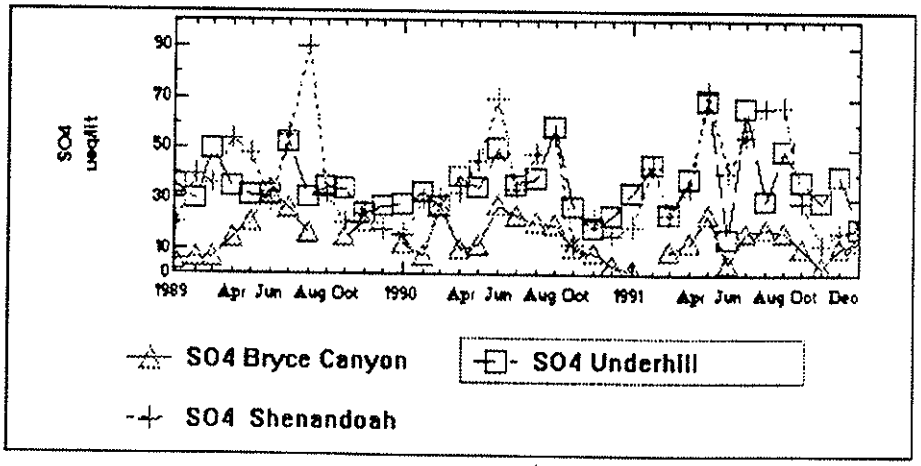
for example, in the aerosol network, there are times and locations (such as at Great Smokey Mountain National Park in August, 1990) when the monthly mean fine particle sulfur concentration exceeds 4 times the aerosol hydrogen concentration - indicating that the aerosol was strongly acidic.



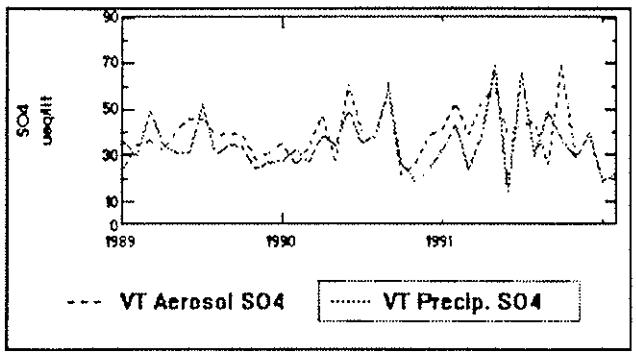


Levels of aerosol sulfur at the VMC site in Underhill, VT can be compared to (cleaner and more polluted) sites in the Southwestern and Southeastern U. S.

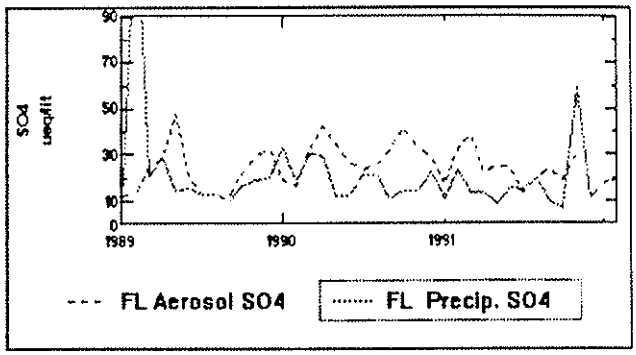
A similar comparison of sulfate concentrations in precipitation indicates a similar pattern, but shows that the regional differences in precipitation sulfate are not as extreme as the differences in aerosol phase concentrations. The precipitation sulfate at Underhill is often as high or higher than at Shenandoah National Park.



The last few pages of the AIRAINS workbook provide for direct comparisons of the two data sets. For example, we can observe that temporal patterns of sulfate in aerosol and precipitation are similar at some sites (like Underhill, VT), and quite different at other sites (like Everglades National Park).



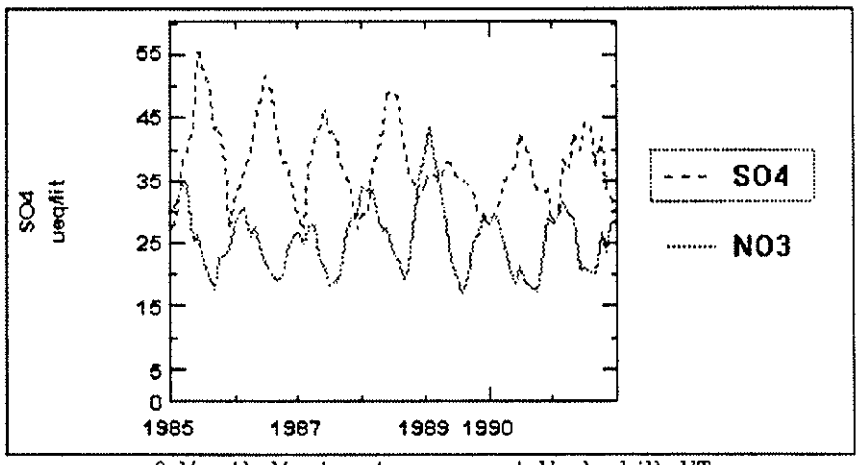
Aerosol & Precip. SO_4 at Underhill, VT



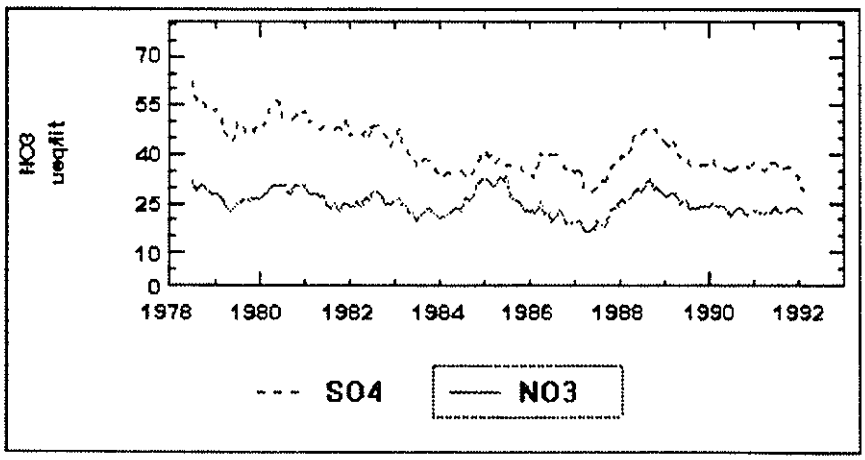
Aerosol & Precip. SO_4 at Everglades NP, FL

On the last page of the workbook, several Time views are included which employ 6 month and 12 month moving average scripts to provide a clear view of seasonal cycles and long-term trends.

For example, precipitation sulfate and nitrate exhibit distinct and opposite seasonal patterns at the Underhill site, with sulfate peaking during the summer. During winter (nitrate peaks) sulfate and nitrate contribute about the same to precipitation acidity on an equivalent basis.



6 Month Moving Averages at Underhill, VT



12 Month Moving Averages from Hubbard Brook, NH

A longer term record from nearby Hubbard Brook, NH suggests that precipitation nitrate levels have remained relatively constant over the past 15 years, while sulfate levels have declined somewhat.

COMPARISONS OF MONTHLY MEAN PRECIPITATION AND LAKE CHEMISTRY

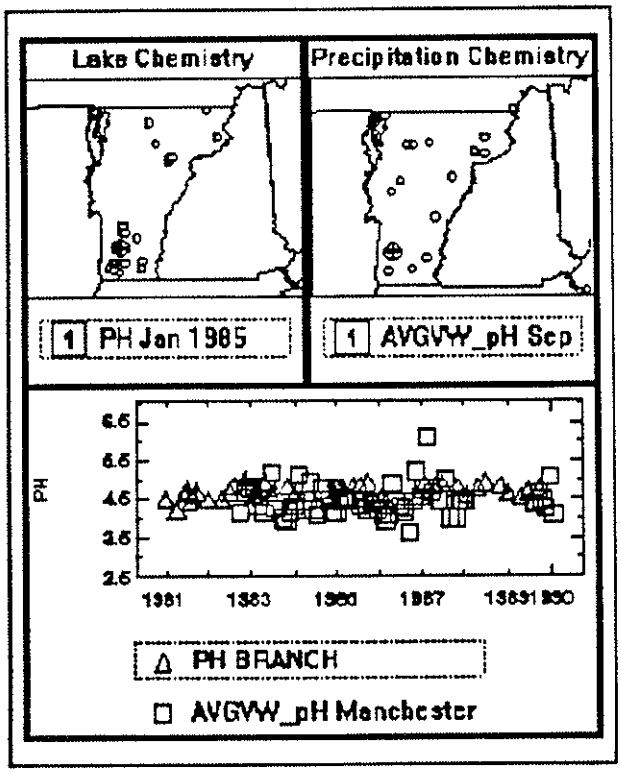
Contributors: VT DEC Water Quality Division and USEPA
Compiled: Ian D. Martin, 11/30/93

This workbook provides for access to and comparisons of two data sets containing precipitation and lake water chemistry data in Vermont.

1. VAPMPMO2.VOY - Monthly mean volume-weighted precipitation chemistry for 16 sites in Vermont.
2. VTDS4.VOY - Aquatic chemistry measurements from the Vermont Long-Term Monitoring (LTM) program from 1980 - 1990.

For additional details on these data sets, see workbooks: VAPMPMO2.WKB & VTDS4.WKB

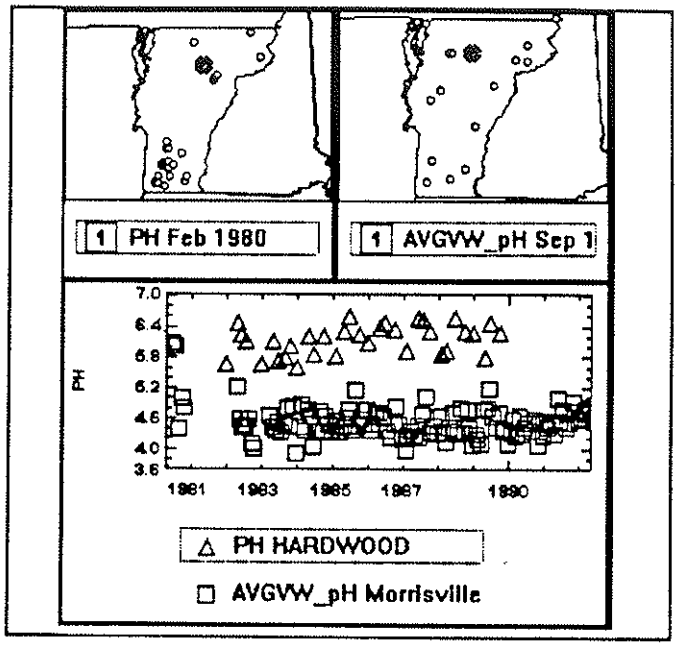
Workbook Name: PH_LAKE1.WKB
Required Files: VAPMPMO2.VOY, VTDS4.VOY, NAM.MAP, US.LAY
Package Size: 1 MB

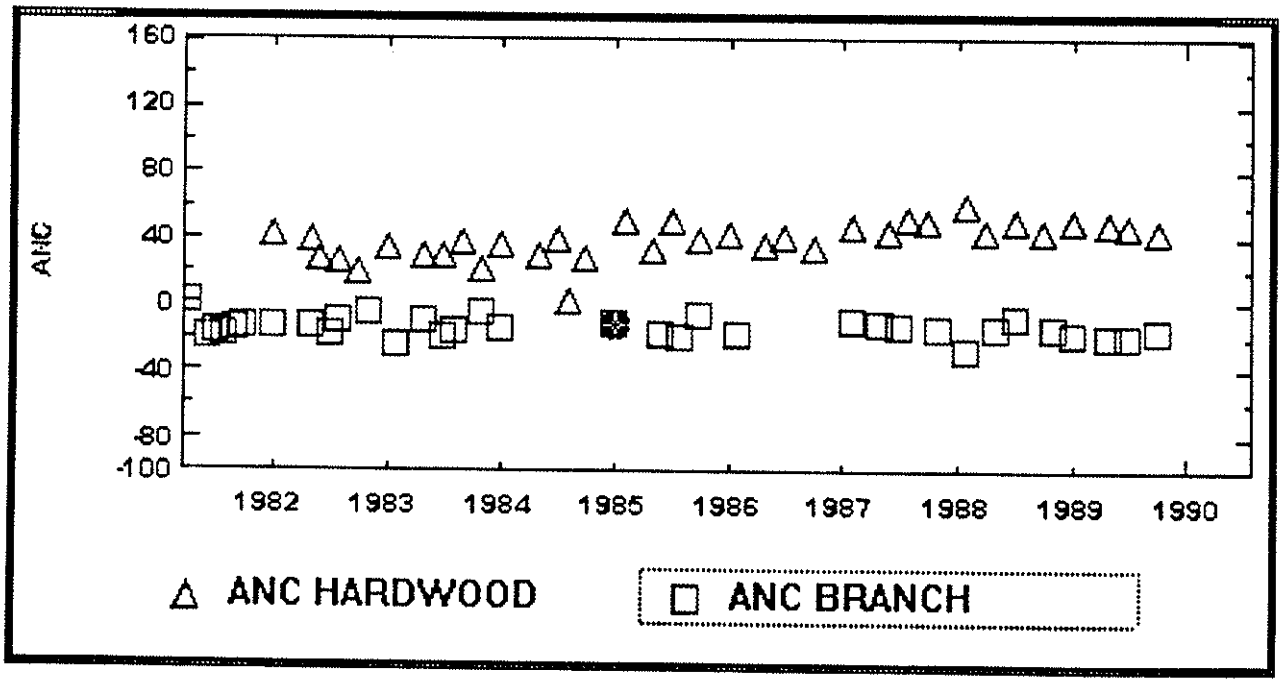


The PH_LAKE1.WKB workbook gives the user access to detailed spatial and temporal data on aquatic and precipitation chemistry. The following simplified example explores the relationship betweens lake and precipitation pH in both northen and southern Vermont.

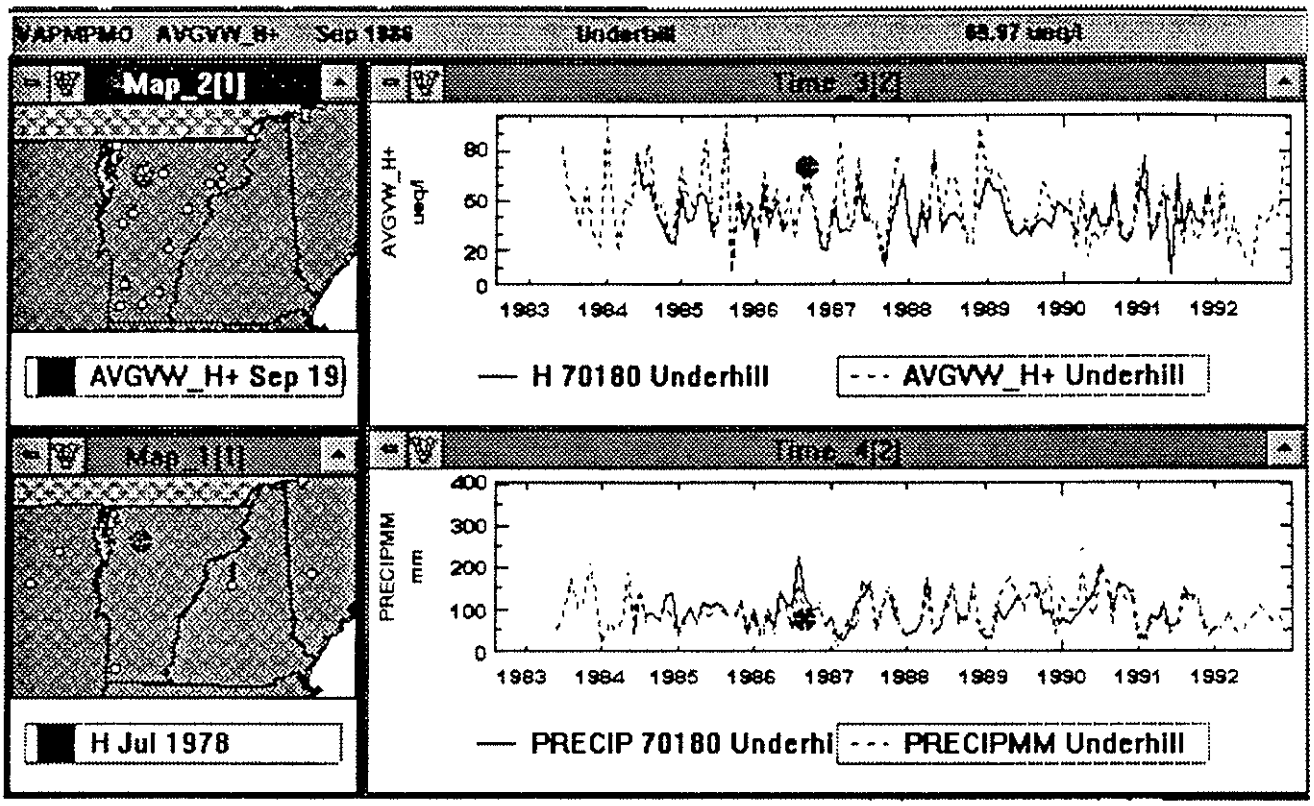
In this view, the map on the left shows the pH of ponds samples in Vermont in 1985, while the map to the right shows precipitation pH for the Vermont precipitation stations. In the chart, the pH of Branch Pond in southern Vermont is shown as triangles, while the monthly weighted precipitation pH at nearby Manchester is shown as squares.

In this view, precipitation pH measured at Morrisville in northernVermont is compared with lake pH of nearby Hardwood Pond. Note that the lake pH is considerably higher (around pH 6) than the precipitation pH (around 4.2).





In this view, Acid Neutralizing Capacity (ANC), a measure of sensitivity ot acid rain, is shown for the two ponds, Hardwood Pond in northern Vermont, and Branch Pond in southern Vermont. Note that the ANC of Branch Pond is much lower than that of Hardwood Pond, conferring greater acid sensitivity on the southern Vermont pond.



CONTRAST OF PRECIPITATION CHEMISTRY MEASUREMENTS BETWEEN NADP AND VAPMP

Contributors: National Atmospheric Deposition Program (NADP) and Vermont Water Quality Division
Compiled: November 11, 1993 by Ian Martin

This workbook provides access to and comparison of two precipitation chemistry data sets both containing Vermont sites.

1. NADPMO.VOY - monthly volume-weighted mean precipitation chemistry from NADP network
2. VAPMPMO2.VOY - monthly volume-weighted precipitation data from 16 Vermont sites.

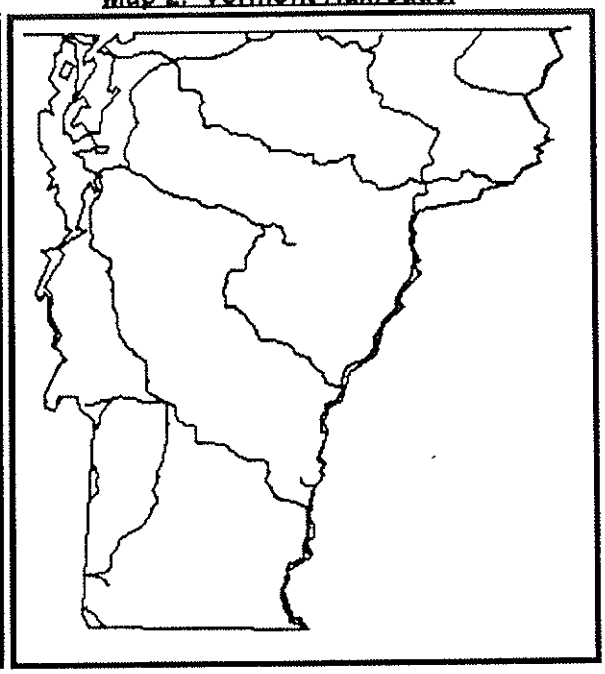
For additional details on these data sets, see workbooks: NADPMO.WKB & VAPMPMO2.WKB

Workbook Name: H_COMP1.WKB
Required Files: NADPMO.VOY, VAPMPMO2.VOY, NAM.MAP, US.LAY
Package Size: 1.25 MB

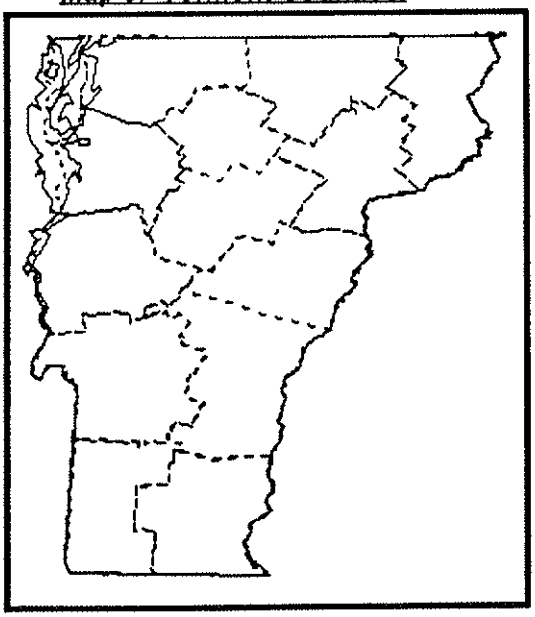
APPENDIX III: SUPPORTING GEOGRAPHICAL INFORMATION

Map 1. Vermont Roadways.

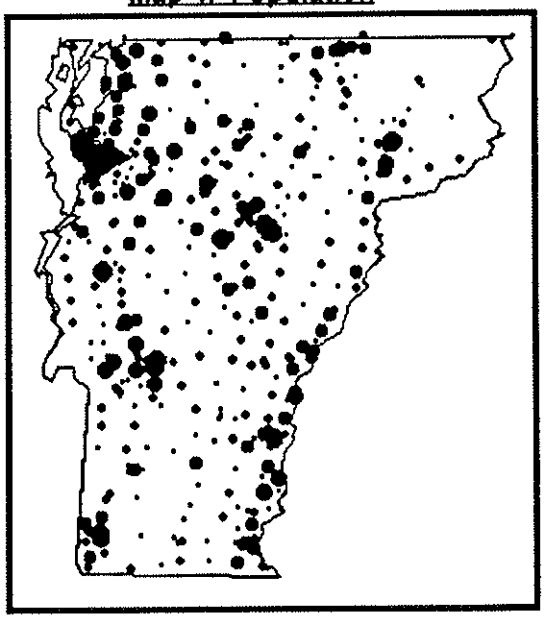
Map 2. Vermont Railroads.



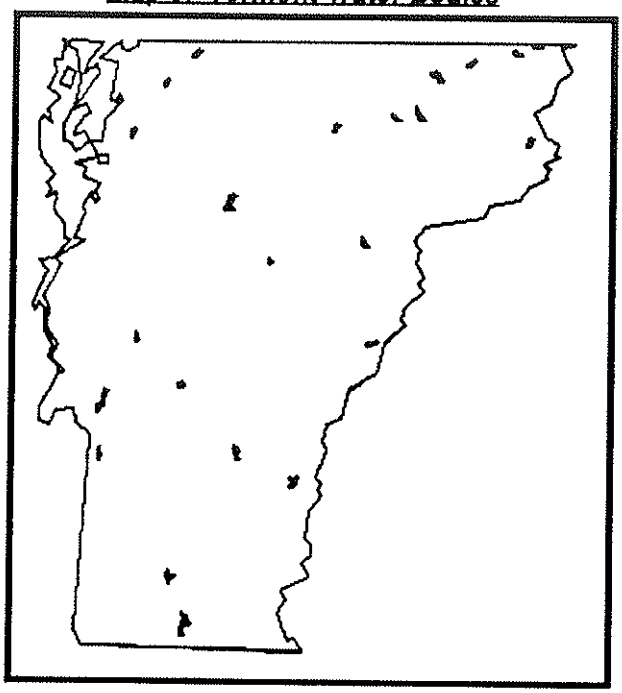
Map 3. Vermont Counties.



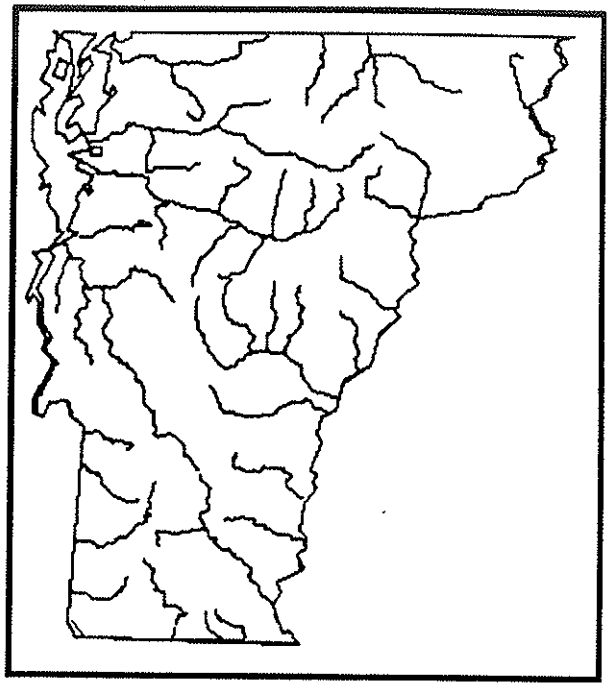
Map 4. Population



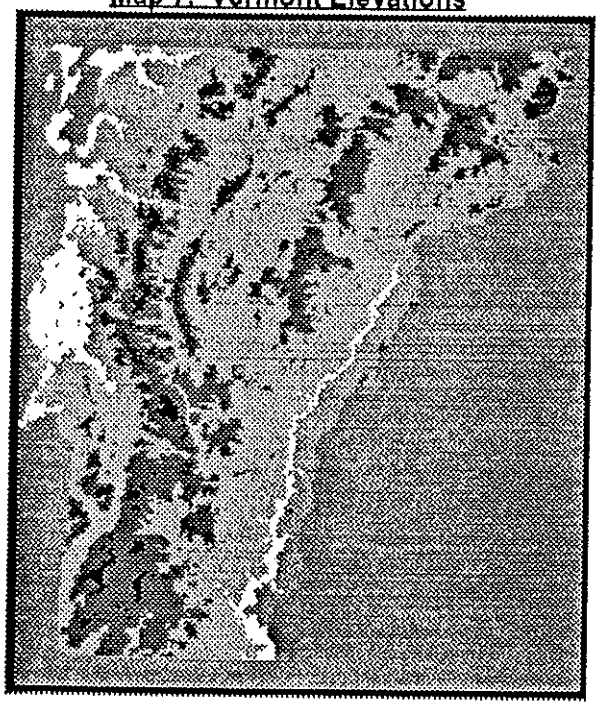
Map 5. Vermont Water Bodies



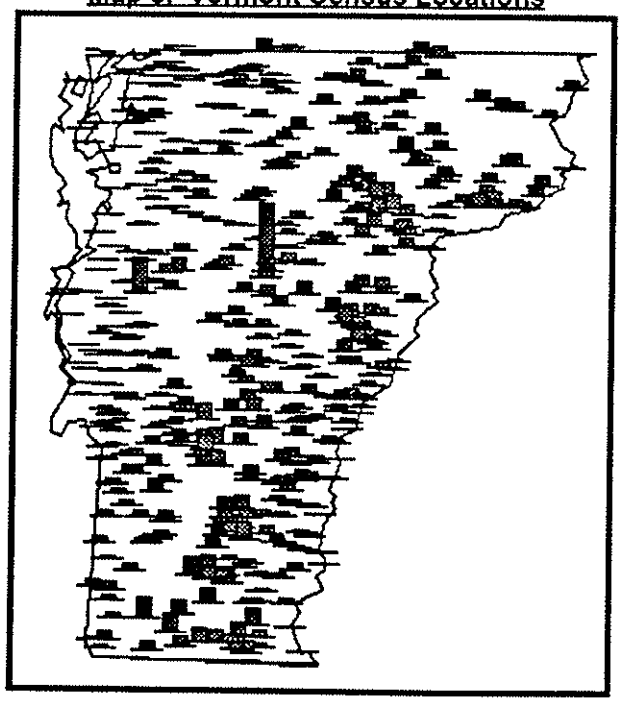
Map 6. Vermont Streams



Map 7. Vermont Elevations

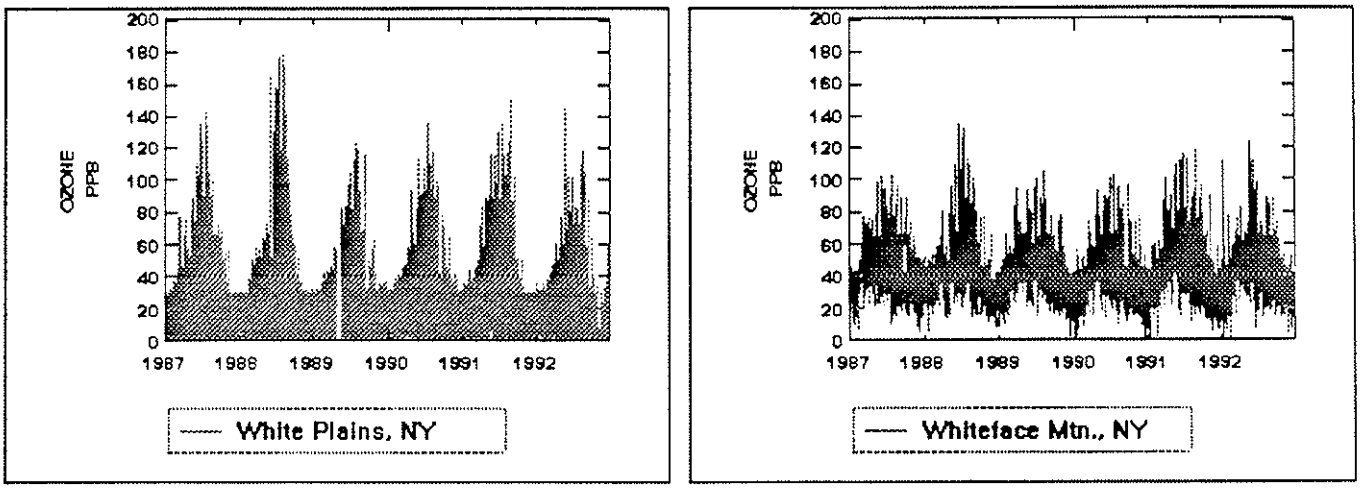


Map 8. Vermont Census Locations

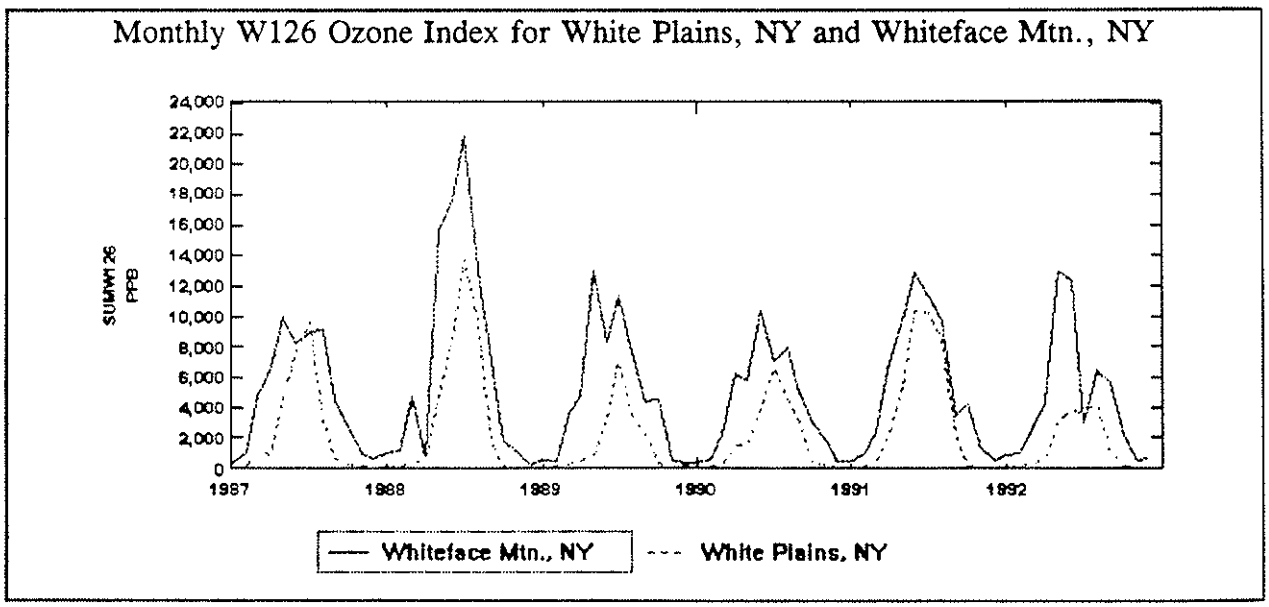


APPENDIX IV: DATA INTEGRATION AND EXCHANGE FROM THE NESCAUM 1992 OZONE SUMMARY.

The following examples of data exchange and integration are taken from a 1993 NESCAUM publication entitled *1992 Regional Ozone Concentrations in the Northeastern United States*. Copies of the full report are available from the NESCAUM Office, 129 Portland St. Boston, MA 02114.



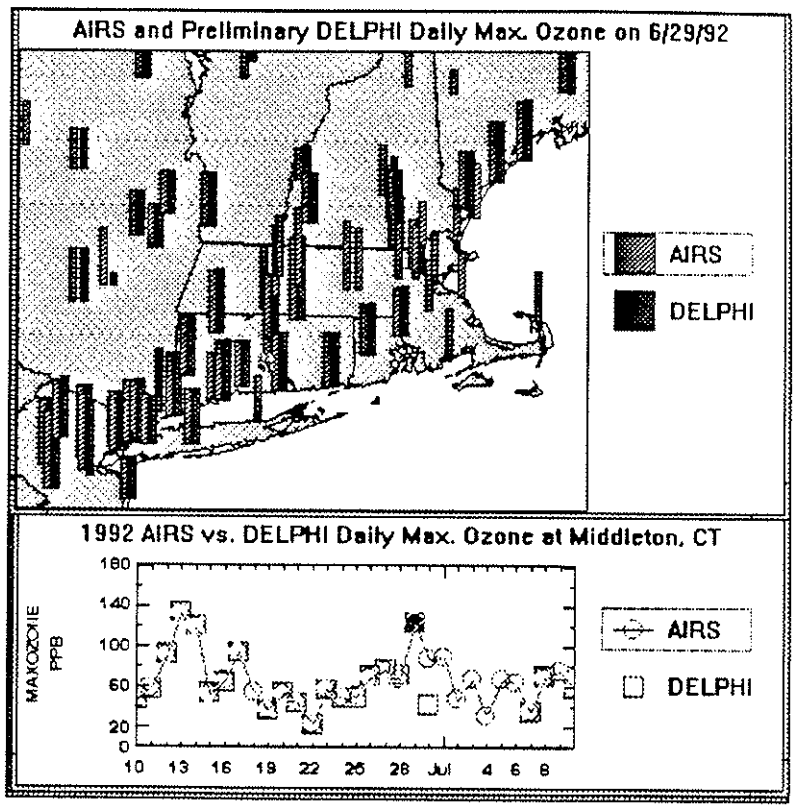
The NESCAUM report compares long-term temporal patterns of hourly ozone data from an urban site in White Plains, NY (20 miles North of NY City) with a rural, high elevation site at Whiteface Mtn., NY (200 miles further North, and about 50 miles from the VMC site). The urban site is clearly characterized by higher peak concentrations (of greatest concern from a human health perspective).



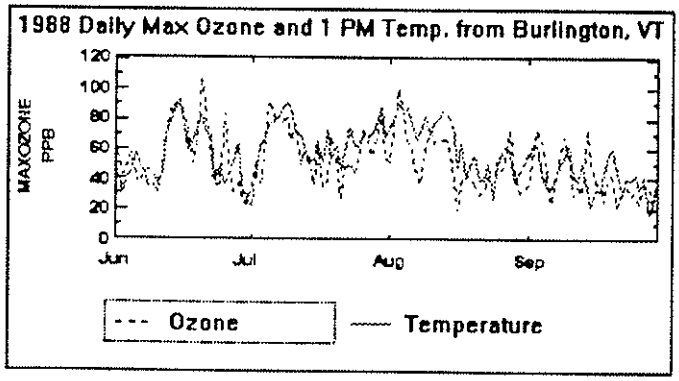
A similar comparison of the monthly biological effects W126 index (provided to NESCAUM by VMC) shows an opposite relationship. The more remote, forested Whiteface Mtn. site commonly experiences higher levels of the W126 Index (intended to represent potential effects on sensitive vegetation from both acute and longer-term exposures). It may be inferred that similarly high levels of these potentially injurious ozone levels are commonly experienced in high elevation forests throughout Vermont as well.

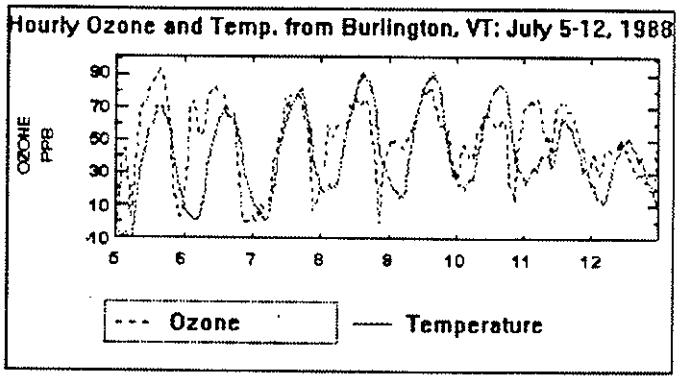
While the NESCAUM report is primarily focused on ozone data from 1992 and preceding years (as available from the EPA AIRS database), it also includes a preview of 1993 data (as available from the NESCAUM/VMC Ozone Data Exchange Network). A concern with the use of the preliminary data from this latter effort is that the rapidly-exchanged data, posted daily on the DELPHI Electronic Bulletin Board, are not quality assurred. Since both the DELPHI and AIRS data are now readily accessable in common Voyager format, it is a relatively simple task to compare them directly, and to assess the degree to which the preliminary data are in error.

The figure at the right compares selected 1992 maximum daily ozone levels from DELPHI (available with a 1-day lag time) and from AIRS (available 45 days after the end of each calander quarter). Note that there are only occasional, minor differences between the reported maximum ozone levels in the two data sets. Note also, the occasional discrepencies between reported locations at several sites (paired bars are not always exactly side by side). This is perhaps most evident at the VMC site (top, center), and provides an extremely valuable form of quality assurance feedback to the two efforts. We are obviously reporting an incorrect VMC site location in one of these 2 data sets. The VMC data integration project will provide for similar QA comparisons among other environmental data sets (for example among precipitation quantity and chemistry in co-located networks).



Another good illustration of effective data exchange and integration from the NESAUM report is illustrated in the following comparison of daily and hourly patterns in Burlington VT ozone concentrations (from AIRS) with Burlington Airport temperature data (from the VMC project).





(Data files employed in Appendix III: NEOZ8792.VOY, NEOZMOAG.VOY, NEOZAGDA.VOY, OZONE92.VOY, BURLDAY.VOY, BURLINGT.VOY, NAM.MAP, and US.LAY).

The Voyager Data Browser

The main PC program that facilitates the convenient display and exploration of AIRS data is the Voyager data exploration software developed by Lantern Corporation in St. Louis. Voyager is a general purpose browser for spatial and temporal databases as illustrated in Figure 1. The Voyager software can also be viewed as a data integrator and transmission system as illustrated in Figure 2. Additional information and description of application to AIRS is given in the references listed below.

Voyager can be applied to specific applications using its programmable features. Multiple data views can be placed on multiple pages of electronic workbooks. The graphic layout of a workbook is accomplished by interactive graphic programming techniques, including clicking, dragging, zooming, and dialog boxes. The behavior of Voyager can be further modified by its built-in event driven script language.

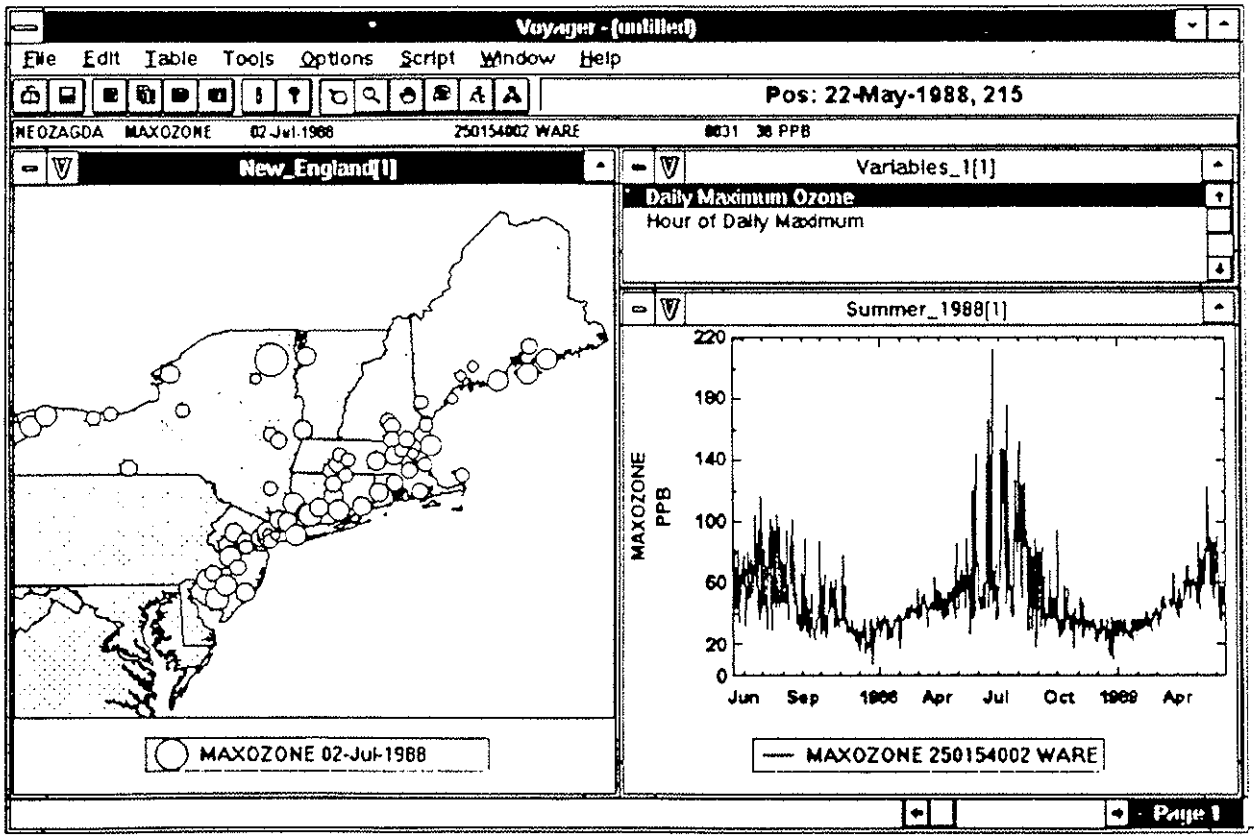


Figure 1. Voyager's workspace showing the Map, Time, and Variables views of an ozone database. Data Browsing is accomplished by point-and-click query: Selecting and displaying the time history for a monitoring site is accomplished by clicking on the site location in the map view

Data Views: Voyager's workspace is divided into several areas called data views, representing the dimensions of the data space: locations, time and variables. The upper right view displays the available variables in the database. Clicking on a variable such as ozone selects it as the variable displayed in the other views. The left area is a map view. In this example, ozone concentration is displayed as circles for each site. The lower right area is a time view for a particular station . Here the ozone concentration is displayed as a trend over a selected period of time. Each data view has two purposes, one to display data and second to provide a selection surface for its linked views.

Linkages and Navigation: All of these views are linked to each other. Selecting a new time, location, or variable in their respective views simultaneously changes all of the other views. One can change the current variable displayed in the map and time views by clicking on the desired variable.

Zooming and Overlays: Voyager also provides a facility to zoom in on a specific region or time domain. Voyager can also overlay several databases at a time. Each of the views can contain a number of data sets, either from the same database or from another database.

Scatter view: The scatter view is used to explore relationships among two or more variables. The range of times and locations for data in the scatter plot is controlled by the zoom range of the time and map views. Since the scatter view is also linked to other views, outlying data points can be easily isolated. Clicking on an outlier in the scatter view, reveals the data point's location and time in map and time views.

Graphic Database Query: The point-and-click selection of display items combined with the linked views is an implementation of a Graphic Query Language (GQL). It is closely related to the Structured Query Language (SQL) used to access data from relational databases. Every click causes the execution of a database command or query compatible with SQL.

Data Manipulation: Voyager has an event-driven built-in script language for data manipulation. One can create new variables from algebraic and logical combinations of existing variables, write data filtering or extraction functions or modify the behavior of Voyager by user written scripts.

Workbook: The metaphor of the Voyager workspace is a picture book. Each page may contain several figures and text windows. A collection of pages is a dynamic workbook that can be saved and retrieved as a disk file. The author of the workbook may organize and display a story as a pictorial summary report. The workbook contains a portion of the author's knowledge that can be transmitted as a file or presented as a slide show of live pictures. A well authored workbook, along with the hypertext documentation facility effectively turns a database into a knowledge base.

Database Documentation: Conventionally, the textual documentation such as the data source, history and data collection methodology is usually contained in hard copy reports. Voyager provides a context-sensitive on-line documentation facility to its databases. One can attach text to a database in general or to a specific variable, location, or time. This is accomplished by a general purpose hypertext Help facility that is dynamically linked to Voyager.

Data Import and Export: High speed browsing and data manipulation is facilitated by a highly indexed binary file format. Prior to usage in Voyager, spatial-temporal data are converted to the internal Voyager format by the Voyager Data Compiler supplied with the software. The compiler accepts as inputs tables containing the data and data dictionaries. Voyager software can extract subsets of data from compiled Voyager data sets and export those to other programs. In this sense, the Voyager data browser can be viewed as a distributor gateway for transferring AIRS data to other PC applications such as spreadsheets, database managers, paint programs, and word processors.

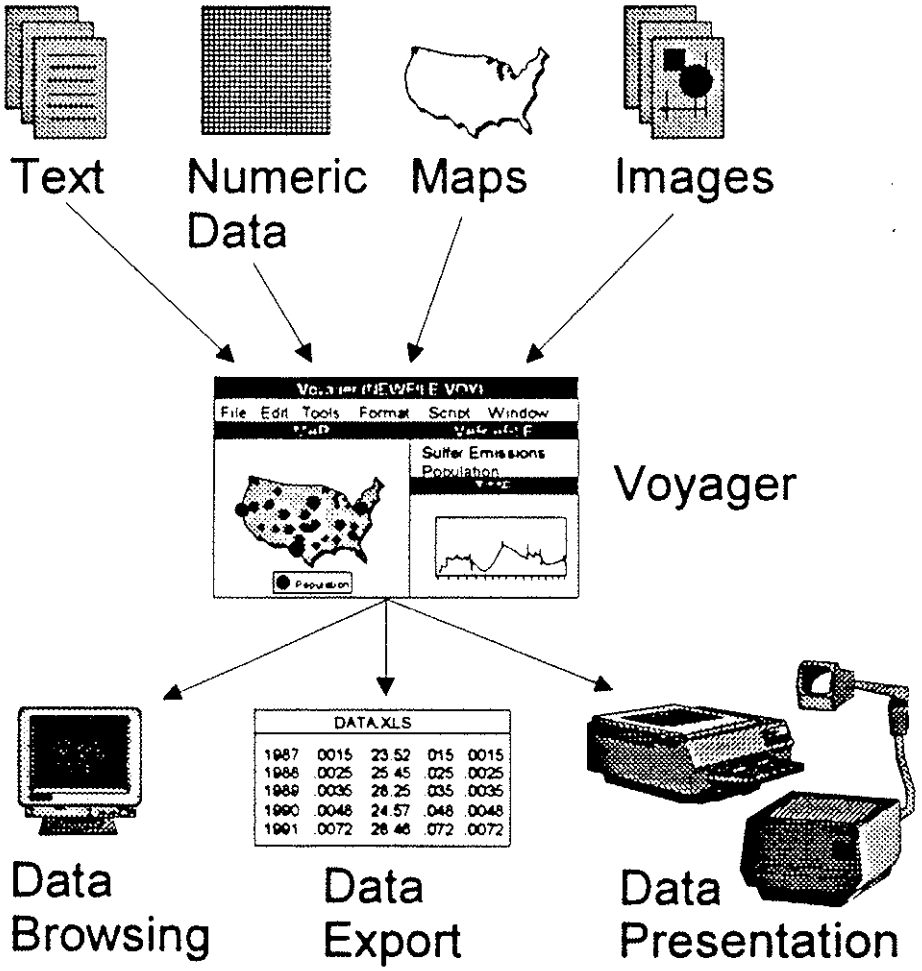


Figure 2. The role of Voyager as data integrator/distributor.