Meteorological and Deposition Chemistry Monitoring
-1995-

Joanne Cummings and Timothy Scherbatskoy
School of Natural Resources, University of Vermont

COOPERATORS:

UVM Proctor Maple Research Center (PMRC), National Atmospheric Deposition Program (NADP), US Geological Survey (USGS), National Oceanic and Atmospheric Administration (NOAA), VT Department of Environmental Conservation (DEC), WCAX-TV staff at Mt. Mansfield transmitter station, Green Mountain National Forest, EPA AREAL Laboratory, University of Michigan Air Quality Laboratory (UMAQL).

ABSTRACT:

Continuous monitoring of meteorological, wet and dry deposition chemistry has been conducted at the VForEM Mt. Mansfield and Lye Brook sites. The work is a fundamental component of the monitoring and research activities there, providing basic information on the physical and chemical environment. Several projects are underway, including collection of basic meteorological data, precipitation chemistry monitoring, and dry deposition monitoring programs.

Continuous hourly meteorology data from PMRC (400 m elevation) are available from 1988 to present, and daily temperature and precipitation data from the summit of Mt. Mansfield (1205 m) are available from 1954 to present. In addition, meteorology is monitored within the forest at the canopy research tower and the Nettle Brook gauging station; these projects are discussed elsewhere in the Annual Report.

The National Atmospheric Deposition Program, operating at PMRC since 1984 and at Bennington, VT since 1981, provides weekly analysis of major ions in precipitation. The Atmospheric Integrated Research Monitoring Network (AIRMoN), established in January of 1993, provides similar data on a daily basis. The Dry Deposition Inferential Measurement system, started mid-year in 1992, provides weekly data on dry deposition of nitrogen (HNO3 vapor, NO3 particulate) and sulfur (SO2 vapor and SO4 particulate). In addition, atmospheric mercury monitoring in precipitation, gaseous and aerosol phases has operated at PMRC since 1993. The Vermont Acid Precipitation Monitoring Program (VAPMP) provides daily precipitation pH since 1980 at the Mt. Mansfield summit, and since 1983 at the PMRC site.

Eight years of meteorological data collection at the PMRC, from June of 1988 to December of 1995, has enabled VForEM to begin to develop a long term record of continuous weather monitoring. An analysis of this record is included in this report, with comparisons of precipitation, growing degree days, and temperature variables.

OBJECTIVES:

Continuous monitoring, at the VForEM Mt. Mansfield and Lye Brook sites, of meteorological variables and the chemistry of precipitation and dry deposition. Summary of representative data from the chemical deposition monitoring programs.

METHODS:

Several monitoring stations and programs were operated at sites in Underhill Center.

1. **Basic Meteorology** (continuous temperature, dew point, wind speed and direction, standard deviation of wind direction, and precipitation amount) is monitored at the air quality monitoring station at the VForEM Mt. Mansfield site located at the Proctor Maple Research Center. This station has remote (modem) access and has been in continuous operation since June of 1988. Data are updated continuously and are archived electronically. Data are available from the VForEM Data Manager or the Site Operator at the PMRC. Station supervision is by Tim Scherbatskoy; operations and maintenance are by Joanne Cummings and Carl Waite. Additional meteorological data are collected at the forest canopy research tower and in the Stevensville Brook watershed; these provide continuous monitoring at within-forest sites. Although not reported here, these data are available from the VForEM data manager.

In 1995, the long term meteorological record (1988 to 1995) was consolidated. This now provides a convenient long term data set, and is being used for the study of trends of variables such as precipitation, growing degree days and temperature. Each year of data was standardized into spreadsheet format, and missing temperature data were supplied using regression calculations with the Mt. Mansfield temperature data. This method was used to determine the probablity of temperature values at PMRC based on values from Mt.Mansfield. Belfort rain gage amounts at the PMRC site were used to supply missing precipitation data.

The National Weather Service (NWS) under NOAA supervises a second weather station at the WCAX-TV transmitter station near the nose of Mt. Mansfield. This station is one of 45 NWS cooperative weather stations currently operating in Vermont. This station has monitored temperature (daily minimum, maximum and temperature at time of observation) and precipitation amount (daily rainfall, snowfall and snow depth on the ground) since 1954. Data are collected and stored by the National Climatic Data Center. These data are being used in other VForEM studies to develop statewide meteorological and deposition maps. VForEM does not directly support this station, but has access to the data for this station and all others in Vermont through the NWS. Data are available from VForEM in Voyager format for the period 1954-1995.

2. **Precipitation Chemistry** -

The NADP/NTN (National Atmospheric Deposition Program/National Trends Network) has maintained a site at the air quality monitoring station at the PMRC since 1984, and another site near Bennington, VT, since 1981. Weekly collection of precipitation for chemical analysis is performed at these sites. Precipitation amount, pH and conductivity are measured locally, and the sample is then shipped to the NADP Central Analytical Laboratory in Illinois for analysis of pH, conductivity, Ca, Mg, K, Na, NH4, NO3, Cl, SO4, and PO4. During January of 1995, the NADP site at PMRC was visited by Richard Shores of the Research Triangle Institute, contracted by NADP to observe collection and handling procedures of the NADP samples, and to check site equipment for proper functioning.

In September of 1995, an intercomparison NADP collection program was initiated at the PMRC site. Collocated collectors are a part of the quality assurance program sponsored by the NADP Coordination Office in Fort Collins, Colorado. An Aerochem Metrics wet/dry collector identical to the collector at the PMRC site, and a Belfort raingage dedicated to that collector were installed by Mark Nilles of the NADP Coordination Office. The colocated collector will function for one year in a comparison study on the accuracy and precision of the collector and raingage.

This station has been in operation since 1984, and is part of a national network of over 200 stations including one other station at Bennington. Data are available from theVMC in Voyager format or in other forms from the NADP Central Analytical Laboratory. The site supervisor is Tim Scherbatskoy, and the site operator is Joanne Cummings.

AIRMoN (Atmospheric Integrated Research Monitoring Network) is an event based precipitation monitoring program established at the end of 1992 to provide high-resolution data on precipitation chemistry to support regional modeling efforts. There are nine wet deposition sites, and fourteen dry deposition sites in the network, located in the eastern U.S. Sites other than the Proctor Center which have collocated NADP/NTN and NADP/AIRMoN collectors are: Bondville, Illinois; Oakridge, Tennessee; and State College, Pennsylvania. Except for being an event based sampling program, it follows the protocol and measures the variables of the NADP/NTN program; the sampler is located at the Air Quality site at PMRC. Station operation is by Joanne Cummings with supervision by Tim Scherbatskoy. The AIRMoN station was installed in December of 1992. Data for the 1995 sample period for both NADP/NTN and NADP/AIRMoN can be accessed on the NADP web page. The address of the web page is HTTP://NADP.NREL.COLOSTATE.EDU/NADP/. Data can be accessed by contacting the VForEM data manager also.

A comparison of pH, sulfate deposition and nitrate deposition for the Underhill NADP (VT99) site and the Bennington, VT NADP site (VT01) was undertaken. Eleven years of annual deposition data were compared to discover trends and variations between the two sites. A brief discussion of these findings is provided in the following pages.

3. <u>Dry Deposition</u> -

The Dry Deposition Inferential Measurement program was started in August 1992 at the forest canopy research tower at the PMRC. This monitoring program uses filterpacks to collect continuous weekly samples of dry deposition of sulfur (SO2 vapor, SO4 particulate) and nitrogen (HNO3 vapor, NO3 particulate), and also continuous meteorology including temperature, relative humidity, wind speed and direction, surface wetness and precipitation amount. The goal of this program is to measure atmospheric concentrations of these species, and model their deposition rates in this forested ecosystem. This station is one of fourteen stations in the NOAA network in the eastern U.S.; the data collected are comparable to other dry deposition monitoring programs in the U.S. operated by the EPA. The equipment is located above the forest canopy at 22 meters on the forest research tower. Station operation is by Joanne Cummings with supervision by Tim Scherbatskoy. Filterpack and data analysis are conducted by NOAA, with data returned to VForEM quarterly.

RESULTS and DISCUSSION:

1. Basic Meterology:

Figure 1 on the following pages graphically displays the monthly summaries for maximum and minimum temperatures and precipitation. The Y-scales for these graphs varies from month to month. Table 1 shows monthly summaries in text form. The mean temperatures columns are designated "A" and "B" because the means are calculated with two different methods. Mean temperature A is the arithmetic average of the daily means for the month, or the addition of daily mean values for the month, divided by the number of days in the month with values. Mean temperature B is the midpoint average, calculated by adding the highest mean and the lowest mean for the day and dividing by two. The National Weather Service uses the mean temperature B method. Growing degree days are calculated by adding the degrees above freezing for a day to the next day's above freezing value. A cumulative number of degrees above zero is derived. Days when the temperature does not go above freezing are given a zero value.

Upon examination of the weather data for 1995, unusually warm temperatures occured for twelve days in January of 1995, and snow pack melted. During December of 1995, snow fall as precipitation occurred for twenty five days during the month.

Eight years of temperature and precipitation data were graphed for comparison on the following pages. Figure 2 shows 1988 to 1995 annual maximum and minimum temperatures along with preciptation totals for each year. In Figure 3, January and July temperatures and precipitation for the eight year period were graphed. The meteorological station at the PMRC began collecting data in June of 1988, therefore data is only available for a six month period in 1988. In 1991, the largest range of temperatures occured, and in December the coldest temperture for the period, -40 degrees centigrade was recorded. There are not enough data to discern any regional trends in annual temperature and precipitation, but information on year to year variations can assist researchers in interpreting other ecological data on insect populations, forest health, growth rates, nutrient cycling, air pollution, etc.

2. Precipitation Chemistry:

NADP published a booklet of maps of the United States, with concentrations and deposition rates for ions analyzed by the Central Analytical Laboratory in Champaign, Illinois. Figure 4, Map A shows the 1995 pH values from field measurements. Map B and C related deposition of sulfate and nitrate to regional areas of the US, and Map D contains total precipitation for 1995. The maps make obvious the fact that north central and north eastern parts of the US experience lower pH values, and higher deposition of sulfates and nitrates. NADP maintains two sites in Vermont, one in Underhill and another in Bennington, in the region of the Lye Brook Wilderness Area. Continued monitoring of atmospheric deposition is enabling researchers to look at regional trends, and observe changes which may occur over time as a result of the Clean Air Act policies.

NADP data from the Underhill (VT99) and Bennington (VT01) sites were compared in an attempt to discover relationships or differences in deposition from the southern and northern parts of Vermont. The protocols for both sites are the same, as with all 191 sites across the country. Figure 5, Charts A, B and C graphically display comparisons of pH, sufate and nitrate deposition. Chart D shows annual precipitation amounts for each site. Annual volume weighted average pH was generally lower for the Bennington site, except for 1993. Since deposition is a function of precipitation amount and concentration, however, climate plays an important role. Examination of annual average sulfate deposition at Bennington may or may not be declining, suggesting that sulfur reduction mandates by the 1990 Clean Air Act Ammendments are or are not affecting precipitation chemistry in southern Vermont. Annual variation in nitrate deposition does not appear to show any trend over this time period at either site.

In order to evaluate the effects of chemical deposition on a local or regional scale, more data must be collected. NAPAP (National Acidic Precipitation Assessment Program) chose a time scale of thirty years to ascertain reductions in atmospheric sulfur inputs, and for the chemical composition of affected surface waters bodies to reach equilibrium with reduced loads. The need to include natural variation in climate with deposition data requires sufficient time to characterize the variability, and to evidence changes. However, these data are valuable now for cooperators researching and monitoring forest health indicator species, nutrient cycling, habitat loss, etc.

On a regional scale, the 1996 progress report of the US-Canada Air Quality Agreement states that there is evidence of a decrease in wet sulfur deposition. It is correlated with sulfate emissions reductions, mainly from coal burning industries using low sulfur coal. Nitrate deposition and precipitation acidity shows no consistent change, however. There also is evidence that calcium and magnesium concentrations in precipitation have declined, contributing to the continued acidification of precipitation, and reduced input of these important nutrients to ecosystems. A U.S. report using the Regional Acid Deposition Model predicts most of the northeast US and lower Canada will experience a 30% or greater reduction in total sulfur deposition by 2010. Results from field experiments and modeling studies indicate that continued nitrate deposition at the current levels could result in an erosion of the benefits of sulfur emissions controls. Figure 6 shows graphs of expected trends in sulfate and nitrate emissions to the year 2010.

The 1996 Progress Report used data from the NADP/NTN and NADP/AIRMoN Networks, and the CASTNET Network in the US. Canada's largest monitoring network is known as CAPMoN (Canada Air and Precipitation Monitoring Network).

3. Dry Deposition:

Figure 7 displays the data collected for the Dry Deposition Inferential Monitoring Program (DDIM) at the PMRC forest research tower from 1992 to November of 1995. No analysis of trends or relationships for this project has been completed at this time. Below zero values on the chart indicate times when the station was not operating.

FUNDING SOURCES:

1. NADP/NTN - United States Geologic Survey (USGS)
2. AIRMoN - National Oceanic and Atmospheric Administration (NOAA)
3. Meteorology station at the PMRC Air Quality Site - Vermont Forest Ecosystem Monitoring, Inc. (VForEM)
4. Dry Deposition Inferential Monitoring Project - NOAA

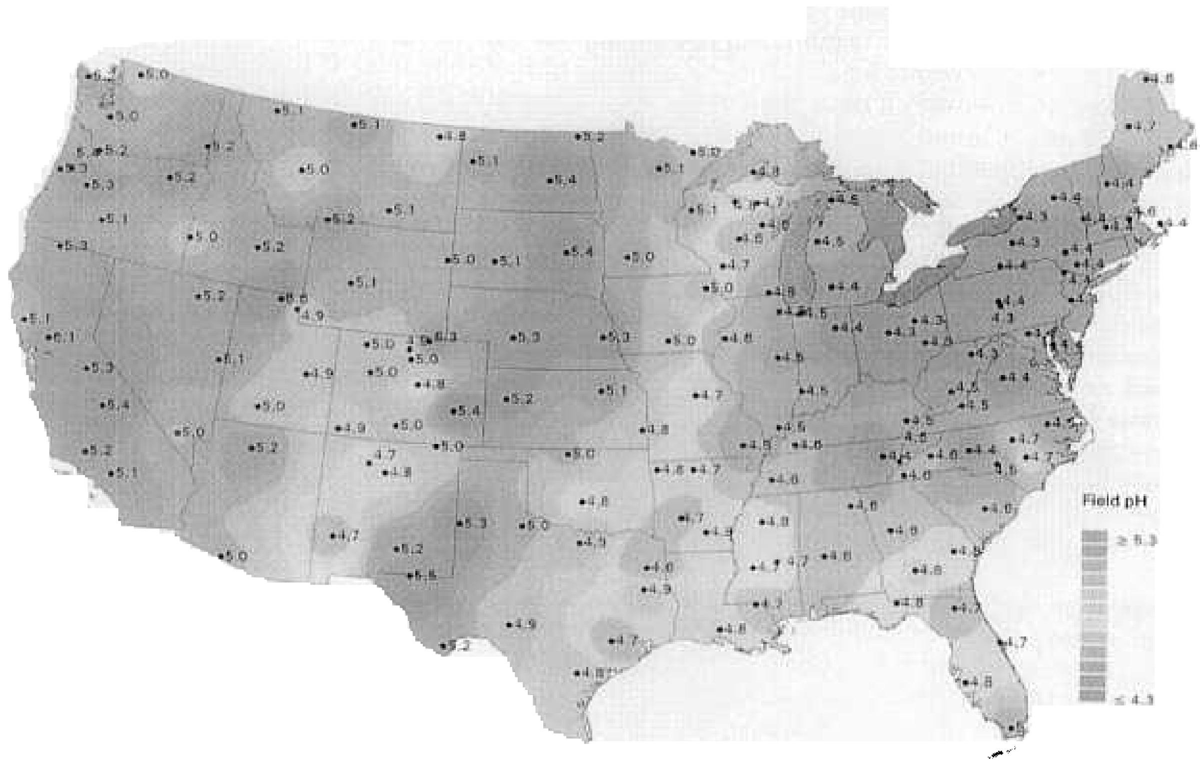
REFERENCES:

United States - Canada Air Quality Agreement. Progress Report 1996. International Joint Commission, 1250 23rd Street, NW, Suite 100, Washington, D.C.

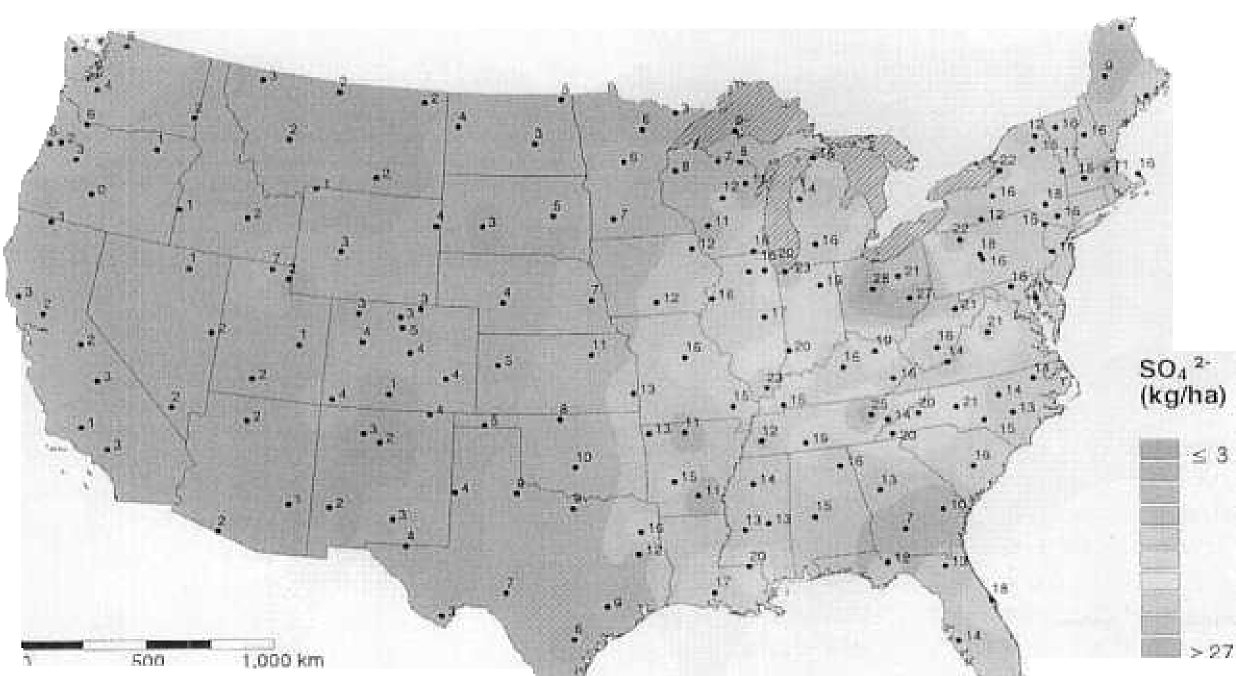
National Atmospheric Deposition Program/National Trends Network. 1996. NADP/NTN Wet Deposition in the United States 1995. Natural Resources Ecology Laboratory, Colorado State University, Fort Collins, CO.

Figure 4. 1995 NADP Wet Deposition Maps

Map A. Hydrogen Ion Concentrations as pH (from field measurements)



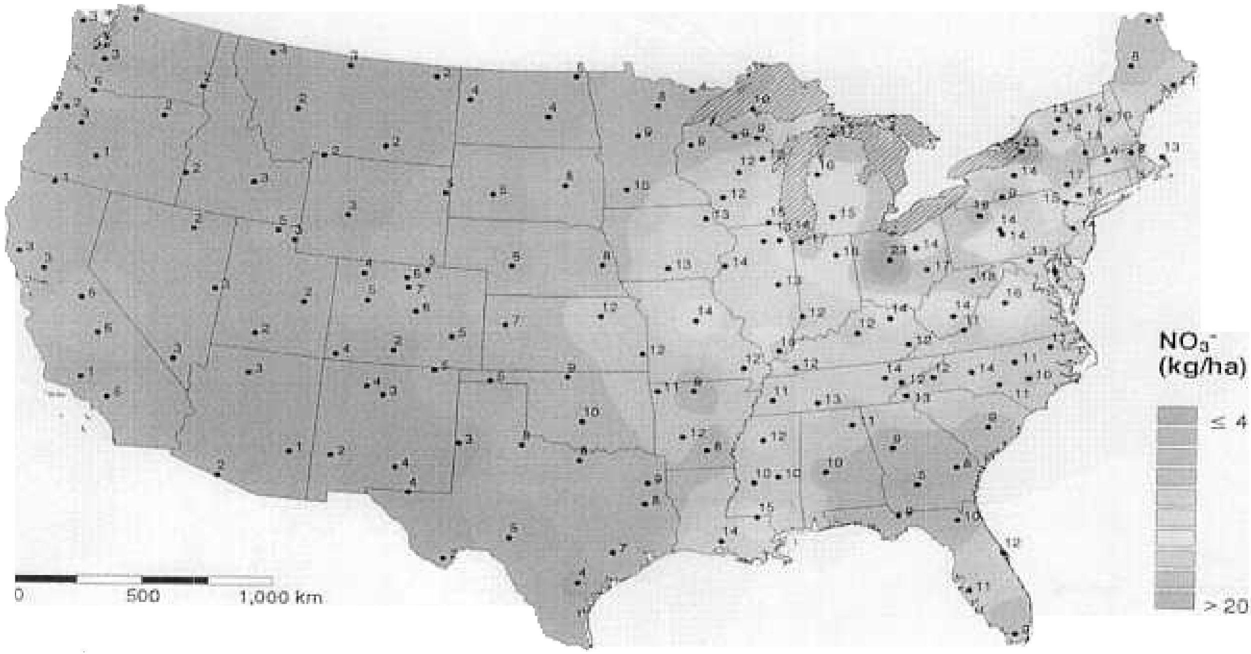
Map B. Sulfate Ion Deposition



National Atmospheric Deposition Program/National Trends Network

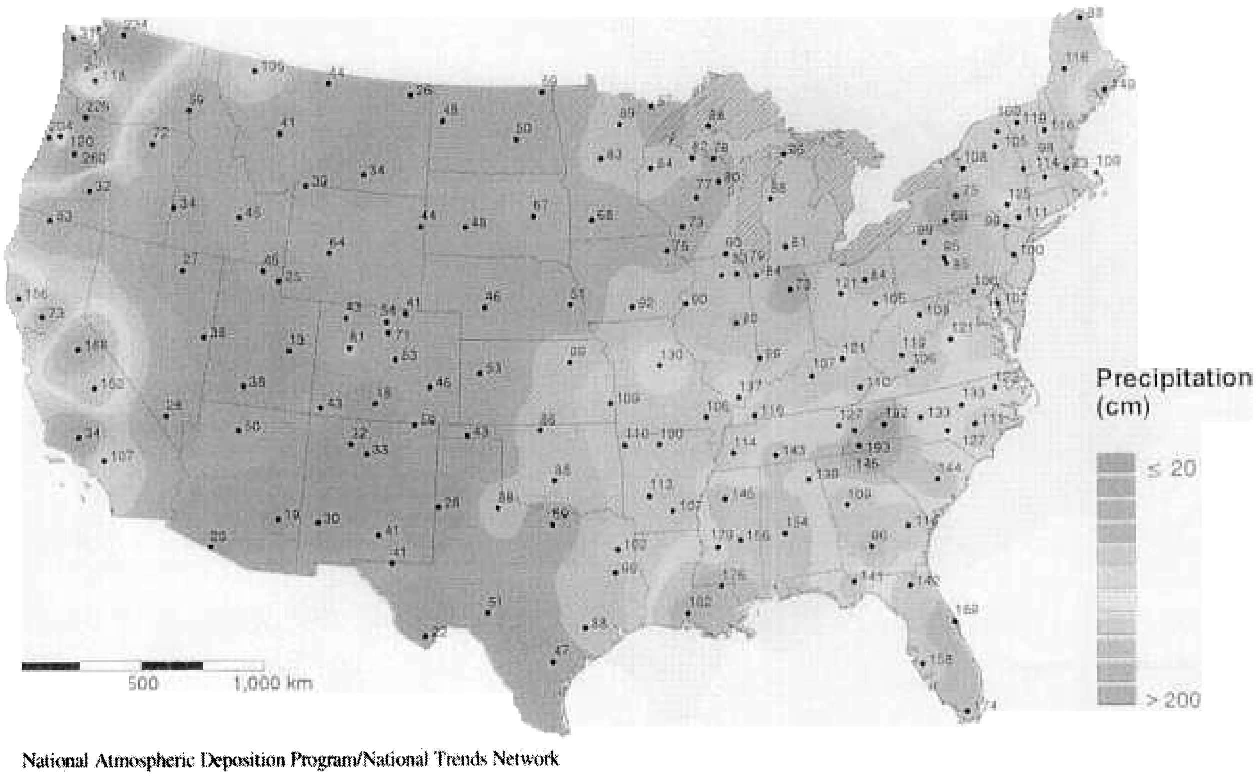
Figure 4. (cont'd) 1995 NADP Wet Deposition Maps

Map C. Nitrate Ion Deposition



National Atmospheric Deposition Program/National Trends Network

Map D. Total Precipitation for 1995



National Atmospheric Deposition Program/National Trends Network

Figure 5. Comparison of Underhill and Bennington NADP Data, 1988 to 1995 - pH and Sulfate Deposition

Chart A. Annual Volume-Weighted Average pH

1984 to 1995 - Underhill, VT and Bennington, VT

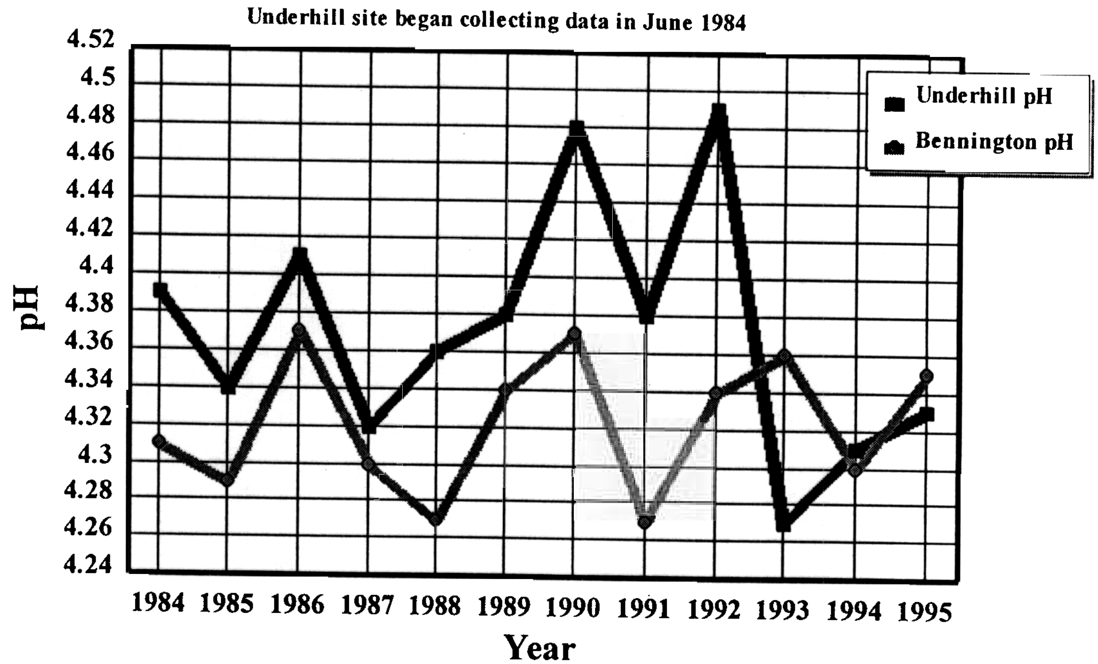


Chart B. Sulfate Deposition - 1984 to 1995

Underhill, Vt and Bennington, VT

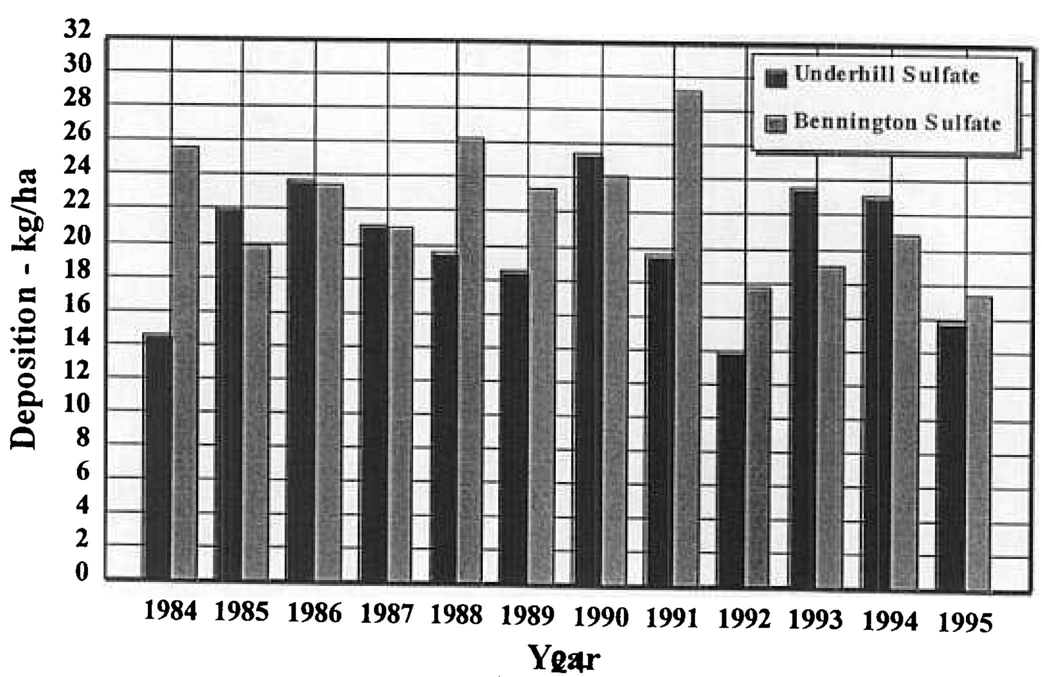


Figure 5. Comparison of Underhill and Bennington NADP Data, 1984 to 1995 - Nitrate Deposition and Precipitation

Chart C. Nitrate Deposition - 1984 to 1995

Underhill, Vt and Bennington, VT

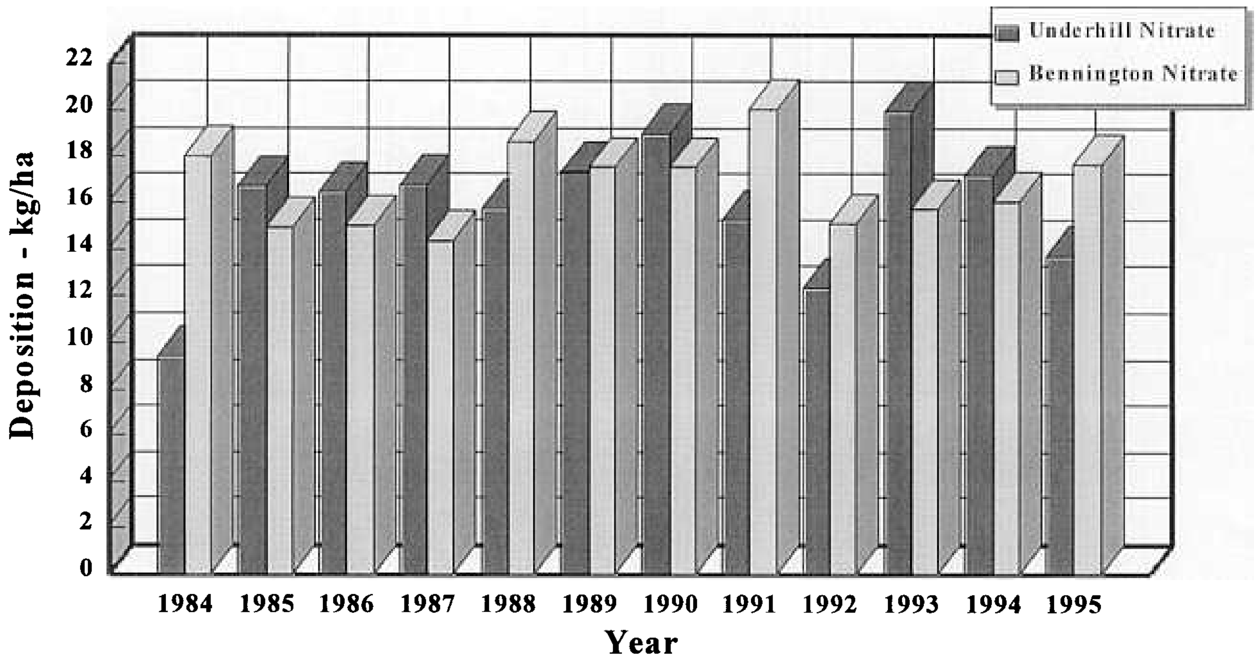


Chart D. Underhill and Bennington Annual Precipitation from NADP Data - 1984 to 1995

Underhill site began collecting data in June of 1984

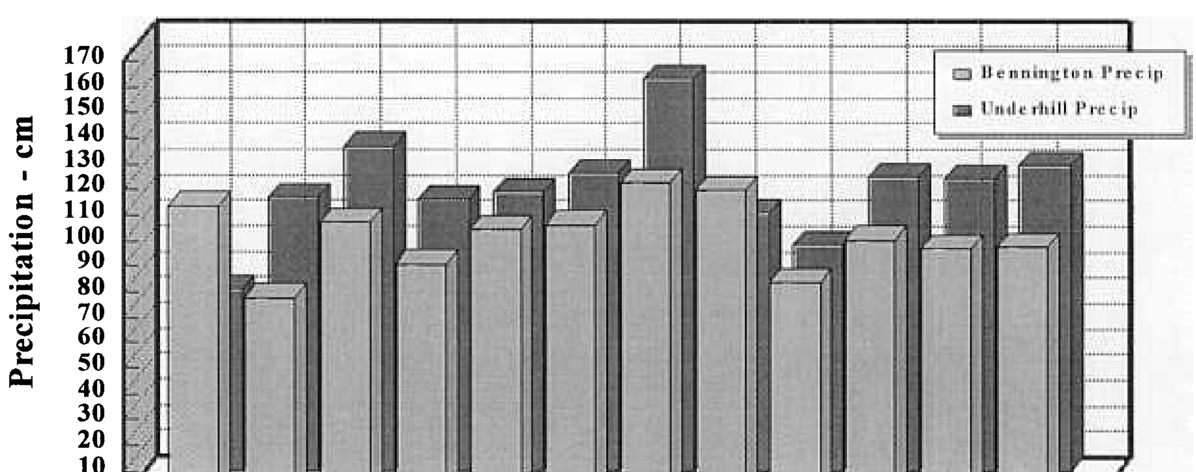
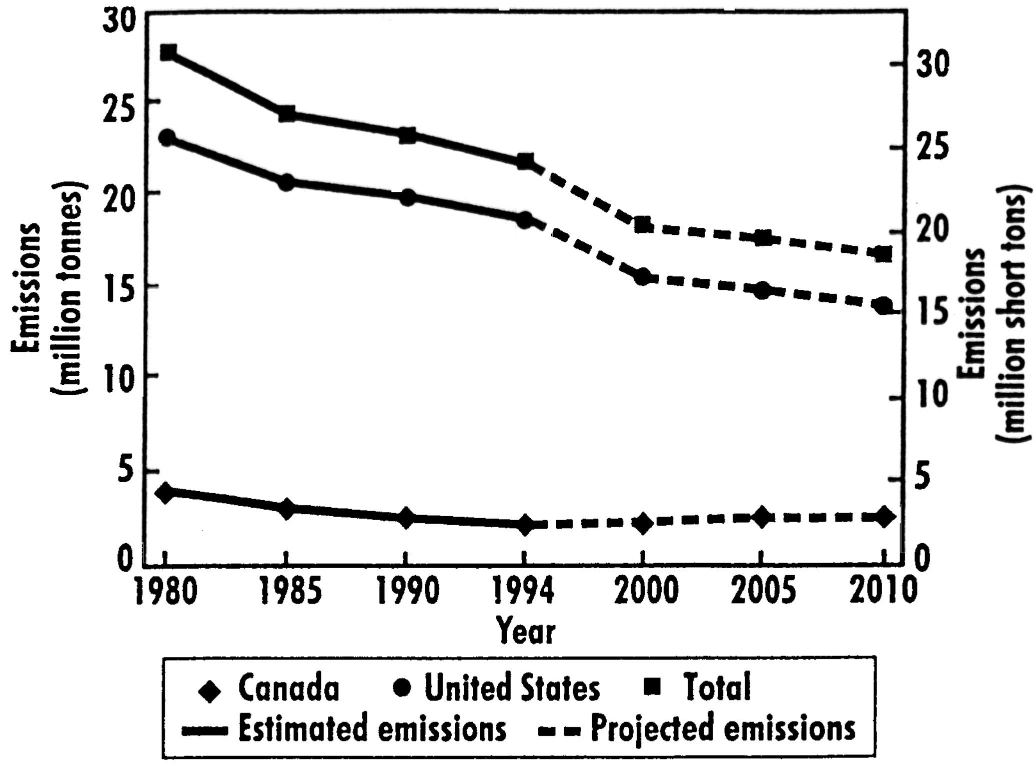
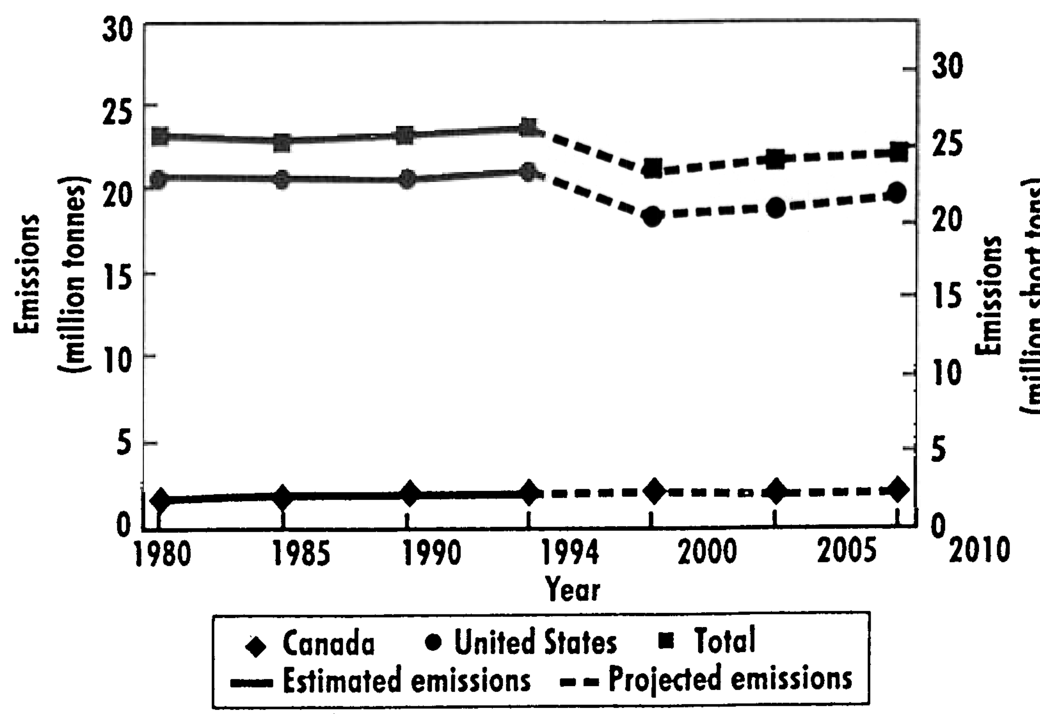


Figure 6. Emissions Estimates for Sulfate and Nitrate in the U.S.A. and Canada, 1980 to 2010



SO_2 Emissions.



NO_x Emissions.

Figure 7. Dry Deposition at the PMRC Forest Tower
December 10, 1994 to November 14, 1995

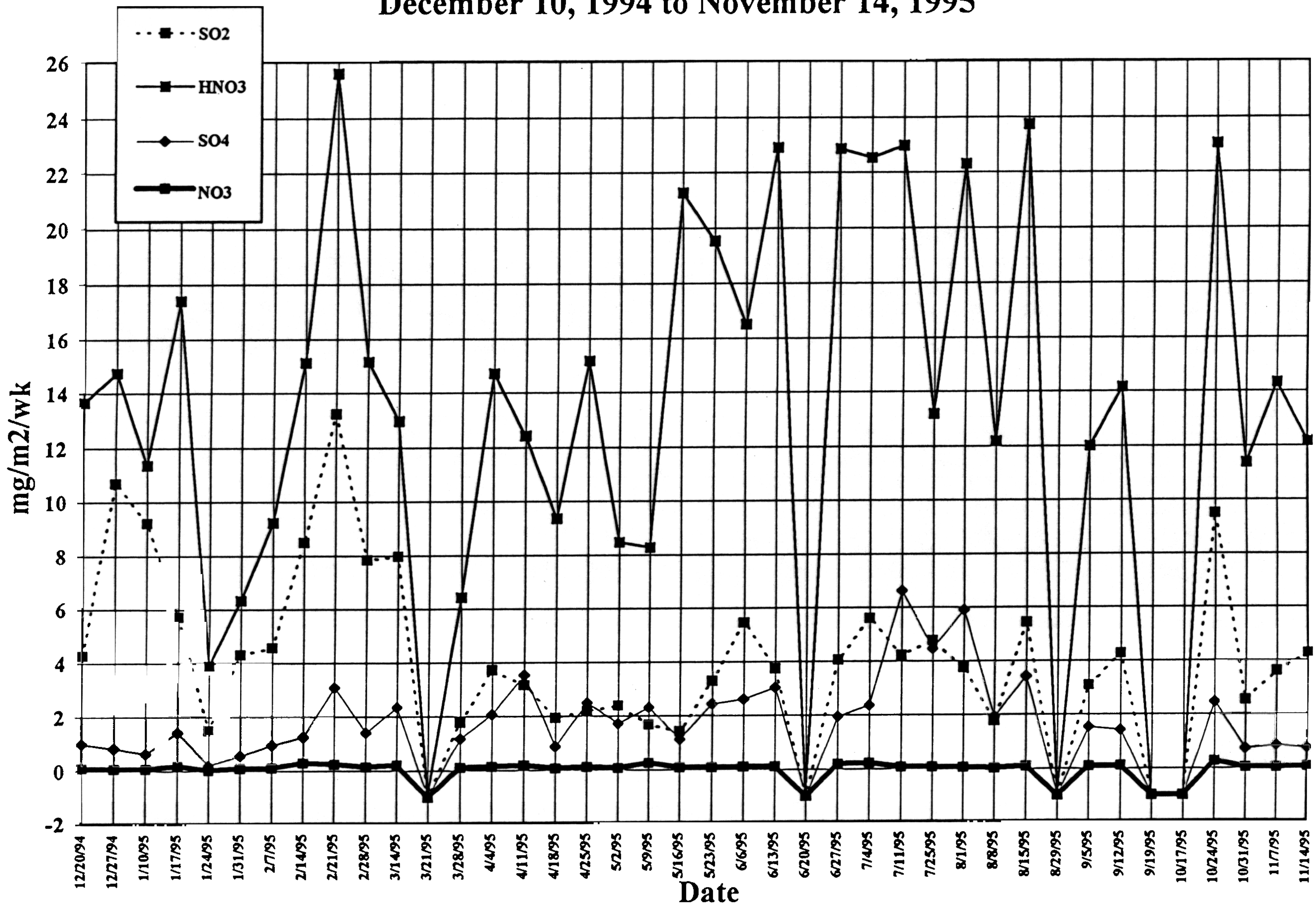


Figure 1. PMRC Monthly Maximum, MinimumTemperatures and Precipitation Data, January to December 1995
(Note: Y-Scales vary from month to month)

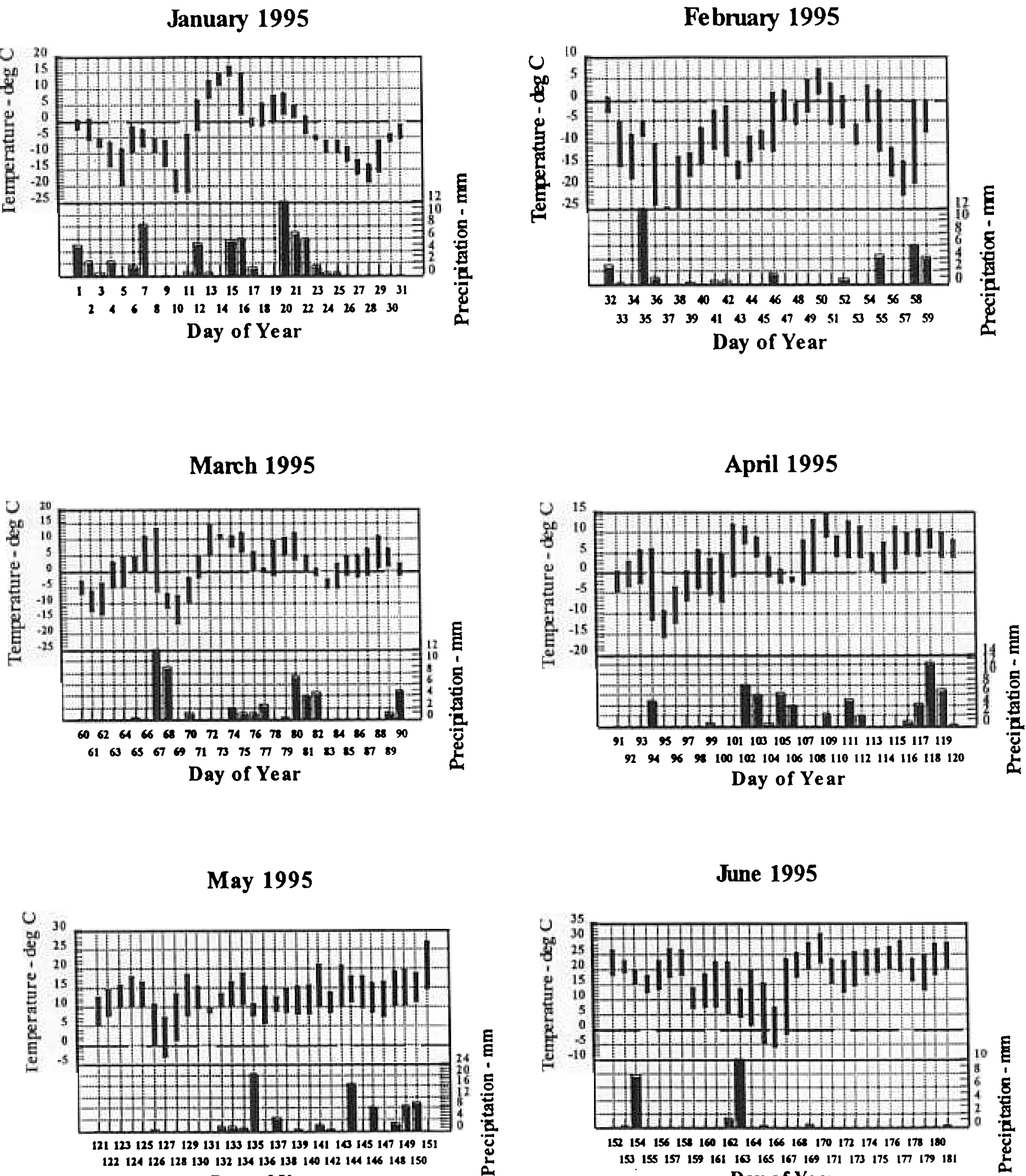
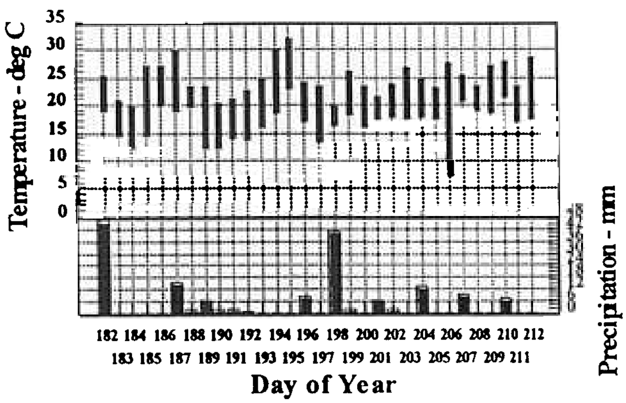


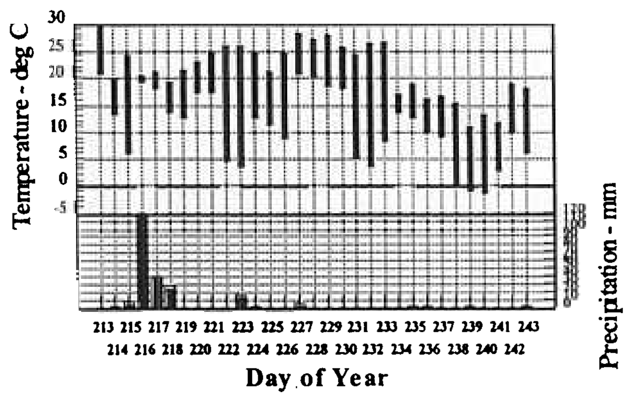
Figure 1. (cont'd) PMRC Monthly Maximum, MinimumTemperatures and Precipitation, January to December 1995

(Note: Y-Scales vary from month to month)

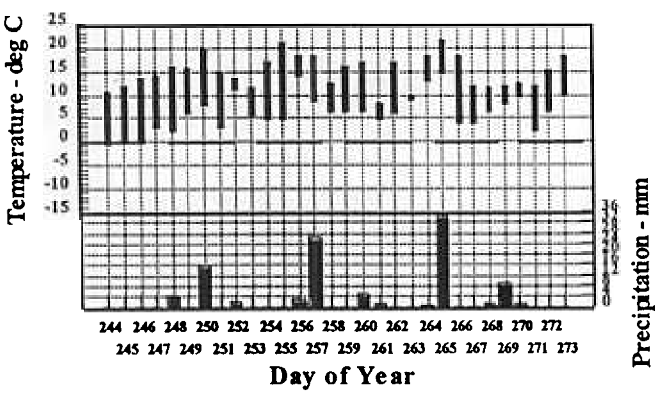
July 1995



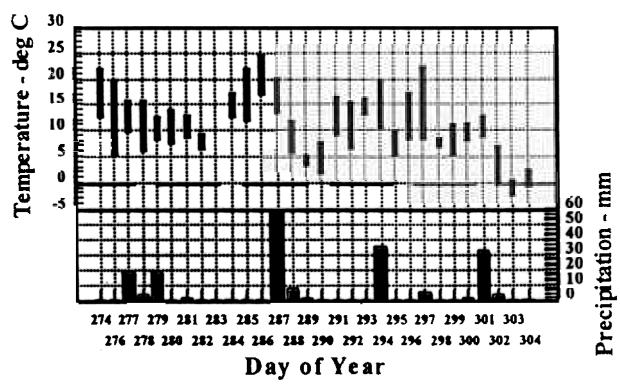
August 1995



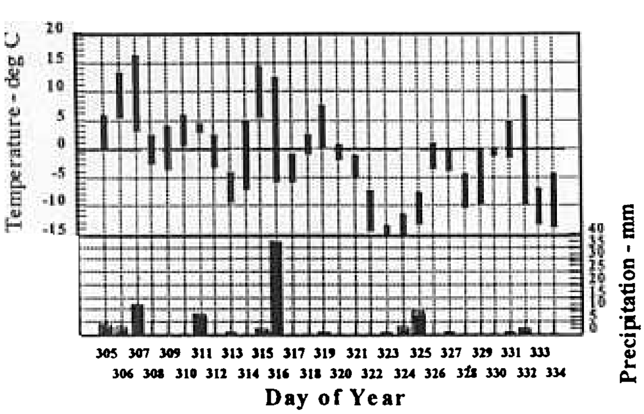
September 1995



October 1995



November 1995



December 1995

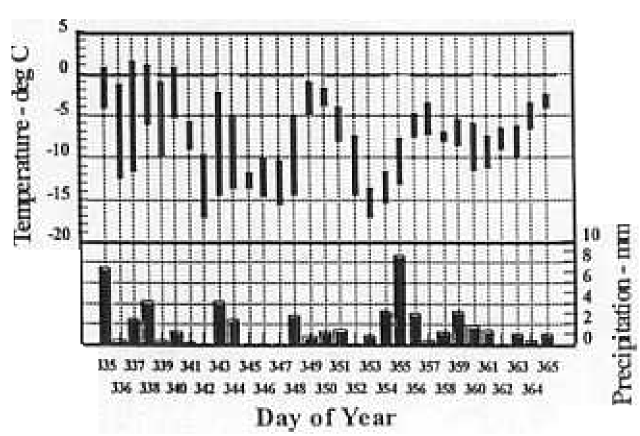


Table 1. PMRC Weather Data Summaries - January to May 1995

	Barometic Pressure	Mean Wind Direction	Wind Direction Deviation	Mean Wind Speed	Max. Wind Speed	Max. Temp.	Min. Temp.	Mean Temp. A	Mean Temp. B	Growing Degree Day	Mean Dew Point	Mean Relative Humidity	Precip-itation
	mb	deg	deg	m/s	m/s	deg C	deg C	deg C	deg C	deg C	deg C	%	mm
1995 Annual													
Mean	963	189	32.1	1.9	3.3	10.0	1.8	5.7	5.6	7.6	-2.1	61.1	3.1
Max	979	341	66.2	5.7	8.1	32.1	22.7	26.5	27.4	26.5	18.9	276.6	119.4
Min	935	76	19	0.5	1.2	-24.7	-28.3	-26.3	-26.5	0	-33.7	9.6	0
Sum										2727.2			1134.0
January													
Mean	955	203	28.9	2.0	3.4	-0.5	-7.1	-3.6	-3.8	2.2	-9.9	60.5	2.2
Max	970	341	61.4	4.9	7.1	17.1	13.6	15.4	15.3	15.4	7.2	84.5	16
Min	940	130	19	0.8	1.6	-14.9	-22.5	-18.2	-18.5	0	-26.6	24.9	0
Sum										67.2			69.6
February													
Mean	958	205	28.2	2.4	4.2	-4.4	-13.0	-8.6	-8.7	0.3	-16.3	51.7	1.3
Max	977	307	42.1	4	6.3	7.1	1	4	4.1	4	-4.8	73.4	12.7
Min	935	118	21	1.2	2.1	-24.7	-28.3	-26.3	-26.5	0	-33.7	33.8	0
Sum										9.3			35.2
March													
Mean	959	193	27.4	1.9	3.3	4.7	-2.9	1.0	0.9	3.2	-7.5	52.8	1.9
Max	977	333	37.5	3.7	6.1	14.9	9.7	11	10.8	11	0.9	75.8	21.3
Min	942	105	19.2	0.9	1.6	-7.9	-17.3	-12.2	-12.6	0	-22.5	26.8	0
Sum										98.8			60.2
April													
Mean	962	213	28.2	2.3	4.1	6.5	-1.4	2.7	2.5	4.1	-7.5	46.4	2.1
Max	979	325	38.9	5.7	7.5	14	8.4	10.7	11.2	10.7	1.6	66.2	12.2
Min	944	118	20.5	1	2.1	-9.4	-16.2	-12.4	-12.8	0	-25	22.8	0
Sum										123.1			64.2
May													
Mean	963	189	32.5	2.0	3.5	15.9	7.9	12.0	11.9	12.0	-1.6	40.9	2.5
Max	975	327	44	4	6.2	26.7	14.2	20	20.4	20	9	68.5	20.1
Min	953	127	22.6	1.1	1.9	7.2	-3.3	2.2	2	2.9	-13	17.3	0
Sum										371.4			76.3

Table 1 . (cont'd) PMRC Weather Data Summary - June to December 1995

	Barometric Pressure	Mean Wind Direction	Wind Direction Deviation	Mean Wind Speed	Max. Wind Speed	Max. Temp.	Min. Temp.	Mean Temp. A	Mean Temp. B	Growing Degree Day	Mean Dew Point	Mean Relative Humidity	Precip-itation
	mb	deg	deg	m/s	m/s	deg C	deg C	deg C	deg C	deg C	deg C	%	mm
June													
Mean	967	171	34.2	1.4	2.6	23.0	12.1	17.2	17.6	17.4	5.5	56.7	0.8
Max	977	247	54.6	1.8	3.7	31.8	21.5	25.9	26.6	25.9	13.4	162.8	13
Min	954	141	22.9	1.1	1.7	7.7	-6.2	-0.7	0.8	1.4	-2	24.3	0
Sum										521.3			23.3
July													
Mean	965	174	36.6	1.4	2.8	24.7	16.4	20.4	20.5	20.4	13.3	65.7	5.2
Max	973	263	66.2	2	4.2	32.1	22.7	26.5	27.4	26.5	17.8	83.1	45.7
Min	957	136	23.2	0.9	1.6	19.6	7.2	14.9	15.7	14.9	7.3	43.5	0
Sum										632.5			161.9
August													
Mean	967	181	37.2	1.4	2.5	21.6	9.8	16.3	15.7	16.3	11.6	79.2	6.9
Max	974	304	51.7	2.8	4.4	29.3	20.6	24.6	24.9	24.6	18.9	125.2	119.4
Min	959	94	24.1	0.7	1.4	11.1	-1.7	5.6	4.9	5.7	4.1	48.4	0
Sum										440.8			187.2
September													
Mean	969	179	38.3	1.4	2.6	15.2	1.3	7.0	7.1	6.3	-0.3	89.9	3.4
Max	978	282	61.4	2.1	3.8	21.4	13.7	16.7	16.1	16.7	13	276.6	34.5
Min	959	128	25.3	0.6	1.4	8.2	-11.3	-13.2	-14.9	0	-21.5	9.6	0
Sum										189.3			101.8
October													
Mean	964	189	33.6	2.1	3.7	13.5	6.8	8.5	8.8	7.3	-4.4	54.5	6.2
Max	976	274	65.3	4.6	8.1	24.6	16.7	19.9	20.6	19.9	11.5	88	58.7
Mini	948	142	21.4	0.7	1.4	0.8	-3.1	-24.9	-17.9	0	-19.3	14.8	0
Sum										218.8			186.7
November													
Mean	963	194	28.0	2.2	3.9	3.4	-3.7	-0.3	-0.2	2.0	-5.5	66.8	2.7
Max	978	319	42.1	4.1	7.1	16.2	5.2	10.8	9.7	10.8	6.1	93.9	37.1
Min	947	128	21.6	0.7	1.3	-7.1	-14.1	-10.1	-10.2	0	-15.6	47.4	0
Sum										54			72.3
December													
Mean	958	173	31.3	1.8	3.2	-5.1	-10.5	-7.8	-7.8	0.0	-12.0	70.5	1.8
Max	973	318	45.6	3.4	6.7	1.6	-3.9	-1.2	-1.6	0.4	-5.1	88	8.6
Min	944	76	22	0.5	1.2	-13.5	-17.3	-15.4	-15.4	0	-20.6	49.9	0
Sum										0.7			56.2

Figure 2. PMRC Long Term Annual Meteorological Record, 1988 to 1995: Comparison of Temperature and Precipitation

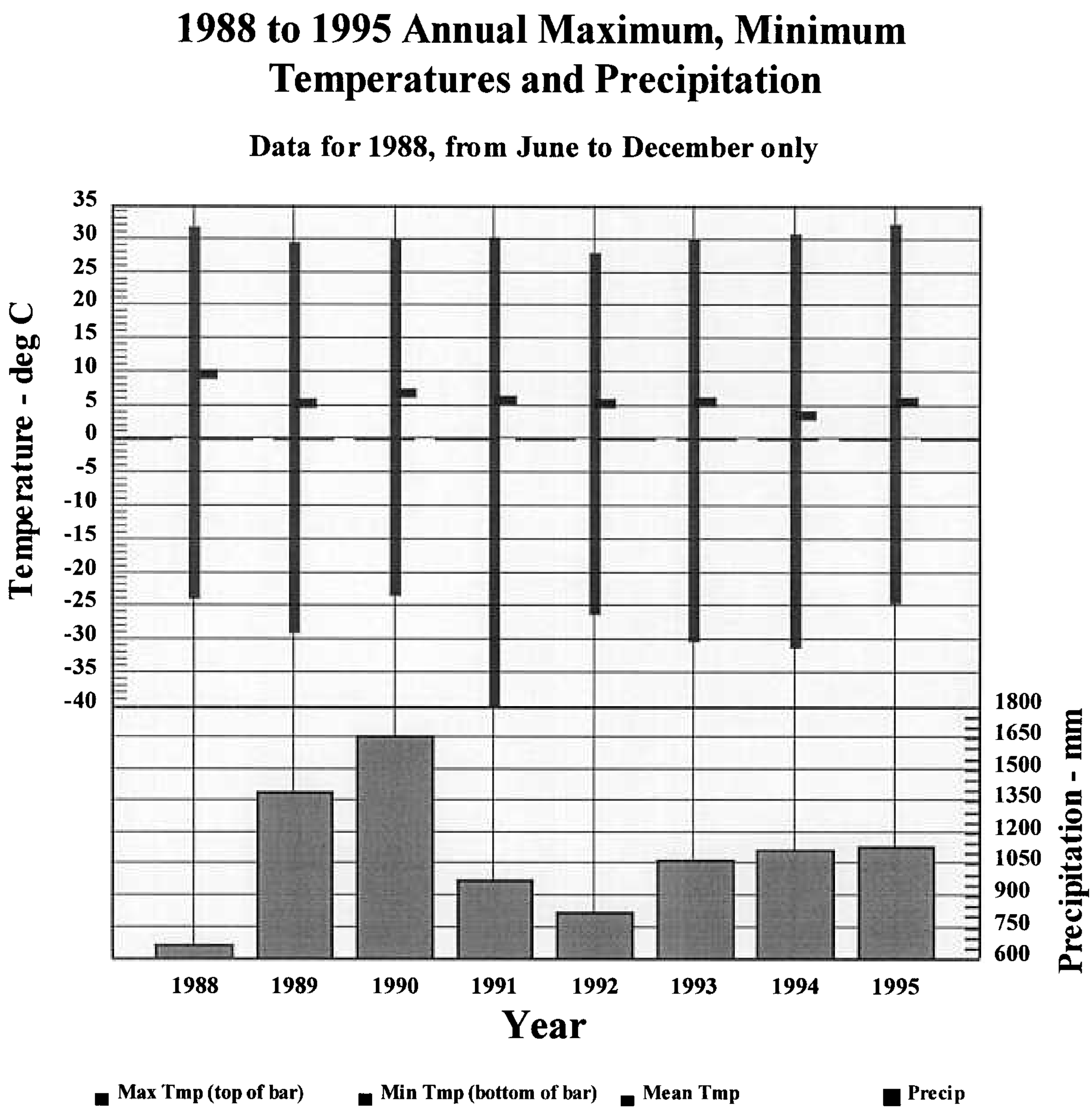


Figure 3. PMRC Long Term Annual Summary: January and July Temperature and Precipitation - 1988 to 1995

Chart A.
January Temperature and Precipitation, 1988 to 1995

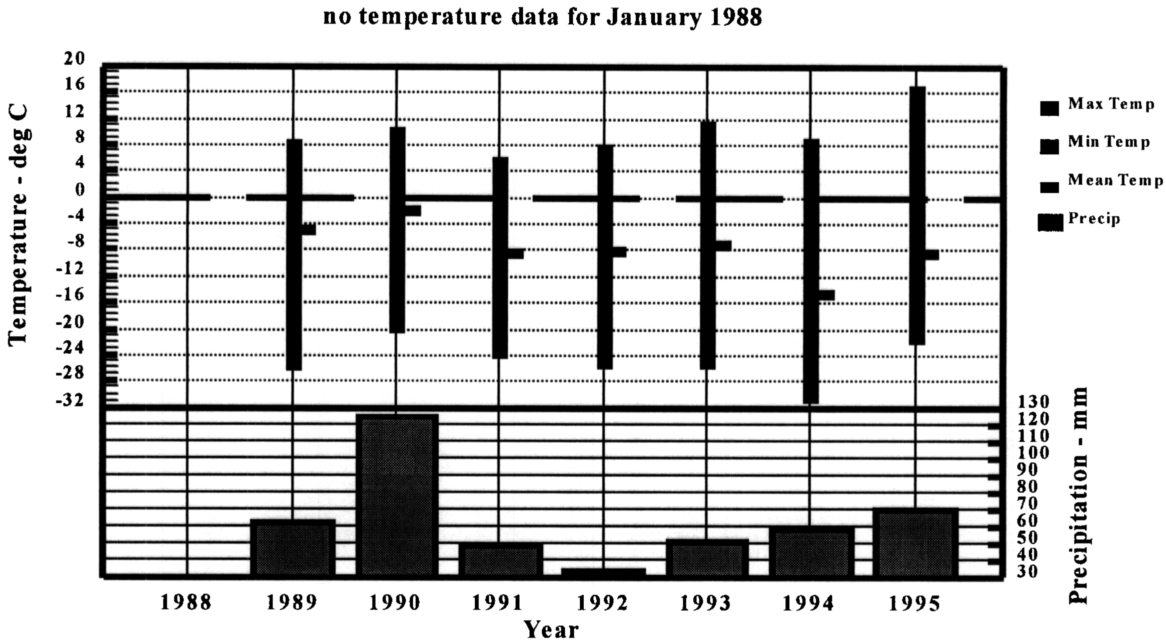


Chart B.
July Temperature and Precipitation, 1988 to 1995