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DEVELOPMENT OF
SEASONAL AND ANNUAL
BIOGENIC EMISSIONS INVENTORIES
FOR THE U.S. AND CANADA

Prepared for

Office of Air Quality Planning and Standards

Prepared by

Air and Energy Engineering Research
Laboratory
Research Triangle Park NC 27711

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TABLE OF CONTENTS

Appendices

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

LIST OF TABLES

Metric Equivalents

Users more familiar with metric units may us the following factors to convert the nonmetric units presented in this document to that system:

Nonmetric	Multiply by	Yields Metric
°F	5/9 (°F-32)	°C
knot	0.514	m/s
mph	1.609	km/hr
short ton	907.18	kg

SECTION 1

INTRODUCTION

The National Acid Precipitation Assessment Program (NAPAP) was established by Congress in 1980 to expand the understanding of the processes that result in acid deposition phenomena in and around the United States. One of the principal objectives of NAPAP was to develop a complete and accurate inventory of natural and anthropogenic emissions of acid deposition precursors. The 1985 NAPAP Emissions Inventory (Version 2) was delivered in February 1990. This inventory included anthropogenic emission data for SO_2, NO_x, NO, NO_2, VOC, THC, CO, TSP, NH_3, SO_4, HCl, HF, 32 hydrocarbon reactivity classes and 15 classes of particulate based on reactivity and size class. Emissions data were also developed for 12 classes of natural particulate data based on reactivity and size classes.

The development of the emissions algorithms and supporting data for the calculation of biogenic emissions was not sufficiently advanced to allow the inclusion of natural hydrocarbon and NO_x emissions in the NAPAP Version 2 inventory. Biogenic emissions algorithms, which depend on meteorological data inputs, were made available shortly after the completion of the NAPAP inventory. These algorithms can be used to estimate emissions of isoprene, alpha pinene, other monoterpenes, unknown hydrocarbons, NO, and NO_2. For this inventory, only grassland NO_x emissions were considered. Other sources of biogenic NO_x are known to exist but have not been well quantified to date. A methodology to apply these algorithms was developed by the EPA Atmospheric Research and Exposure Assessment Laboratory (AREAL) for episodic (day specific) simulations using the Regional Acid Deposition Model (RADM) for model evaluation and research purposes.

While the availability of the episodic emissions estimates were valuable for application to the specific days selected for the RADM evaluation simulations, it was desirable to develop representative seasonal and annual emissions estimates for other NAPAP and EPA analyses. Earlier efforts, performed by researchers at the Washington State University[1,2] were based at the county level and relied on monthly average meteorological data (e.g., temperature and wind speed). The emissions rates calculated by the emissions algorithms are highly dependent on hourly temperature and solar radiation data. A comparison of the results of this study with earlier efforts is presented with the emissions data. In general, biogenic hydrocarbon emissions estimated using data and methodologies presented in this report are lower than those reported in earlier efforts on an annual and seasonal basis.

BACKGROUND

Historically, ozone control programs based on reductions of emissions from identified anthropogenic sources of volatile organic compounds (VOCs) have had little success. As a result, researchers have been searching for categories of VOC emissions which have not been routinely considered in the evaluation of ozone control strategies. One potentially large source of reactive VOCs in certain areas is thought to be emissions resulting from biogenic processes in forest and crop biomass[3,4]. Although the details regarding the emission mechanisms and the controlling factors affecting biogenic sources are not well understood, significant advances have been made in attempts to quantify these emissions source strengths[1,2].

Biogenic VOC emissions can affect the atmospheric chemistry of urban ozone plumes when they are introduced to an urban area as a background flux[3]. In addition, these emissions can react with small amounts of NO_x left over from urban processes or with additional natural sources of NO_x. The principal known sources of VOC from natural processes are direct emissions from the leaf surface of forest biomass and agricultural crops. Emissions of NO_x from natural sources are thought to arise from chemistry and biochemistry in soils and from lightning. Natural sources of other air pollutants may also be important for other environmental concerns. For example, emissions of natural particulate can have effects on visibility and the alkaline components of particulate may interact in the atmospheric and cloud chemistry of acid rain.

OBJECTIVES

The purpose of the research described in this report is to develop representative monthly, seasonal and annual emissions estimates for natural sources of VOC and NO_x. Since the emissions algorithms available rely on meteorological data as input, diurnal profiles for each month were developed for a three year period that would be representative of the meteorological conditions around the year 1985. The representative diurnal meteorological parameters were spatially interpolated to 1/6 degree latitude by 1/4 degree longitude grid cells and were used to calculate biogenic emissions using gridded land cover data with the same spatial resolution. The calculated emissions were then aggregated spatially to the county and State levels, and temporally to monthly, seasonal, and annual levels. The resulting database provides estimates of biogenic emissions that rely on spatially and temporally variable conditions, but are represented at larger spatial and temporal scales for use in emissions assessment evaluations comparing the magnitude of anthropogenic and natural sources. Biogenic emissions data summaries are presented in Section 4 and Appendix A.

A secondary objective of the research was to process an updated version of the county level natural particulate data which was developed after the completion of the 1985 NAPAP Emissions Inventory (Version 2). The updated natural particulate data incorporated improvements to the emissions calculation methodologies for dust resulting from unpaved road travel in the United States and improvements in the State to county allocation methodologies. The county level data were processed using the NAPAP inventory allocation software known as the Flexible Regional Emissions Data System (FREDS)[5] that was used in the development of the Version 2 NAPAP inventory.[6] A summary of these data is presented in Appendix A.

PROJECT APPROACH

The methodology used to develop the representative hourly, monthly, seasonal and annual diurnal profiles of biogenic hydrocarbon and soil NO_x emissions is outlined below. Details of the methodologies and quality assurance activities are presented in subsequent sections of this report.

Three years of hourly surface airways meteorological data from the National Climatic Data Center, reported at over 300 measurement sites in the United States, were obtained and quality checked. Data at over 130 measurement sites in Canada were obtained from the Canadian Climate Centre of Environment Canada. These data were used to develop diurnal profiles representative of each month of the year at each reporting site. The spatial distribution of meteorological stations analyzed is presented in Figure 1-1. These data were spatially interpolated to generate monthly average diurnal profiles for the entire study region in a grid based system defined by grid cells of 1/4 degree longitude by 1/6 degree latitude. Gridded land use cover data were available from the NAPAP program. Leaf biomass data were available at the county level from the Oak Ridge National Laboratory Geoecology data base. These data were disaggregated to the grid level using gridded land use/cover data. Documentation of these data are provided in Appendix B.

Biogenic hydrocarbon emissions were calculated for the representative hour and day in each grid cell for each month of the year using the Canopy Emissions Model developed for NAPAP by researchers at the Washington State University.[2] The Canopy Model considers the leaf temperature and solar radiation gradient within the forest canopy. Since the emissions from trees are highly dependent on both temperature and solar radiation this algorithm provides more representative estimates of the emissions rates than does a simpler treatment based on the assumption that all of the biomass is exposed to the same unattenuated solar radiation intensity. Algorithms were provided by NOAA to calculate emissions of NO_x from undisturbed (uncultivated) grassland areas. Similar to the biogenic hydrocarbons, grassland NO_x emissions are also dependent are temperature. NO_x emissions algorithms for other land use types were not available for application to this study. Additional emissions of NO_x from soils in forests, from agricultural lands, for deserts and from wetlands have been observed in measurement programs, however, the dependencies on meteorological and other factors were not yet determined for use in this effort.

The resulting hourly gridded emissions calculations were aggregated to develop monthly mean emissions magnitudes at the grid level. Allocation factors, based on the grid/county overlap, were used to aggregate the gridded emissions to county and then State totals. Finally, the monthly averages were aggregated to seasonal and annual totals. The seasonal emissions were developed on the following basis:

Winter	December, January, February
Spring	March, April, May
Summer	June, July, August
Autumn	September, October, November

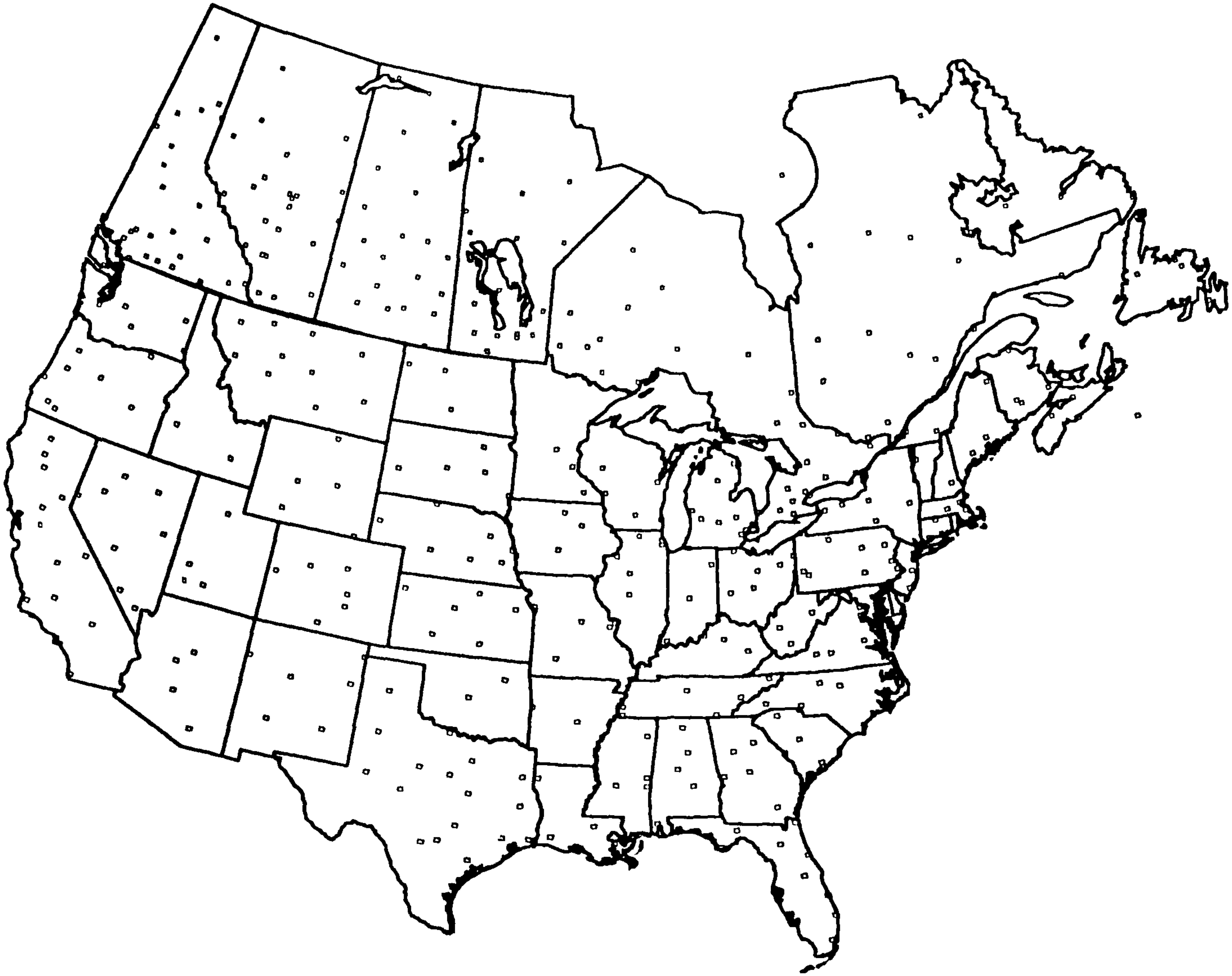


Figure 1-1. Meteorological Stations Analyzed for the United States and Canada.

REPORT ORGANIZATION

The primary objectives of this report are to document the development of a biogenic hydrocarbon emissions inventory using representative monthly diurnal profiles of meteorological data and the implementation of the Canopy Model software. A summary of the calculated emissions at varying levels of spatial and temporal aggregation is also presented.

The remainder of this document is comprised of the following sections:

Section 2: Development of Representative Gridded Diurnal Meteorological Profiles
Section 3: Calculation of Biogenic Hydrocarbon Emissions
Section 4: Natural Particulate and Biogenic Emissions Data
Section 5: Summary and Recommendations.

The emissions calculation methodology and summary for grassland NO_x emissions are also provided in Sections 3 and 4.

SECTION 2

DEVELOPMENT OF REPRESENTATIVE GRIDDED DIURNAL METEOROLOGICAL PROFILES

Biogenic emissions flux algorithms are expressed as a function of leaf temperature and solar radiation. In forested areas, the Canopy Model corrects for leaf temperature and solar radiation based on the vertical structure of the forest vegetation and meteorological data. Hourly meteorological data for specific parameters are required for input to the Canopy Model to calculate emission rates of biogenic hydrocarbons and NO_x. These include surface temperature, incident solar radiation, cloud cover, relative humidity and wind speed. The incident solar radiation is adjusted to account for attenuation of incoming solar radiation by cloud cover. In order to develop seasonal and annual biogenic emission estimates, representative gridded monthly diurnal profiles were developed using three years of hourly surface meteorological data.

Two meteorological data bases were used to generate representative monthly diurnal profiles for the United States and Canada. Hourly surface meteorological data for the United States were obtained from the National Climatic Data Center (NCDC) Surface Airways Hourly Files (TD-3280)[7] for 1984, 1985, and 1986. The meteorological data for Canada were supplied by Environment Canada in the NCDC TDF-1440 format[8] for 1983, 1984, and 1985. Three concurrent years of meteorological data for the United States and Canada were not available; the 1986 data for Canada were not available and meteorological data for 1983 for the United States were not complete.

Generation of gridded representative hourly diurnal profiles was accomplished in three phases: (1) collect, process, analyze and quality assure the meteorological data; (2) develop representative hourly diurnal profiles based on statistical analyses; and (3) interpolate the profiles to fill in data for grid cells for which no meteorological data were present. Additionally, solar radiation for each 1/4 degree longitude by 1/6 degree latitude grid cell was calculated for the midpoint day for each month as a function of latitude, longitude, day of the year, and hour of the day. Solar radiation is attenuated for cloud cover prior to input into the Canopy Model. Throughout each phase, quality control checks were performed to assure the completeness and validity of the data. Each of these phases and quality control checks is discussed in more detail in the following pages.

COLLECTION AND PROCESSING OF METEOROLOGICAL DATA

During the first phase, three years of meteorological data were obtained for the United States and Canada. The data were provided in Surface Airways Formats TD-3280 and TDF-1440, respectively. In the Surface Airways File TD-3280,[7] each logical record contains hourly data values for one station for a specific meteorological parameter for one day. Preceding the hourly meteorological data values, each logical record contains a control variable and identification information. The control variable contains the record length for each logical record. The identification information includes the record type (e.g., hourly), station identification, meteorological parameter and units, year, month, day, and the number of values in the record.

The Surface Airways TDF-1440 File[8] contains four physical records for each twenty-four hour period. Each physical record contains six logical records which contain observations for a six hour period. Each physical record contains an identification portion and is followed by six logical 80 byte records with meteorological observations. These records always begin with the hour (local standard time, LST).

U.S. Meteorological Data Processing and Quality Control

Twelve magnetic tapes were read and processed on the National Computer Center's (NCC) VAX computer to obtain hourly values of temperature, cloud cover, relative humidity and wind speed over a three-year period. The data required for this effort were extracted from the original NCDC data tapes using a Fortran program provided by EPA's Atmospheric Research Exposure and Assessment Laboratory (AREAL). The data were transferred to the NCC IBM for further processing and quality control checks.

Quality control checks were performed on the three years of data to assess the completeness of the data before any processing was initiated. As a preliminary check, the number of records in each of the three years of data were tallied and compared. This indicated that for 1984, there was approximately 400,000 fewer records than for 1985 or 1986. A comparison of the 1984 data with that on the tapes for 1985 and 1986 indicated that the missing stations were located in the northwest and northern plains sections of the U.S. Further evaluation indicated that the missing data were the result of a physical flaw on one of the 1984 meteorological data tapes. These problems were corrected and the missing data were obtained. The geographical coverage of the meteorological recording sites provided on the NCDC tapes is illustrated in Figure 1-1. The number of sites available for each year are 307, 299, and 302 for 1984, 1985, and 1986, respectively. It should be noted that Figure 1-1 contains "cloned" meteorological data sites in areas of sparse coverage. The procedures and necessity of the "cloned" sites is discussed under *Spatial Interpolation.*

To further assess the completeness of the data, the number of records available per site per year were determined in order to identify potential data gaps during the period of record. Stations indicating less than 8760 hours per year (for 1984, less than 8784 hours per year) were identified and output for further evaluation. This analysis indicated that for 1984, 16 stations reported observations for less than 8784 hours. In 1985, 19 stations had fewer than 8760 observations and 22 stations did not report a full year of data in 1986. It should be noted that this preliminary analysis did not assess the frequency of missing data for hours contained within each file. Determination of missing data will be discussed later.

Each of the sites reporting less than a full year of data were examined to determine if the missing data were scattered randomly over individual hours throughout the year or were missing in blocks of hours (e.g., over the large part of a month or over several months). This was accomplished by summing over the number of hours for each day for each month. The results of this analysis indicated that for most of the sites reporting less than a full year of observations, entire days and sometimes several months were missing from the file rather than sporadic missing hours. The impact of the missing data on the representativeness of the diurnal profiles was evaluated while calculating univariate statistics over the three year period. This will be discussed further in *Calculation of Representative Diurnal Profiles.*

Once the completeness of the data was determined and potential data gaps identified, error checks were performed on the values reported for temperature, relative humidity, wind speed and total cloud cover for the three year period. The acceptable data ranges used as criteria for each parameter and the suspect values noted as a result of this analysis are presented in Table 2-1. Dew point values were also checked to help identify any potentially suspect relative humidity values. The data in Table 2-1 indicate that for the 7,351,532 observations evaluated, very few contained suspect values. The 42 occurrences of 999 for wind speed are most likely miscoded missing values (the missing value code for wind speed is -999). Records with suspect values were checked to assure they were not the result of a short lived weather anomaly (e.g., the high wind speed values were checked to see if they corresponded to changes in pressure, wind direction, and temperature as would be common with the passage of a gust front). Suspect values were recoded to missing so as not to influence the data when determining representative diurnal profiles.

TABLE 2-1. SUSPECT METEOROLOGICAL DATA VALUES - U.S.

Parameter	**Acceptable range**	**Suspect values (frequency)**
Relative humidity	5 to 100%	0(1)
Dewpoint	-50 to 85° F*	87(1), 97(1)
Wind speed	0 to 50 knots	86(1), 80(1), 999 (42)
Temperature	-50 to 110°F	275(1)
Total cloud cover	0 to 10 tenths	None

*Readers more familiar with metric units may use the factors listed on Page vii to convert units to that system.

Univariate statistics were calculated individually for each year and sample statistics were plotted such that gross anomalies in the data could be identified. As a result of this evaluation, it was noted that Phoenix appeared to be unusually cloudy for July 1984. Since

July is of particular interest for biogenic emissions calculations, the potential for erroneous cloud cover data was checked. A review of the Daily Weather Maps[9] showed July 1984 to be unusually wet and cloudy for the Phoenix area. When compared with data in the hourly records, this appeared to be reasonable.

The U.S. meteorological data files included sites in Hawaii, Alaska, the Caribbean Islands, and other overseas stations of the National Weather Service (NWS), U.S. Navy, and U.S. Air Force. Therefore, a decision was made to remove these sites along with other sites not within the NAPAP grid boundaries. Since the meteorological data will be spatially interpolated to grid cells where data are not available, stations within 5 degrees latitude and longitude of the grid boundaries were retained in the data base. The inclusion of these sites improved the interpolation results along the grid and land boundaries. Removal of sites outside this 5 degree margin resulted in more efficient processing in the steps which follow.

In preparation for calculation of representative diurnal profiles, the three annual meteorological files for the U.S. were concatenated into a single file. The concatenated file was used along with the SAS UNIVARIATE procedure in the development of representative diurnal profiles for each meteorological parameter.

Canadian Meteorological Data Processing and Quality Control

Ten magnetic tapes were read and processed to obtain hourly meteorological data for three years: 1983, 1984, and 1985. The data for 1983 and 1984 were each contained on a single tape, while the data for 1985 were supplied on eight magnetic tapes. The desired meteorological data were obtained from the files using a Fortran program supplied by AREAL which was modified for this application. Processing during the initial stage was performed on the NCC VAX computer. Once the desired meteorological parameters were extracted from the original data tapes, the data were transferred to the NCC IBM for further processing and quality control checks.

Preliminary quality control checks, similar to those described for the United States, were performed on the data to assess the completeness of the data for each year. An initial check on the number of records for each year indicated that about twice as many records were present in the 1985 data than were available for the other two years. A comparison of the 1985 data with that of 1983 and 1984 revealed that 131 and 137 sites were provided for 1983 and 1984, respectively, while 277 stations were available on the tapes for 1985. The stations present in the data for 1983 and 1984 were compared with those provided for 1985 to determine the cause of the discrepancy in the number of reporting stations. A review of the data found that the tapes for 1985 included secondary stations which record data for less than 24 hours per day.

The primary meteorological data sites represented in the Canadian database are presented in Figure 1-1. It should be noted that Figure 1-1 contains "cloned" meteorological stations. The procedures and necessity for the cloned stations is discussed under *Spatial Interpolation*. The applicability of these sites for use in the interpolation was evaluated while other checks were performed on the data.

In an effort to identify secondary sites in the 1985 meteorological data file, the number of hours for which nonmissing data values were reported for 1985 per site were counted. Several secondary stations were identified as a result of this analysis; however, the remaining number of stations in the 1985 data file still exceeded the number of sites present for 1983 and 1984.

To further identify other potential secondary stations in the 1985 data file, the number of nonmissing observations was counted for each of the desired meteorological parameters individually. The results indicated that the data capture for wind speed and wind direction (note that wind direction is not used for biogenic emissions calculations but is used as a check for suspect wind speed data) was significantly higher than that of the other parameters. The reason for this is that many stations report wind data on a 24-hour basis, and the remainder of the data is reported for limited time spans. As a result, a more specific check was performed on the number of nonmissing observations for temperature, cloud cover and relative humidity.

The results of this effort provided a list of 130 stations reporting data on a 24-hour basis, and an additional 7 which report data for most of the day. Of these 137 sites, 5 were exclusive to 1985 and the remaining 132 stations reported data in at least one of the other two previous years. Completeness checks on the number of nonmissing observations in 1983 and 1984 did not indicate any large data gaps. The effect of missing data on the representativeness of the diurnal profiles was evaluated while calculating univariate statistics for the three year period.

Additional quality control checks were performed on the reported values for temperature, cloud cover, relative humidity and wind speed for the three year period. The acceptable data ranges used as criteria for each parameter and the suspect values noted as a result of this check are presented in Table 2-2. Dew point values were also checked to help identify potentially suspect relative humidity data. Twelve of the 16 suspect values were noted for relative humidity. An additional four suspect values for dew point were also noted. The suspect relative humidity data did not have corresponding dew point data and as such, could not be verified. These were recoded to missing. The four suspect dew point values were not modified since they did not correspond to suspect relative humidity values and the dew point is not used by the Canopy Model.

In preparation for calculating representative diurnal profiles, sites not within the NAPAP borders including a five degree margin beyond the boundaries were eliminated from the data base. The three annual Canadian files were concatenated into a single file and used with the SAS UNIVARIATE procedure to develop representative diurnal profiles for the four meteorological parameters.

TABLE 2-2. SUSPECT METEOROLOGICAL DATA VALUES - CANADA

Parameter	Acceptable range	Suspect values (frequency)
Relative humidity	5 to 100%	≤ 4% (12)
Dewpoint	-50 to 85° F	90(1), 99(1), 100(1), 114(1)
Wind speed	0 to 50 knots	None
Temperature	-50 to 110°F	None
Total cloud cover	0 to 10 tenths	None

CALCULATION OF REPRESENTATIVE DIURNAL PROFILES

Hourly Surface Meteorological Data

Monthly representative diurnal profiles of temperature, cloud cover, relative humidity, and wind speed were developed for each surface station for the United States and Canada using three years of hourly meteorological data. The SAS univariate procedure was used to calculate the means, medians, and modes for each meteorological parameter for each site by month and by hour. As a preliminary check on the univariate output, a portion of the data was printed and examined for any irregularities (e.g., a large number of hours in which there were no observations used to calculate descriptive statistics for one or more parameters).

While reviewing the printed output data for Canada, a mode of 0.0 for wind speed was noted for several station/month/hour combinations. To determine the frequency and extent of this occurrence, all records reporting a mean, median, and mode of 0.0 for wind speed were output and compared with the raw data. Thirty-eight stations indicated a high frequency (i.e., >12 hours out of 24) of a 0.0 mode for wind speed. Examination of the raw data indicated that calm winds were frequently reported at these stations during the suspect periods.

In addition to descriptive statistics, the number of observations used in the statistical calculations for each meteorological parameter and the number of missing observations by site, month, and hour were tallied in order to identify stations with a large amount of missing data. Statistics for all hours which were based on less than one third the possible number of observations (where the number of possible observations is equal to n-days per month times 3 years) for any parameter were printed and reviewed.

Table 2-3 presents the results of these checks for each meteorological parameter for the United States data for the three year period. Forty three sites indicated statistical calculations based on less than one third of the possible number of observations for one or more of the desired meteorological parameters for the three year period. Nine of these sites either initiated or terminated observations within the three year period, resulting in partial yearly records. Thirty three of these sites reported data only during certain time spans, ranging from 6 to 15 hours per day, and usually included daylight hours.

The preliminary checks on the diurnal profiles of the means, medians, and modes for Canada indicated very few hours of reported data at the secondary stations provided for 1985. Since the data for these stations were not available for 1983 and 1984, statistical calculations at these sites were based on a very limited number of observations. Therefore, prior to further evaluation of the diurnal profiles, these stations were removed from the Canadian file. Table 2-4 contains the results of the completeness checks for each meteorological parameter for the Canadian data for the three year period after removal of the secondary sites. Nine stations indicated statistics based on less than one third of the possible observations or no data for one or more of the desired meteorological parameters over the three year period. In most cases, data were missing during the evening hours when the stations did not operate or only reported automated wind readings.

While performing quality control checks on the Canadian diurnal profiles, it was noted that four stations were deleted due to no match in the latitude/longitude file. Univariate statistics by station/month/hour were calculated separately for these sites and the data concatenated to the file containing the Canadian diurnal profiles. Latitude and longitude data for these sites were obtained from EPA/AREAL and the GMT adjustment values were determined from an atlas[10].

Comparison of Means, Medians, and Modes

To determine which statistical parameter would be used to develop representative diurnal profiles for each meteorological variable, the calculated means, medians and modes were compared for each station by month and by hour using the SAS COMPARE procedure. The COMPARE procedure allows the user to compare the values of variables based on one of three equality criterion: relative, percent, or absolute. For the comparison of the means, medians, and modes, the absolute method was used. Using the absolute criterion, values are considered unequal if the absolute value of their difference [i.e., ABS (y-x)] exceeds the user specified criterion value. For example, when comparing mean and median temperatures, values were considered unequal if the absolute difference between the mean and the median was greater than 5°F. Each of the equally criterion is defined under the COMPARE procedure in the SAS Basics manual[11]. The Criteria values were chosen subjectively for this assessment and the COMPARE procedure was executed for the first 1,000 observations of the data set using the following criteria values:

temperature difference > ABS(5°F)
relative humidity difference > ABS(10%)
wind speed difference > ABS(3 knots)
total sky cover difference > ABS(1 tenth).

TABLE 2-3. NUMBER OF METEOROLOGICAL SITES WITH STATISTICS BASED ON LESS THAN ONE-THIRD OF POTENTIALLY AVAILABLE DATA - U.S.

Parameters	**Number of Sites with Statistics Based on <1/3 of the Data**
Total Cloud Cover (SKYT)	8
Relative Humidity (RELH)	2
Wind Speed (WIND)	0
Temperature (TEMP)	0
ALL 4	18
RELH and WIND	1
RELH, SKYT, and WIND	14
TOTAL	43

TABLE 2-4. NUMBER OF METEOROLOGICAL SITES WITH STATISTICS BASED ON LESS THAN ONE-THIRD OF POTENTIALLY AVAILABLE DATA - CANADA

Parameters	**Number of Sites with Statistics Based on <1/3 of the Data**
SKYT, RELH, and TEMP	5
ALL 4	4
TOTAL	9

As an additional comparison, the SAS PROC PLOT procedure was used to plot diurnal profiles of the means, medians and modes for the month of July for three sites in the U.S. and three sites in Canada.

Examination of the preliminary comparison and plots indicated that for all variables, the mode would not be representative as it behaves erratically and does not follow expected diurnal patterns. This was also apparent from the diurnal plots. For most parameters, the mean and the medians follow each other closely, with the exception of cloud cover. The preliminary evaluation indicates that the means and medians of the other meteorological parameters follow expected diurnal profiles.

Based on the results of the preliminary comparisons, the COMPARE procedure was executed for all observations for the means and the medians for the United States and Canada using modified criteria values as follows:

United States

temperature difference > ABS(6 degrees F)
relative humidity difference > ABS(10%)
wind speed difference > ABS (3 knots)
total sky cover difference > ABS(3.5 tenths)

Canada

temperature difference > ABS(5 degrees F)
relative humidity difference > ABS(10%)
wind speed difference > ABS(3 knots)
total sky cover difference > ABS(3 tenths).

The results of this analysis indicated that the mean and the median for wind speed and relative humidity are very close. For temperature, the mean and the median are also fairly close. However, the median is more representative of the central tendency of a parameter as it is not affected by extreme values (the median may be affected by the frequency of occurrence of extreme values but not by the magnitude of the extremes themselves). Of all statistical measures of central tendency, the mean is most affected by extreme values in a population sample. For total sky cover, the mean shows a smoother transition from hour to hour, which is more desirable for a representative diurnal profile. Therefore, median values were employed for temperature, relative humidity, and wind speed, and mean values were used for sky cover.

Quality control checks on the representative diurnal profiles generated revealed that in some cases a monthly median wind value of 0.0 was present in the output dataset. Since a 0.0 value is not considered representative and results in slightly negative interpolation results, all occurrences of median winds of 0.0 were replaced with the mean wind speed for that hour. The Barnes interpolation routine may produce negative values under certain conditions. The first pass through the grid produces values for every grid point based on weighting of nearby

To facilitate testing of the routine, the input data and interpolation results were output in an array with each array column and row corresponding to the subgrid columns and rows. Using this method, the original data could be displayed along with the interpolation results from the lower bound, upper bound and the differences resulting from subtracting the lower bound from the upper. A section of the NAPAP grid, with the lower left corner located near Little Rock, AR and the upper right corner located near Pittsburgh, PA, was used in the series of tests. This subgrid contains 35 rows and 50 columns.

Temperature values were initially used as input data for the tests. Gamma was set to 0.3 in the first test while D_0 values of 0.1 and 0.6 were tested. The range of differences for the interpolation tests using $D_0 = 0.1$ and $D_0 = 0.6$ was -1.8 to 2.3 degrees F. This 4.1 degree F range represents nearly 5% of the input values. Approximately 5% of the cells had differences exceeding plus or minus 1 degree F with the remaining cells having values less than plus or minus 1 degree F.

In the second test, D_0 was set to 0.5 while gamma values of 0.3 and 0.5 were employed. Differences ranged from plus to minus 0.2 degrees F. More than 95% of the cells had differences of less than 0.05 degrees F.

From these results, it was evident that interpolation results are more sensitive to changes in D_0 than gamma. A value of 0.5 for D_0 when used with either of the above values of gamma produces a reasonably smooth field of interpolated values.

Testing was then expanded to the entire NAPAP grid for all four meteorological parameters. A plot of test results showed the data sparse areas of northern Canada contained regions with no interpolated data. Several cells in the Rio Grand valley of Texas also had no coverage. Since biogenic emissions could not be calculated without the meteorological data, the following strategy was implemented to provide complete interpolation coverage. Station data were duplicated and assigned as data points in nearby grid cells in the areas lacking coverage. The assignment of duplicate station data was kept to the minimum necessary to ensure that the greatest number of uncovered cells were provided interpolation results.

The duplication of meteorological data and false location assignment or "cloning" was performed a total of nine times to provide coverage over land areas. Figure 2-1 presents the coverage provided after duplication/relocation was performed. Prior to the data duplication, candidate sites were scanned by parameter by hour to assure complete records. Data for only five sites was required to accomplish this coverage. The region south of Hudson's Bay required four duplicates of data from one site to provide complete coverage in that area. A second site in northeastern Quebec was duplicated twice to cover far north-central Quebec. Three other sites, located in northwestern Manitoba, northern Saskatchewan and southwestern Texas, were duplicated once.

The climatology of northern Canada is quite uniform with the exception of areas near the coast of Hudson's Bay. When deciding on the location of duplicate sites for application to the uncovered region in northern Quebec, it was felt that duplicating either of the sites on Hudson's Bay could propagate coastal influences to inland locations. It was preferable to

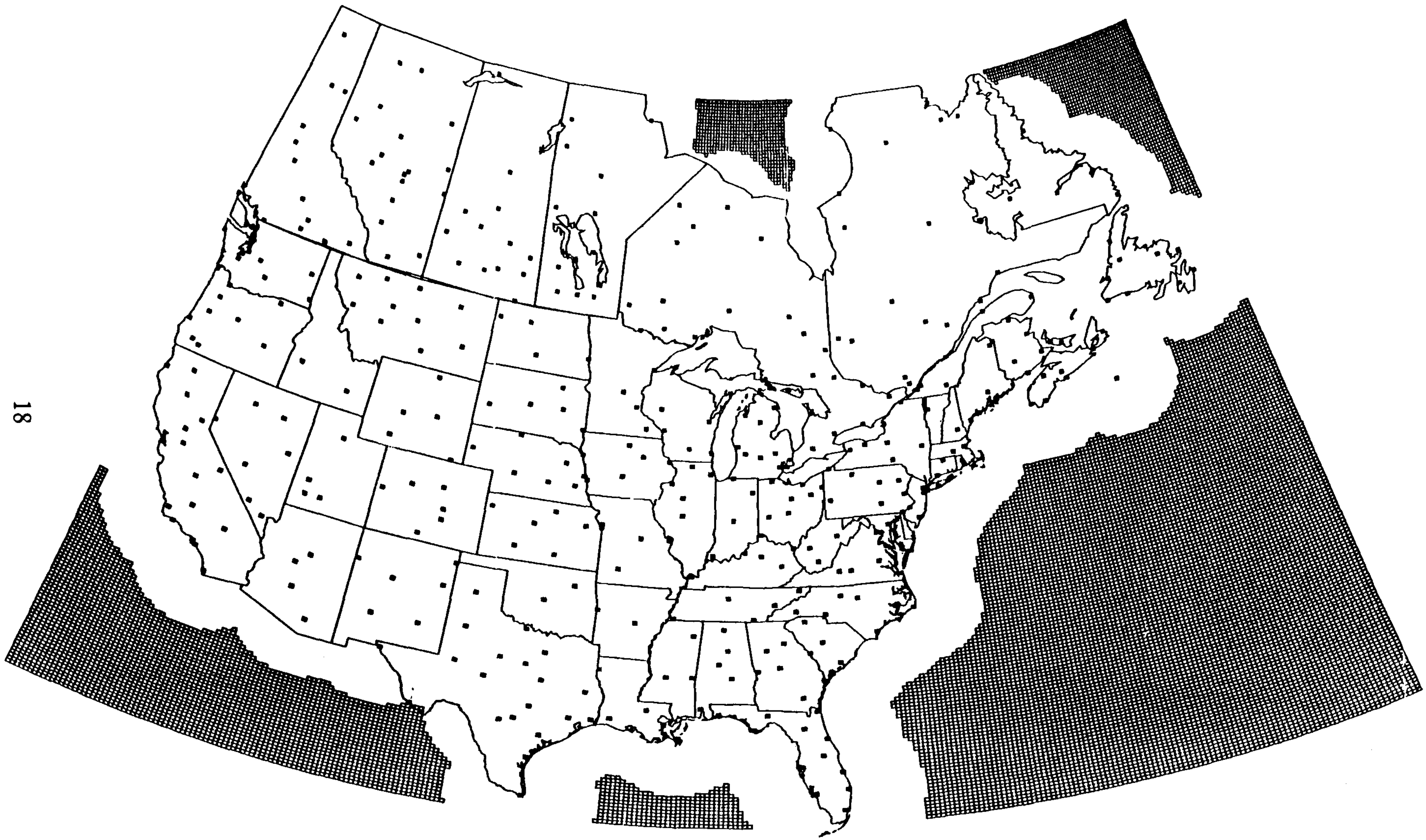


Figure 2-1. Plot of Interpolation Test Results.

data points. The second pass uses the first pass results to perform a simple bilinear interpolation at each grid cell using the four surrounding grid cells. This interpolation may result in positive and negative adjustments to the first pass results. A grid cell having an initial value of zero and adjacent cells with non-zero values could become slightly negative after the bilinear interpolation is complete. This condition was found to occur in data sparse regions. This problem was not observed for any of the other meteorological parameters.

Final Data Processing

To prepare the meteorological data for interpolation, the diurnal profiles for the U.S. and Canada were concatenated into a single file. Column and row numbers were calculated for 1/6 degree latitude by 1/4 degree longitude grid cells from the latitude and longitude of each station using the NAPAP grid origin (i.e., 1,1 = 25 degrees N latitude and 125 degrees W longitude). Meteorological parameters were converted to units for compatibility with the Canopy Model (i.e., temperature = degrees C, relative humidity in fractions [e.g., 0.50], and wind speed in m/s). (Sky cover data is not directly input to the Canopy Model. Use of this data will be discussed under *SOLAR RADIATION*.) In addition, hourly values were adjusted to GMT and missing values were coded to -99.0. Prior to output, records corresponding to representative hourly values in which statistics were based on less than 80% of a single month in which only one year of data were available (i.e., n < 24) for *all* meteorological variables were deleted as these would not be considered representative. The data were sorted by month and hour and output to an EBCDIC file for interpolation.

SPATIAL INTERPOLATION

The Barnes interpolation technique[12,13] was investigated as a means of providing meteorological data for all cells in the NAPAP grid. This technique has been widely used for temporal and spatial interpolation of meteorological data. It has found wide acceptance for two major reasons; it is a computationally simple algorithm, thus minimizing computer program execution times, and it allows the user to adjust key parameters (i.e., the convergence factor and the initial resolution) until results are considered acceptable. The initial resolution (D_O) is a dimensionless measure of the first pass response. The interpolation routine employed allowed the user to select a value for this variable in order to produce the desired results. The convergence parameter (gamma) is a factor which controls the degree of convergence between the observed field and the results of the second pass interpolated field.

The version of the Barnes algorithm employed in this study, modified in 1973, performs the interpolation in two steps. The user must first define a grid area, usually a subsection of an area for which data are available. The program initially determines the number of data points in the selected area and measures the distance between every pair of data points to determine data spacing. The program then loops over every grid point, measuring the distance to each data point to determine a weight for each data point. The weight is calculated by a Gaussian relation of the form

$$W=\exp[-(r^2/k_0)]$$

where **W** is the weight, **r** is the distance from data to grid point, and $\mathbf{k_0}$ is the weight factor. The weight factor is defined by the relation

$$k_0=(-\log D_0)(avespa)/(2)(3.1416)$$

where $\mathbf{D_0}$ is the initial resolution and **avespa** is the average data spacing. The average spacing, calculated by the program, is the average distance between data points (km) in the grid area. It is calculated by summing the distances between all data points and dividing by the total number of data points. Should a data point be coincident with a grid point, the weight assigned to that grid point is the maximum value of 1. When 2 or more data points fall within a grid cell, an average of the values is taken. As grid points further removed from the data are evaluated, the weight drops exponentially.

This process of assigning weights is conducted for all data points in the defined area. Grid points will typically fall within the region of influence of many data points. The routine then incorporates the weight factors as it calculates a value for each grid point. The spatial extent of the region of influence is dependent on the data spacing and user specified parameters.

When the distance between a data point and an interpolation point increases, the weight for that data point-interpolation point pair decreases. The user is allowed to define maximum distances between data points and interpolation points that will be considered to ensure complete coverage and representative interpolation values while maintaining computational efficiency. This approach is most valuable when interpolating over a large region that has many data points.

To facilitate computing of interpolated values, grid points beyond a user specified distance of a data point are not considered as the weight becomes insignificant. This approach can be of value when interpolating for a grid with many points.

At the conclusion of the first pass, all grid points have been assigned values. The second pass uses the results of the first pass to perform a simple bilinear interpolation using the four surrounding grid points. This interpolation will produce an adjustment to the first pass yielding smoother final results. The user can select values for the convergence factor (gamma) and initial resolution (D_0). Because the two parameters may be varied, a series of tests may be required to assess the effects of each on the interpolated values.

In reviewing the related literature provided by AREAL[14], a recommended range of 0.3 to 0.5 for convergence factors was used in the tests. By definition, D_0 ranges from 0 to 1. A value of 0.1 for D_0 was believed to provide a reasonable lower bound for testing purposes. In order to compare results for the lower and upper bounds for both variables, one variable was set to a constant value while the second was run at both upper and lower bounds. For D_0 values of 0.7 and greater, a floating point error condition was encountered. The system, however, took "standard corrective action" and results were obtained. The interpolation results for these values of D_0 were not desirable. Results were not considered to be smoothed sufficiently with relatively large gradients present in the areas tested.

duplicate a site in northern Quebec, located further inland, and relocate it to the west. In this way, any coastal effects of the bay would diminish with increasing distance from the water.

Three steps were performed in order to provide evidence of complete interpolation coverage. First, the composite 3 year meteorological data file was scanned to produce the number of sites reporting data for at least one of the four parameters for each hour of each month. This tally yielded a maximum of 399 and a minimum of 384 sites before the nine false sites were incorporated. A plot of the entire grid area was produced for the time period reporting the minimum number of sites. This plot demonstrated complete coverage over land areas.

The second method of addressing completeness of coverage was performed by scanning the interpolated data files for cells with values of 0.00, indicating no coverage. (Note: this test could not be performed for temperature during cold months as 0.00 could be valid data. It is highly unlikely that any of the other three parameters could have valid data with a value of 0.0. In order to test temperature, warm months were scanned.) The time period indicating the greatest number of empty cells was plotted, and indicated complete land coverage. The greatest and least number of empty cells are 14,465 and 14,072, respectively. These cells are located over the water as can be seen in Figure 2-1. This reasonably narrow range (393 out of 64000) also supports the premise that coverage is adequate and consistent over time.

The third check scanned twenty sites in northern Canada which singularly provide interpolation coverage to a land area. Coverage in these areas is most vulnerable to missing data because of the interpolation dependence on a single site. This final check, done by parameter by hour, demonstrated complete data capture for sites in the data sparse areas, precluding additional cloning.

With the question of coverage adequately addressed, the interpolation runs were executed. Based on the results of the preliminary tests, values of 0.5 for initial resolution and 0.3 for gamma were used in the interpolation runs. This exercise required 48 computer runs - 4 parameters for 12 months each, with each run processing 24 hours of data. Grid plots of interpolated meteorological data for select months are presented in Appendix C.

SOLAR RADIATION

Monthly average hourly solar radiation values for each grid cell were calculated as a function of latitude, longitude, day of the year, and hour of the day using existing computer software (SOLENGY.FORT) developed by AREAL. Minor modifications to the software were required for execution on the NCC IBM and for the NAPAP grid boundaries. A new solar radiation algorithm was provided by EPA/AREAL and incorporated into SOLENGY.FORT to calculate the solar insolation for this project. This algorithm was obtained from the Urban Airshed Model Emissions Preprocessor System[15]. The new software provides calculations of hourly total and visible radiation for use in the Canopy Model (note that visible is estimated as half of the total radiation). The effect of the new algorithm resulted in reduced emissions magnitudes for isoprene relative to other studies completed previously (since the modified Tingey curves for isoprene are based on visible radiation). Additionally, the new algorithm allows a more gradual increase and decrease in solar insolation near sunrise and sunset. A listing of the SOLENGY.FORT Fortran code is provided in Appendix D.

The solar flux over a twenty-four hour period for the midpoint day of each month was calculated to represent the average diurnal solar insolation for each month. Representative samples of the output data for each season were read into SAS and checked for reasonableness (e.g., order of magnitude and relative flux from season to season and diurnally from hour to hour) and were compared to previous output from SOLENGY.FORT.

Cloud cover data were used to adjust the clear sky total and partial solar intensities for attenuation by cloud cover to more closely represent actual conditions present in the atmosphere. Gridded cloud cover data for each month and hour output from the spatial interpolation routine were merged with gridded solar insolation data for each month and hour.

The algorithm used for attenuation was obtained from Kaston and Czeplak (1980)[16]:

$$\text{attenuated solar rad.} = \text{solar rad.} \times [1 + C * (\text{skyt}^{D})],$$

where C = -0.75, D = 3.4, and skyt is the fractional total sky cover (e.g., 0.4). Quality control checks were incorporated into the attenuation software to flag and print out any potential occurrences of missing cloud cover or solar radiation data and any interpolated values less than zero. Additionally, portions of the attenuated solar radiation data were printed and checked for anomalies and correspondence with cloud cover data and expected diurnal behavior. No problems were found with the data.

SECTION 3

CALCULATION OF BIOGENIC HYDROCARBON EMISSIONS

Methodologies for calculating emission rates of biogenic hydrocarbons and NO_x require estimates of vegetation density and cover, seasonal variations of biomass growth, emission rates for vegetative classes, and meteorological parameters such as temperature and solar intensity. The previous section describes the methodology used to develop monthly representative diurnal profiles for the required meteorological parameters. This section describes the methodology and data bases used to estimate monthly gridded leaf biomass, land cover data, and emissions. Aggregation of hourly gridded emissions to the county and State levels for monthly, seasonal, and annual temporal scales is also discussed in this section. Software used to calculate gridded biomass and the Canopy Model used for this project were obtained from EPA. New temperature correction algorithms for soil NO_x, provided by NOAA, were incorporated into the Canopy Model for this project.

Emissions for each vegetation class are calculated by multiplying gridded leaf biomass and land use data (hectares) by the compound specific emission factor for each vegetative type. Using the Canopy Model, emission correction factors are calculated to adjust emissions for environmental factors such as temperature, solar insolation, leaf orientation, and location in the canopy. A description of the biomass data, methodology and software has been documented by EPA and is provided in Appendix B. A brief description is also provided here for completeness.

CALCULATION OF BIOMASS

Data from Oak Ridge National Laboratory's Geoecology Data Base[17] and the LANDSAT and Land Use/Cover Inventory[18] form the basis for the gridded biomass and coverage data for the United States and Canada. The Geoecology Data Base contains leaf biomass and noncanopy land use data at the county-level for various crop types, tree species and urban trees. County-level data were allocated to the grid level using the gridded LANDSAT Land Use/Cover Inventory previously developed for the NAPAP project. This land use/cover inventory represents data collected in the middle to late 1970s. Gridded leaf biomass and land use data for Canada were based on the LANDSAT Land Use/Cover Inventory and on Vegetation, Land Use, and Seasonal Albedo data sets.[19] Agricultural lands for Canada were allocated to specific crop types by EPA.

Vegetative classes used for biogenic emissions calculations include: natural forested vegetation (specifically, oak, coniferous, and other deciduous); other natural vegetation such as scrubland and grasslands; and agricultural crops (alfalfa, barley, corn, cotton, hay, oats, peanuts, potatoes, rice, rye, sorghum, soybean, tobacco, wheat, and miscellaneous crops). The three forest classes (oak, coniferous, and other deciduous) are each disaggregated to four biomass classes (high isoprene deciduous, low isoprene deciduous, nonisoprene deciduous, and nonisoprene coniferous) to account for understory vegetation and mixed forest types. Canopy biomass and noncanopy land cover data are provided at the county-level in the

Geoecology Data Base. The LANDSAT and Land Use/Cover Inventory is used to spatially allocate these county level data to 1/4 longitude by 1/6 latitude grid cells. A more detailed description of the methodology used to adapt these data bases for use in the biogenics emissions inventory has been documented by EPA in Appendix B.

The gridded leaf biomass and land use data are input to a SAS program (BIOMASS.SAS) created at EPA's Atmospheric Research and Exposure Assessment Laboratory (AREAL). The SAS code for this program is provided in Appendix D. This program uses the gridded leaf biomass and land use areas, biomass density factors, and growth factors to create a file of episode (e.g., month) specific leaf biomass and land use data which are subsequently used to calculate biogenic emissions estimates. Biomass for the noncanopy classes are not calculated directly since emission rates for these classes are a function of surface area instead of biomass amounts.

Seven input files are required for execution of BIOMASS.SAS: an episode file containing the month desired for biomass estimates: gridded growth factors for noncanopy vegetation; gridded biomass factors for canopy vegetation; a file containing the user specified grid origin and boundaries; and three files containing the gridded leaf biomass and land use areas for canopy, noncanopy and urban tree vegetation. Files containing the growth and biomass factors and gridded biomass areas were provided by EPA. The episode and grid origin files were created for this application.

Previous efforts indicated a possible problem in the canopy biomass factors originally provided by EPA (e.g., a high percentage of isoprene and monoterpene emissions during the winter). During the colder months, it is assumed that coniferous species retain one third to one half of their summer foliage. A review of the biomass factors by EPA revealed that deciduous and oak species within coniferous forests had been assigned foliage during the winter. Conversely, coniferous species in oak and deciduous forests were assigned no foliage during the winter. The new factors, used in the current inventory, have been corrected such that coniferous species in oak and deciduous forests are assigned foliage during the winter months and all oak and deciduous species have no foliage during the winter months.

BIOMASS.SAS execution results in three output files which are used in conjunction with species specific emission factors to calculate biogenic hydrocarbon and NO_x emissions. These include the canopy biomass, noncanopy areal coverage, and urban tree coverage. BIOMASS.SAS output for each month was checked by printing the biomass for specific geographic areas for each month and comparing the changes in biomass from month to month with expected monthly or seasonal growth patterns.

In a previous work assignment, quality control checks were performed on the leaf biomass and land use areas input to BIOMASS.SAS[20]. The focus of the quality control effort was to check the data for *reasonableness* of crop, forest and urban area distributions. The analysis utilized grid plots, statistical parameters calculated for each vegetative species, and various literature sources such as almanacs and data from the U.S. Bureau of the Census and Department of Agriculture. For canopy vegetation, additional reference materials were not available in the required time frame, and therefore, these were not compared with additional data sources. The details of this analysis have been previously documented[20]. A brief summary of the findings is presented below.

A comparison of the noncanopy vegetation distribution with selected reference information indicated that for a few crop types, the presence of specific crops in various States did not correspond to data derived from the Geoecology Data Base. For example, *Agricultural Statistics 1988*[21] indicated that rye is planted in States such as Oregon, New Jersey, Michigan, Oklahoma, Virginia, and Texas. The grid plots generated from the land use areas however, do not indicate this growth. Quality control checks indicated that the urban area distributions were valid based on urban geographic locations. The results of this analysis were submitted to EPA.

CALCULATION OF CORRECTION FACTORS

Emission rates of biogenic hydrocarbon and NO_x from soils are dependent on temperature and for isoprene, incident solar radiation intensity as well. Researchers at Washington State University have developed a Canopy Model for forested areas. In forested areas, the Canopy Model corrects for leaf temperature using the heat energy balance computed for representative levels at different heights in the forest canopy. The model applies factors to calculate leaf temperatures and leaf exposures to sunlight in eight representative layers from the forest floor through the height of the canopy. In addition to temperature and solar radiation, wind speed and relative humidity are used for calculating the heat energy balance in the canopy.

Monthly representative diurnal profiles of ambient temperature, solar radiation, wind speed and relative humidity were developed for use with the Canopy Model. The methodology for development of these data is detailed in Section 2 of this report. A SAS version of the Canopy Model (CORRECT2.SAS) was provided by EPA for use with the meteorological data profiles developed for this project. Additionally, based on additional field measurements, new soil NO_x emissions and temperature correction algorithms were provided by the National Oceanic and Atmospheric Administration (NOAA) in Boulder, CO and incorporated into the Canopy Model for this project. The SAS listing for CORRECT.SAS is provided in Appendix D.

CORRECT2.SAS utilizes gridded hourly meteorological data and calculates emissions correction factors for noncanopy, canopy, and urban tree classes. The correction factors are used to adjust mean emission rates, which are based on a temperature of 30°C, to leaf temperatures (which are in turn determined from ambient temperature). Additionally for isoprene, correction factors adjust emissions for the intensity of solar radiation (i.e., visible radiation). Noncanopy correction factors use hourly temperature data and temperature relationships from Tingey[22] to calculate correction factors for monoterpenes, alpha-pinene, and unknown hydrocarbons. For isoprene, correction factors use hourly temperature, solar insolation data, and a modified version of the Tingey curves[22] to calculate correction factors. Correction factors for forested areas use hourly temperature, wind speed, and relative humidity data to calculate correction factors at eight levels in the canopy using a heat energy balance. In addition, isoprene correction factors are also adjusted for solar intensity based on solar insolation data and location in the canopy using a modified version of the Tingey curves.

The Canopy Model algorithms are based on the assumption that ambient meteorological conditions are representative of the top of the canopy. The basis for the Canopy Model calculations is the leaf radiation balance of a typical leaf's surface using an iterative approach downward through the canopy. The total solar radiation intensity is decreased exponentially downward through the canopy as a function of the biomass distribution. The leaf temperature is calculated by a radiative balance algorithm which uses ambient temperature, total radiation, relative humidity, and wind speed and is used with Tingey's equations to calculate the correction factors.

Two files are output for use with the biomass and land use data to calculate biogenic hydrocarbon and NO_x emissions: a file of canopy emission correction factors and a file of noncanopy emission correction factors. Correction factors for a limited geographic area for each month were printed and checked to assure they followed expected diurnal and seasonal patterns.

CALCULATION OF BIOGENIC HYDROCARBON EMISSIONS

The final step for calculation of biogenic hydrocarbon and NO_x emissions (RADMBIO.SAS) uses the month specific hourly corrected emissions factors output by CORRECT2.SAS and the monthly leaf biomass and land use data generated by BIOMASS.SAS to calculate gridded hourly biogenic hydrocarbon and NO_x emissions for isoprene, monoterpenes, alpha-pinene, unknown hydrocarbons, NO and NO_2. The SAS source code listing for RADMBIO.SAS is presented in Appendix D. RADMBIO.SAS first calculates standard gridded hourly canopy and noncanopy biogenic emissions. The standard conditions are adjusted for ambient conditions using the correction factors. The canopy emissions are calculated by multiplying the layered biomass by canopy specific emission factors. Grassland NO_x emissions are calculated with the noncanopy emissions. The calculated emissions for each vegetative species are summed together such that the resultant output file contains the total emissions of isoprene, monoterpenes, alpha-pinene, unknown hydrocarbons, NO, and NO_2 for each grid cell. The final units of the output emissions data are grams per second which represents the emission rate of compound for a specific hour for a given month for that grid cell.

RADMBIO.SAS outputs a single file containing the combined canopy, noncanopy, and urban tree biogenic emissions in a format consistent for input to the Regional Acid Deposition Model. Emissions for selected geographic areas were printed and evaluated to assure they followed expected diurnal and seasonal patterns. Additionally, calculated emissions were compared with hourly correction factors to assure they followed similar behavior patterns.

SPATIAL AND TEMPORAL AGGREGATION OF EMISSIONS DATA

Hourly gridded emissions (grams per second) were generated for input to regional models such as RADM. Larger temporal and spatial scales however are required for use in emissions assessment evaluations comparing the magnitudes of anthropogenic and natural sources.

Therefore, the biogenic emissions estimates were aggregated spatially to the county and State levels (province level for Canada) and temporally to monthly, seasonal, and annual levels. Spatial aggregation of the data used a data file obtained from EPA containing the gridded land areas by county for the U.S. and by province for Canada.

Temporal aggregation to the monthly level required multiplying the resultant emissions for each hour output as grams per second by 3600 to arrive at grams per hour. Hourly emissions were summed over the twenty-four hours in each representative day for each month and multiplied by the number of days in each month. Monthly emissions, reported in grams, were converted to tons (i.e., short tons) to be consistent with anthropogenic VOC data developed for the NAPAP inventory. Seasonal emissions were obtained by summing over the three months which comprise each season. Seasonal values were summed to arrive at annual emissions values (tons/season). Later in this report, emissions data are also presented in teragrams and in kilograms/hectare for comparisons with other biogenic inventories.

Spatial aggregation of emissions to the county level required assigning the gridded emissions data to the appropriate State and county. This was accomplished using an area file provided by EPA which contained the land area of each grid cell in each county. Several adjustments to this file were required for processing and for compatibility with the NAPAP emissions inventory. These are summarized below.

For use with the NAPAP emissions inventory, the grid number and FIPS codes provided in the area file had to be converted to column and row numbers and to NEDS (AEROS) codes, respectively. Additionally, modifications to the file for Massachusetts and Virginia were required for compatibility with the NAPAP inventory. Specifically, Massachusetts counties were apportioned to Air Pollution Control Districts and Virginia Independent Cities were incorporated into the FIPAEROS file. Other minor modifications to the FIPAEROS and area files were made to discrete counties to assure compatibility.

The area file was used to calculate the fraction of each grid cell in each county for the U.S. and to calculate the fraction of each grid cell in each province for Canada. The gridded biogenic emissions were multiplied by the fraction of each grid cell in each county/province to arrive at the biogenic emissions for each county (province)/grid combination. Grid cells for each county were summed to arrive at county-level emissions. County-level emissions for each State were summed to obtain State level emissions.

Quality control checks of the spatially aggregated emissions data revealed that species specific and total biogenic hydrocarbon emissions increased slightly (<2%) as a result of the grid to county aggregation. To determine the possible source of this anomaly, the calculated land area fractions for each county were summed. Any fractions which summed to more than one at the county level were output and printed to six significant digits. Three hundred seventeen counties indicated fractions summing to greater than one. However, the excess in all cases was less than six significant digits.

SECTION 4

NATURAL PARTICULATE AND BIOGENIC EMISSIONS DATA

PARTICULATE MATTER

Natural particulate matter emissions data were calculated for three source categories in the 1985 NAPAP Emissions Inventory (Version 2).[6] These categories include unpaved road dust, wind erosion (wind blown dust), and dust devils. The methodologies used to calculate county level annual and resolved gridded hourly particulate emissions were documented with the 1985 NAPAP Version 2 inventory.[6] Improved annual emissions estimates for county-level unpaved road dust were developed for the United States following the completion of the 1985 NAPAP Emissions Inventory (Version 2). The improvements resulted from modifications of the assumptions used to specify the emission factors and improvements in the methodology applied to allocate State totals to the county-level. The change in the emissions calculation methodology involved the addition of a plume depletion factor in the emission flux algorithm. The plume depletion factor was implemented to account for the large fraction of particles less than 10 μm that fall out within several feet of the roadway and therefore are not considered to be released into the atmosphere.[23] The plume depletion factor used in these analyses was 0.1, which is based on measurements that indicate that 90% of the total mass of road dust gravitationally settles very soon (within minutes) after the road surface disturbance.

The updated annual county-level unpaved road particulate matter data for the United States were spatially resolved to the grid level, speciated into component alkaline fractions and temporally resolved to the hourly level for a typical weekday, Saturday, and Sunday in each of the four seasons. The allocation was accomplished using the Flexible Regional Emissions Data System (FREDS).[5] Tabular summaries of the revised United States natural particulate data are presented in Appendix A. An index of the pollutant identification names used as column headings in these tables is also provided in Appendix A. Tables A-1, A-2 and A-3 list the data totals by State, EPA region and source category respectively. These data supersede the data contained in Tables A-7, A-14, and A-26 in the 1985 NAPAP Emissions Inventory report.[6] Tables A-4 and A-5 for Canadian natural source particulate emissions correspond to Tables A-21 and A-31 of the NAPAP inventory report. The Canadian methodologies for estimating unpaved road dust emissions were not affected by the changes in the United States' methodology. The data in the Canadian emissions summary tables, therefore, were not modified from the Version 2 inventory report and are included here only for completeness.

Table 4-1 lists the revised tape totals for the combined U.S. and Canadian natural source particulate matter data. The data in this table update Table 9-21 from the Version 2 inventory report. It should be noted that the sum of the tape totals in Table 4-1 do not correspond to

TABLE 4-1. TAPE TOTALS FOR COMBINED U.S. AND CANADIAN NATURAL PARTICULATE SOURCES

SCENARIO	Total 01 (TSP)	Total 06 (Ca1)	Total 10 (Mg2)	Total 18 (PM1)	Total 20 (PM3)
01	187,608.01	131.86	251.56	21,414.14	24,183.44
02	178,459.87	129.75	250.02	18,692.22	22,934.11
03	167,843.65	127.49	265.44	16,171.30	30,106.20
04	242,597.35	157.09	303.60	24,561.52	30,037.22
05	232.397.34	154.70	302.53	21,526.73	28,644.80
06	215,857.30	151.43	299.91	18,613.21	27,087.52
07	268.629.95	148.45	285.16	27,536.91	33,001.41
08	257,157.65	145.78	284.04	24,124.32	32,435.94
09	241.426.12	142.54	281.72	20,916.33	30,801.23
10	210,446.00	136.69	254.06	24,041.27	26,387.67
11	200,164.98	134.30	253.06	20,982.84	24.984.84
12	185,531.81	131.33	250.85	18,096.99	23,498.16
Total	2,588,120.03	1,691.41	3,281.95	256,677.78	334,102.54

Scenarios refer to day types in the 1985 NAPAP Modelers Emissions Inventory (Version 2).
The scenarios represent the typical weekday, Saturday and Sunday in each of the four seasons.
The scenarios run from number 01 which is the winter weekday, through 12 which is the fall Sunday.

The column headings refer to the species represented: TOTAL 01 (TSP) represents total suspended particulate; TOTAL 06 (Ca1) represents calcium in the 0.0 - 2.5 micrometer diameter size range; TOTAL 10 (Mg2) represents magnesium in the 2.5 - 10.0 micrometer diameter size range; TOTAL 18 (PM1) represents total particulate in the 0.0 - 2.5 micrometer diameter size range and; TOTAL 20 (PM3) represents total particulate in the 6.0 - 10.0 micrometer diameter size range.

the annual totals presented in Appendix A as each of the scenario totals represents emissions for a given day type (weekday, Saturday, or Sunday) in each season. To arrive at an annual total, emissions for each of these day types would have to be multiplied by the number of occurrences in each season (e.g. 5 weekdays x 13 weeks per season).

The revised United States emissions estimates for natural total suspended particulate (TSP) emissions from unpaved roads is 36,922,642 TPY. The original U.S. total for unpaved road emissions in the 1985 NAPAP Emissions Inventory (Version 2) was 35,775,602 TPY (short tons). A detailed description of the revised methodology used in the development of the current version of the county-level natural particulate emissions estimates is presented elsewhere.[23] As a result of the changes in the emissions calculation methodology for unpaved road dust, the total natural particulate emissions for the U.S. increased from 50,253,334 TPY reported in the original NAPAP data[6] to 51,400,375 TPY reported in this document. Canadian natural particulate emissions remain unchanged from the NAPAP Version 2 Emissions Inventory.

BIOGENIC HYDROCARBON AND GRASSLAND NO_x EMISSIONS

Overview of Emissions Data

Hourly gridded biogenic emissions estimates were spatially aggregated to the county- and State-levels for each month and season and annually as discussed in Section 3. Seasonal and annual emissions totals for the individual hydrocarbon compounds and NO_x species are presented for both the United States and Canada in Table 4-2. These data are presented in teragrams (Tg) for comparison with previous biogenic hydrocarbon emissions data generated by Lamb, et al[1,2]. Tabular summaries of seasonal biogenic emissions estimates for the United States by State in short tons are presented in Tables A-6 through A-9 for winter, spring, summer, and autumn, respectively. Similar tables for Canada by province are presented in Tables A-10 through A-13.

The relative contributions of biogenic hydrocarbons and grassland NO_x emissions by season are shown in Figures 4-1 and 4-2 for the United States and Canada, respectively. Grassland NO_x emissions which are dependent not only on the growing season but also on temperature are zero for Canada in the winter and are very small for the spring. Figure 4-1 for the U.S. shows that approximately 50% of the biogenic hydrocarbon and natural grassland NO_x emissions occur in the summer months, approximately equal amounts in the spring and fall and much lower amounts in the winter. Figure 4-2 for Canada also shows that approximately half of the biogenic hydrocarbon emissions occur in the summer months with almost equal amounts in the spring and fall and much lower amounts in the winter. Grassland NO_x emissions for Canada (Figure 4-2) occur mainly in the summer (84%) with most of the remainder occurring in the fall (16%) and less than 0.1% (1.83 tons) occurring in the spring.

TABLE 4-2. BIOGENIC HYDROCARBON AND GRASSLAND NO_x EMISSIONS SUMMARY

	Seasonal Emissions (Tg)				
	Winter	**Spring**	**Summer**	**Fall**	**Annual**
U.S. Sources					
isoprene	0.02	0.72	2.36	0.69	3.79
alpha-pinene	0.23	0.68	1.50	0.70	3.11
other monoterpenes	0.22	0.67	1.54	0.69	3.12
unknown hydrocarbons	0.27	1.83	4.64	2.04	8.78
total hydrocarbons	0.74	3.90	10.04	4.12	18.8
Grassland NO *	2.4×10^{-3}	0.043	0.12	0.048	0.21
Grassland NO_2	2.2×10^{-4}	4.0×10^{-3}	0.01	4.4×10^{-3}	0.019
total NO_x	2.6×10^{-3}	0.047	0.13	0.052	0.23
Canadian Sources					
isoprene	0	0.02	0.38	0.08	0.48
alpha-pinene	0.14	0.38	0.93	0.40	1.85
other monoterpenes	0.12	0.36	0.95	0.38	1.81
unknown hydrocarbons	0.12	0.41	1.51	0.51	2.55
total hydrocarbons	0.38	1.17	3.77	1.37	6.69
Grassland NO *	0	1.5×10^{-6}	2.5×10^{-3}	5.0×10^{-4}	3.0×10^{-3}
Grassland NO_2	0	1.3×10^{-7}	2.3×10^{-4}	4.6×10^{-5}	2.8×10^{-4}
total NO_x	0	1.6×10^{-6}	2.7×10^{-3}	5.5×10^{-4}	3.3×10^{-3}

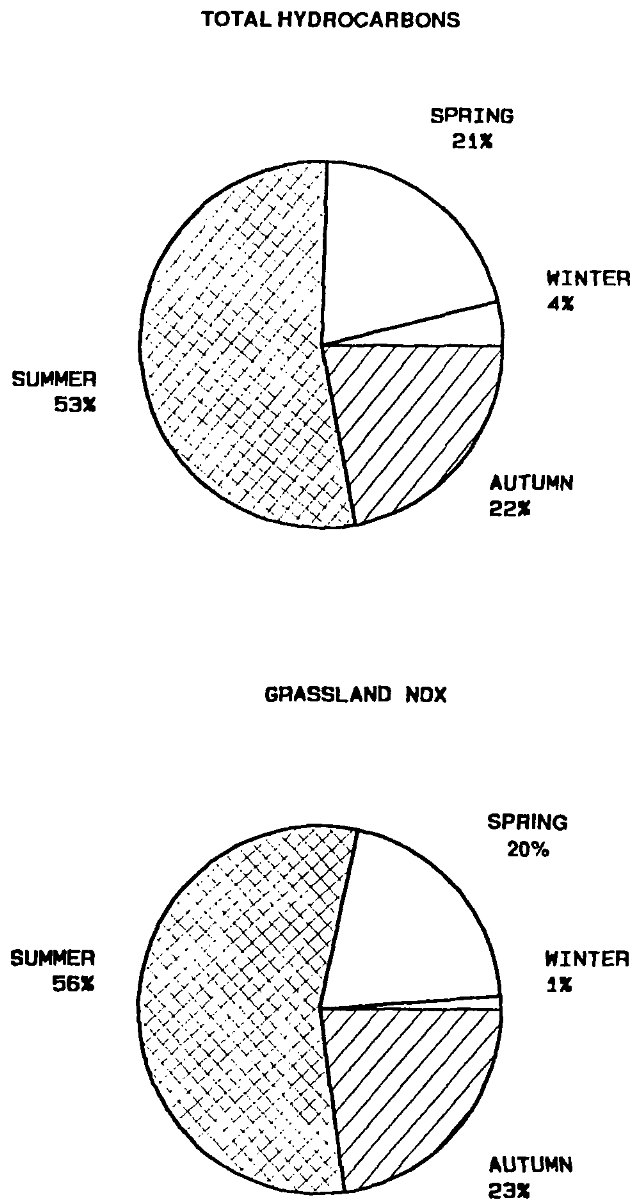


Figure 4-1. Seasonal Distribution of Total Biogenic Hydrocarbon and Grassland NO_X for the United States.

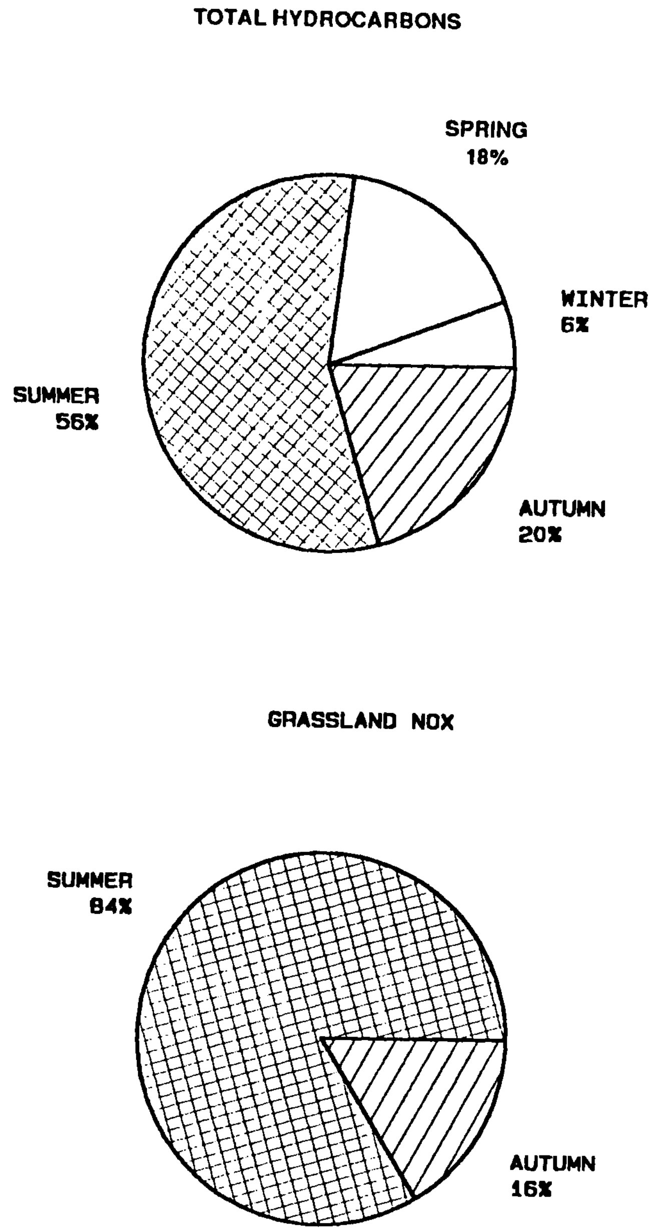


Figure 4-2. Seasonal Distribution of Total Biogenic Hydrocarbon and Grassland NO_x for Canada.

Figures 4-3 and 4-4 are pie charts that show the percent of total hydrocarbon represented by each of the hydrocarbon species in the four seasons for the United States and Canada, respectively. The data for the United States show a much lower contribution of isoprene in the winter months relative to the other seasons. Isoprene emissions result primarily from deciduous tree species in forest canopies, and therefore the contribution is lower in winter months relative to the other seasons since deciduous biomass is assumed to be zero between the first and last frost dates. The relative Figure 4-3 contribution of isoprene to the total biogenic hydrocarbon is nearly the same for the spring and fall, greater for summer and a minimum in the winter. Isoprene emissions from deciduous trees are dependent on the incident solar radiation intensity and therefore have a maximum emission rate with warm temperatures and maximum solar intensity which occur during the summer months.

The contribution of alpha-pinene and other monoterpenes to the total hydrocarbon emissions *is higher in the winter months relative to the other seasons in the United States, while the* relative contribution of alpha-pinene and other monoterpenes is similar throughout each of the other three seasons. High winter alpha-pinene and other monoterpenes result from the large contribution by coniferous tree species, especially in the south where the climate is relatively moderate during the winter months.

The distribution of species for Canada by season exhibits a different pattern as is evident from Figure 4-4. The Canadian data show no contribution of isoprene to the total biogenic hydrocarbon emissions in the winter. The maximum isoprene contribution to total biogenic hydrocarbon occurs in the summer, as would be expected, followed by the fall and then spring. The relative distribution of alpha-pinene and other monoterpenes remains relatively constant over the winter and spring in Canada and decreases in the summer and fall as the contribution of isoprene and unknown hydrocarbons to total biogenic hydrocarbon increases. This trend is similar to that observed in the United States where the contribution of alpha-pinene and other monoterpenes to total biogenic hydrocarbons is higher in the winter months than in the summer. During the spring and fall however, the relative contribution of alpha-pinene and other monoterpenes to total hydrocarbon in Canada is higher than in the U.S. as more deciduous foliage is present in the U.S. in the fall and spring.

Biogenic hydrocarbon emissions calculated for this project were compared with those developed by Lamb, et al[1,2]. The first generation biogenic emissions inventory was developed during the earlier portion of the NAPAP study[1]. For this inventory, emissions data developed by Zimmerman[24] were used to determine arithmetic mean emission rates for isoprene, alpha-pinene, and other hydrocarbons. Emissions were adjusted to temperature and light intensity using the Tingey relationships.[22] Land use and climatic data were obtained from the Geoecology Data Base.[17] Mean county monthly temperatures were used and 15 hours of daylight was assumed for the summer and 9 hours for the winter. For deciduous and noncanopy species, growth was assumed to occur between the last and first frost dates.

For the second generation inventory, data from a number of field and laboratory experiments were used to develop emission rate algorithms for isoprene, monoterpenes, and other

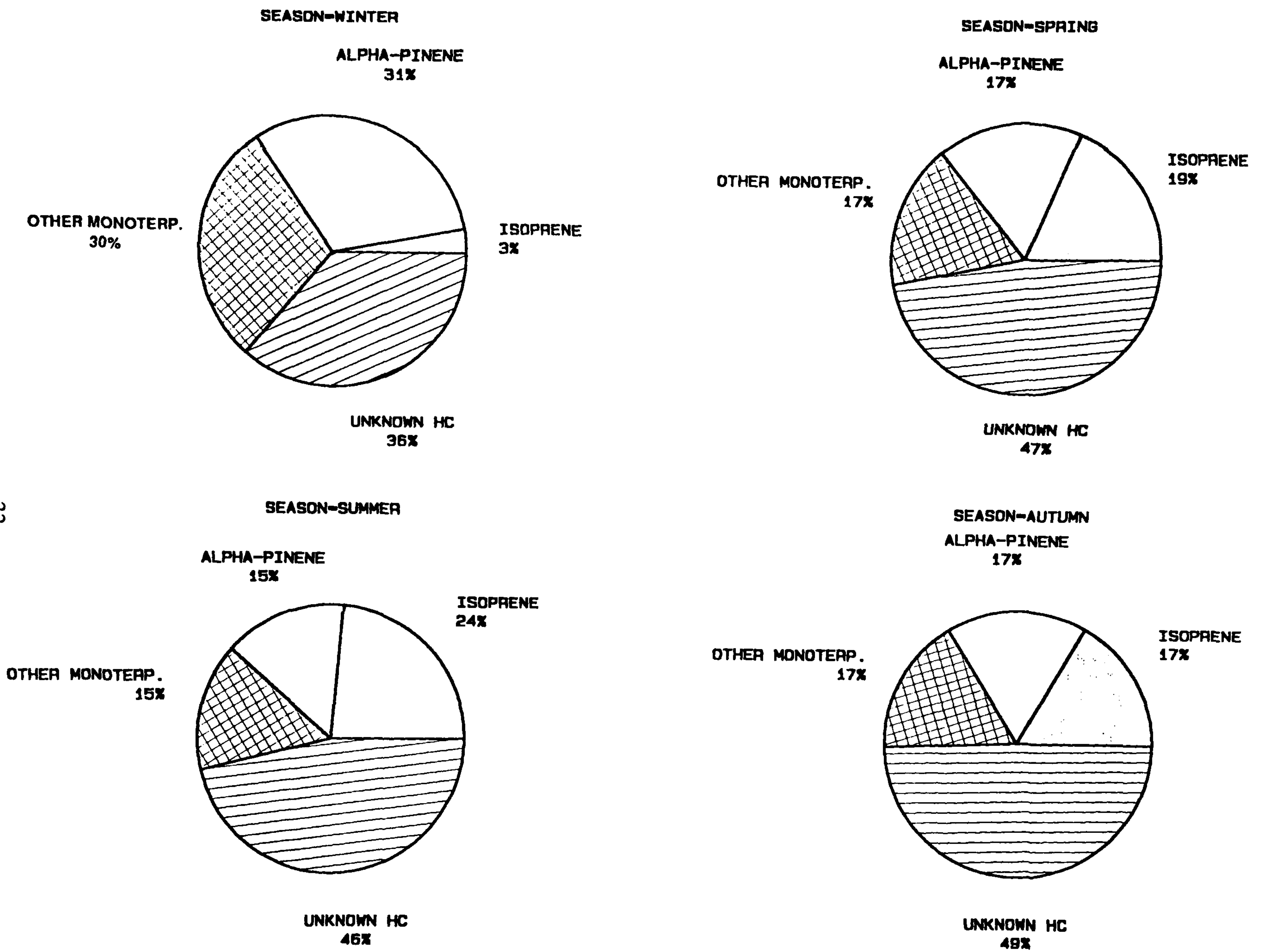


Figure 4-3. Distribution of Biogenic Hydrocarbon Components for Each Season for the United States.

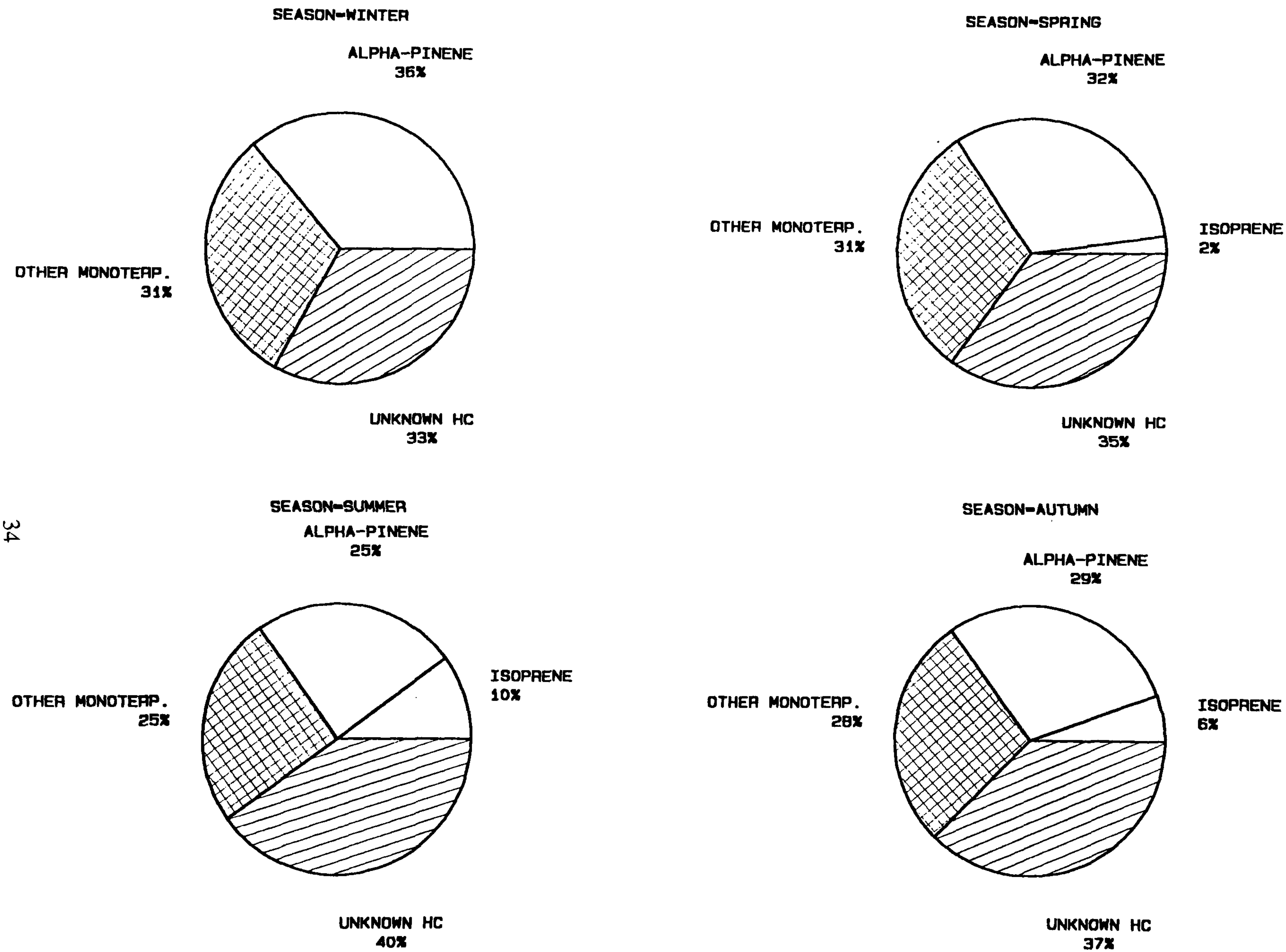


Figure 4-4. Distribution of Biogenic Hydrocarbon Components for Each Season for Canada.

hydrocarbons. Mean maximum and minimum monthly temperatures for state climatic divisions from the Geoecology Data Base were used to generate diurnal profiles and solar radiation was calculated seasonally for each climatic division. In addition, a canopy model was developed for calculation of emissions within the forest canopy.

In the third generation inventory[2], geometric mean emission rates were calculated from Zimmerman's[24] data and corrected to ambient conditions using Tingey's relationships.[22] Mean monthly maximum and minimum temperature by state climatic division were used for this inventory.

Data from the three generations of biogenic hydrocarbon emissions inventories developed by Lamb, et al[1,2] yielded total annual biogenic hydrocarbon emissions of 30.7, 19, and 27 Tg, respectively. Total hydrocarbon emissions calculated for this project are 18.8 Tg annually. A comparison of seasonal totals from the first and third generation inventories with those from the current project is presented in Table 4-3. The data in this table indicate that in all cases, seasonal data reported by Lamb, et al are higher than those determined in the current effort. On a percentage basis however, the relative seasonal contributions from the first generation inventory are very similar to those developed for this project. The relative seasonal contributions for the third generation inventory are also similar with the exception of the spring and fall. In the first generation and current inventory, the contribution to total annual hydrocarbons is greater in the fall than the spring. In the third generation inventory, the reverse is true.

what about excellent comparison w. 2nd generation.

Compound specific data are presented in Table 4-4 for the first and third generation inventories and for the current effort. The data in this table indicate fewer similarities among the inventories on a compound specific basis. In all cases, the contribution by unknown or "other" hydrocarbons is the greatest.

Differences in the magnitudes of emissions are most likely due to several factors including differences in emission factors, input climatological data, and growth and biomass factors. A detailed sensitivity study would be required to determine the predominant factors influencing these differences. A qualitative comparison of data used in each of these studies indicates that biogenic hydrocarbon emissions are very sensitive to biomass growth assumptions and climatological data. Additionally, as noted by Lamb, et al[1,2] the uncertainty in these estimates due to the emissions algorithms, emissions rate measurements, biomass densities and land use areas is approximately a factor of 3.

Gridded emissions of isoprene, monoterpenes, alpha-pinene, unknown hydrocarbons, and total hydrocarbons for the summer are presented graphically in Figures 4-5 through 4-9. Corresponding graphical representations of gridded annual total biogenic hydrocarbons and grassland NO_x are presented in Figures 4-10 and 4-11, respectively. The resolution of the data presented in the seasonal maps (Figures 4-5 through 4-9) are expressed in kilograms per

TABLE 4-3. SEASONAL TOTALS FOR BIOGENIC EMISSIONS INVENTORIES

	1st Generation Inventory[1]		3rd Generation Inventory[2]		Current Effort	
	Tg	%	Tg	%	Tg	%
Winter	1.50	4.9	0.97	3.5	0.74	3.9
Spring	6.00	19.5	5.89	21.5	3.90	20.8
Summer	15.90	51.8	16.15	59.0	10.04	53.4
Fall	7.30	23.8	4.35	16.0	4.12	21.9
TOTAL	30.70	100.0	27.36	100.0	18.80	100.0

TABLE 4-4. COMPOUND SPECIFIC ANNUAL TOTALS FOR BIOGENIC EMISSIONS INVENTORIES

	1st Generation Inventory[1]		3rd Generation Inventory[2]		Current Effort	
	Tg	%	Tg	%	Tg	%
isoprene	5.10	16.6	7.45	27.2	3.79	20.2
alpha-pinene	6.60	21.5	4.36	15.9	3.11	16.5
other monoterpenes	--[3]	--	6.23	22.8	3.12	16.6
unknown hydrocarbons	19.0	61.9	9.32	34.1	8.78	46.7
TOTAL	30.7	100.0	27.36	100.0	18.80	100.0

[1]Lamb, et al, 1987
[2]Lamb, et al, 1990
[3]Other monoterpenes are not reported in this inventory

hectare (kg/ha) for the 91 days representing the summer season, and the annual maps (Figures 4-10 and 4-11) of total hydrocarbon and NO_x are totals for all four seasons combined. The grid system in these plots have approximate 80 x 80 km grid cell dimensions.

Gridded isoprene emissions (Figure 4-5) for the summer indicate a large area of maximum isoprene in the southeastern U.S. Smaller areas of maxima are also found in California, Arizona, and Texas. These maxima correspond to areas of maximum coverage of oak and deciduous species reported in the Geoecology Data Base. Additionally, the southern areas of the U.S. report the warmest temperatures and receive the maximum solar insolation, especially during the summer. Minimum isoprene emissions were calculated for Alberta, Saskatchewan, Minnesota, and Iowa.

Gridded summer emissions of alpha-pinene and other monoterpenes (Figures 4-7 and 4-6, respectively) exhibit almost identical patterns for the summer. Maximum emissions of alpha-pinene and other monoterpenes are located in much of the Pacific Northwest (British Columbia, southwestern Alberta, Washington, Idaho, western Montana, Oregon, and northern California) and portions of Ontario, Quebec, Oklahoma, Texas, Louisiana, and Georgia. These calculated maxima correspond to large areas of coniferous canopy coverage reported in the Geoecology Data Base. Minimum values for alpha-pinene and other monoterpenes are found in eastern Alberta and Saskatchewan, coinciding with areas of minimal coniferous coverage.

Maximum unknown hydrocarbon emissions for the summer (Figure 4-8) are found in much of the southeastern and midwestern States. Emissions of unknown hydrocarbons may be influenced by emissions from crops in these agricultural areas. This may be particularly true for corn due to its relatively large emission factor. Minima for unknown hydrocarbons are located in Eastern Alberta and Saskatchewan. These minima correspond to areas of sparse canopy coverage for all forest types.

Figure 4-9 exhibits gridded biogenic emissions of total hydrocarbons for the summer. Areas of maximum emissions correspond well with areas of high isoprene (Figure 4-5) and unknown hydrocarbon (Figure 4-8) emissions. A comparison of Figure 4-9 with the county averaged hydrocarbon flux (kg/ha) for the summer reported by Lamb, et al[1] indicates similar patterns of maxima; however, the magnitudes reported by Lamb, et al are higher by a factor of about 1.5. Additionally, areas of maximum total hydrocarbon emissions in Iowa and Illinois, shown in Figure 4-9, do not coincide with emissions in these states reported by Lamb, et al.

Annual gridded total biogenic hydrocarbon emissions (Figure 4-10) exhibit similar patterns of maxima and minima as summer isoprene and total hydrocarbon emissions (Figures 4-5 and 4-9, respectively). This also corresponds to the maximum contribution of summertime biogenic hydrocarbon emissions to total hydrocarbons, presented in Figure 4-1. A maximum contribution of summertime hydrocarbon emissions to total hydrocarbons results from a maximum vegetation growth, warmer temperatures, and maximum solar insulation.

Figure 4–5 Seasonal Gridded Biogenic Emissions of Isoprene for Summer

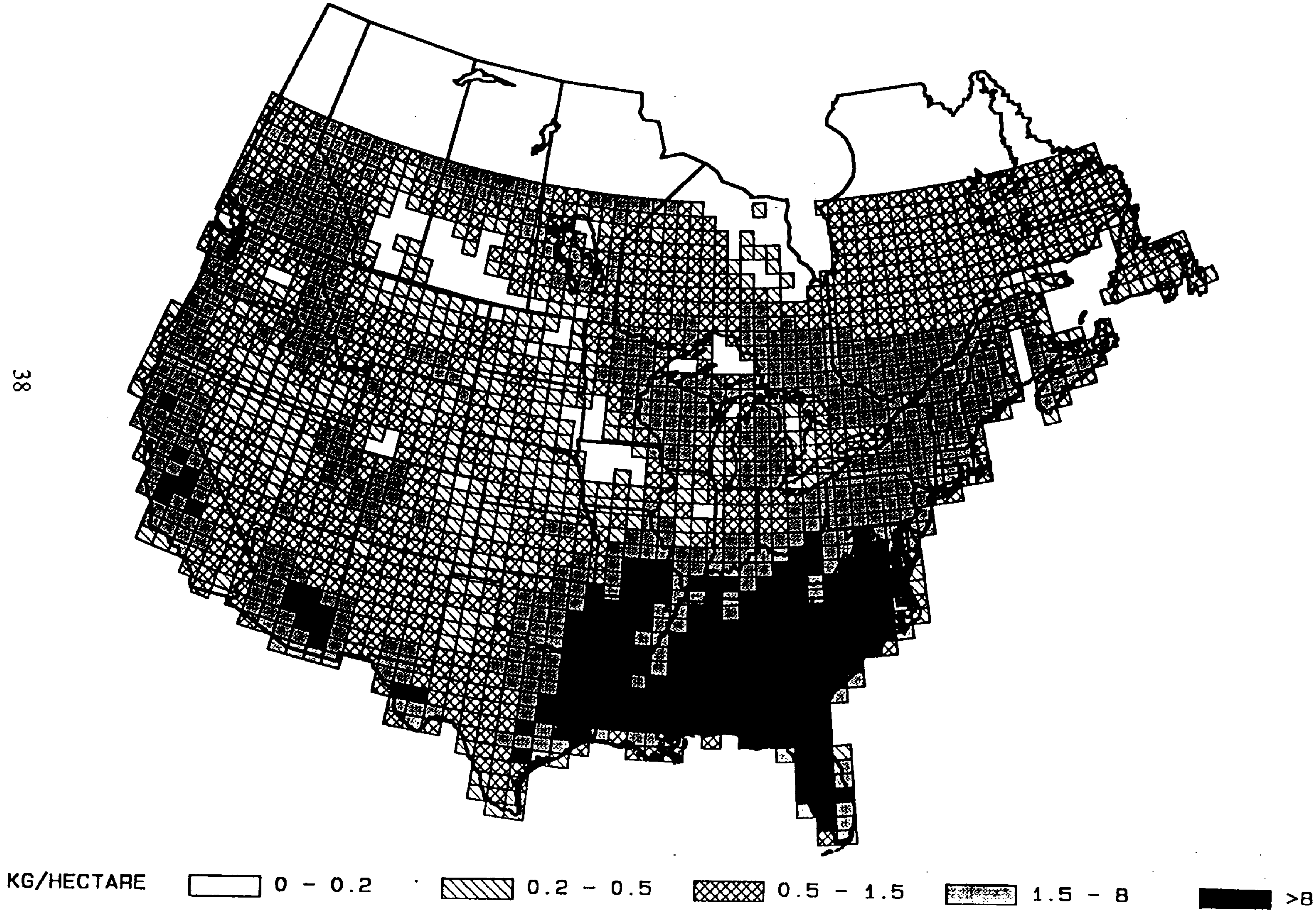


Figure 4–6 Seasonal Gridded Biogenic Emissions of Other Monoterpenes for Summer

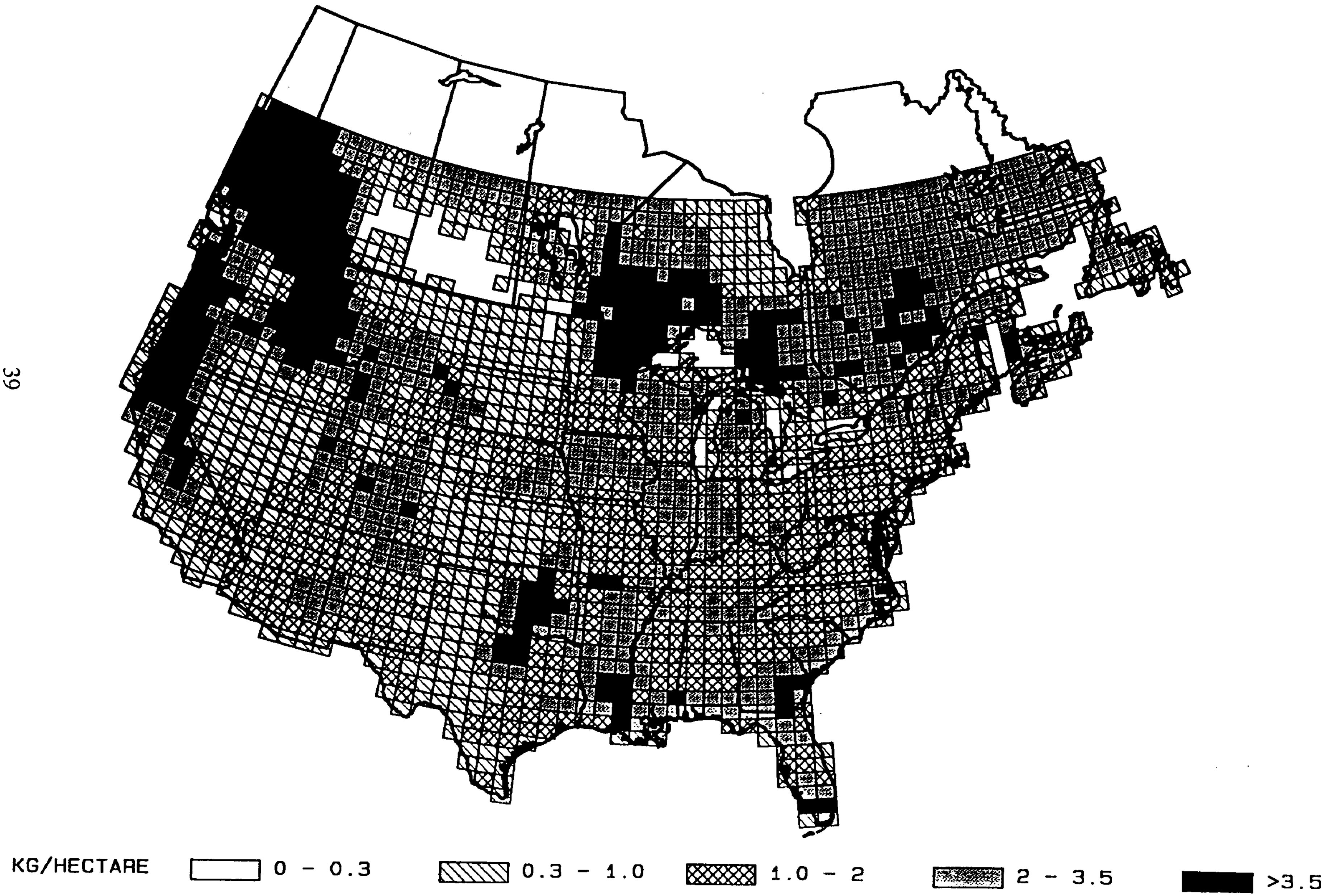


Figure 4-7 Seasonal Gridded Biogenic Emissions of Alpha-pinene for Summer

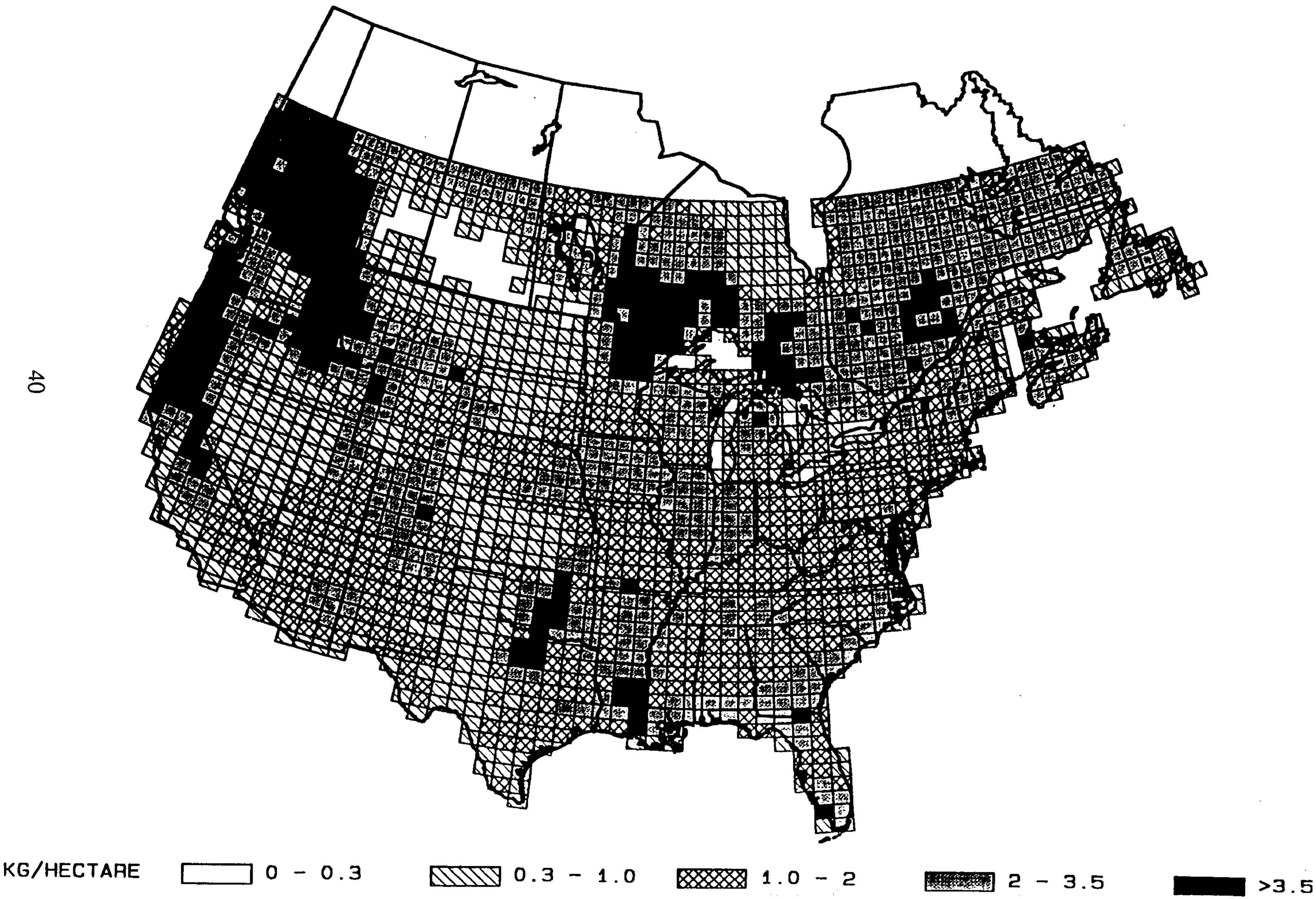


Figure 4 8 Seasonal Gridded Biogenic Emissions of Unknown HC
for Summer

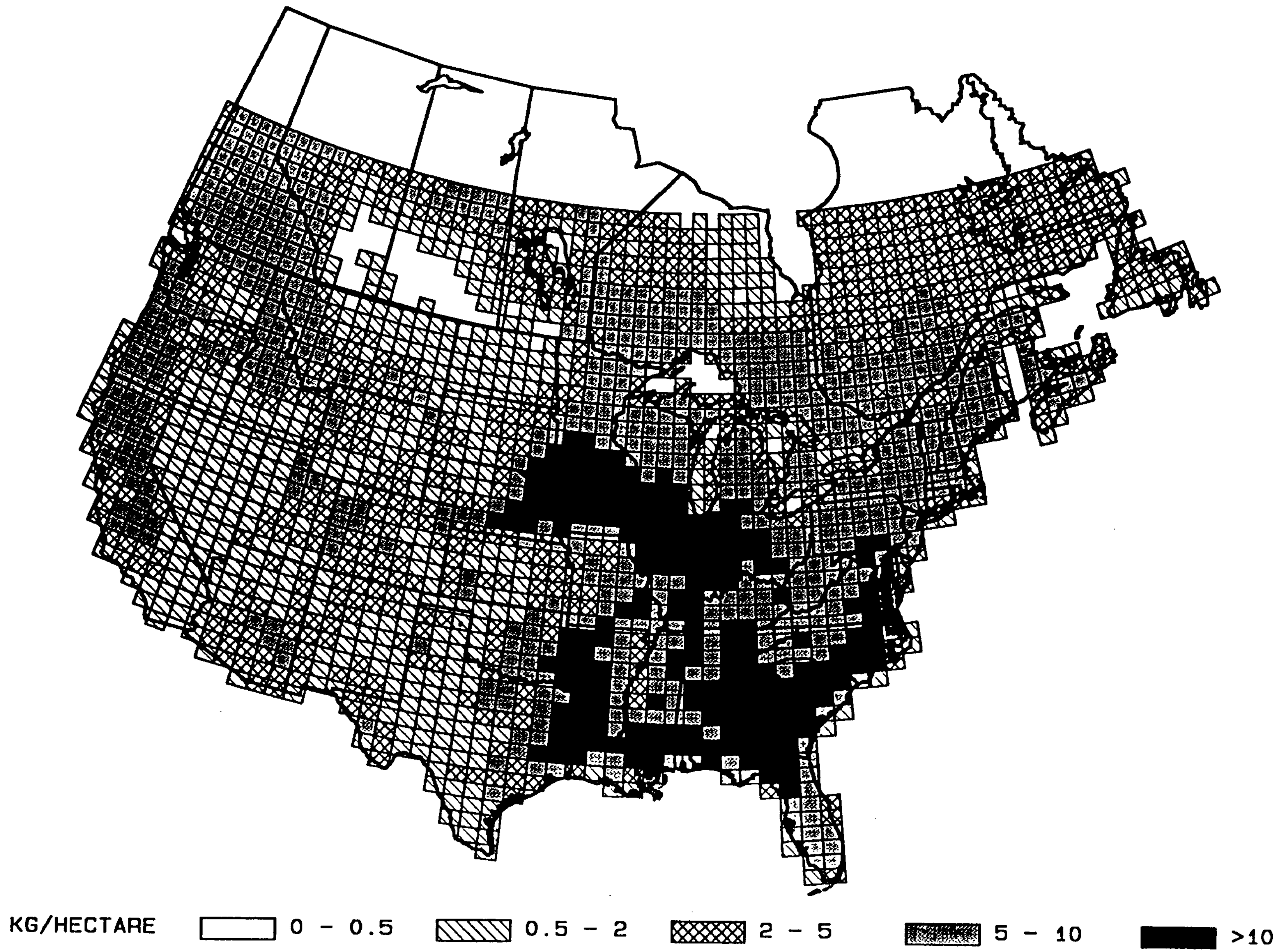


Figure 4–9 Seasonal Gridded Biogenic Emissions of Total Hydrocarbons for Summer

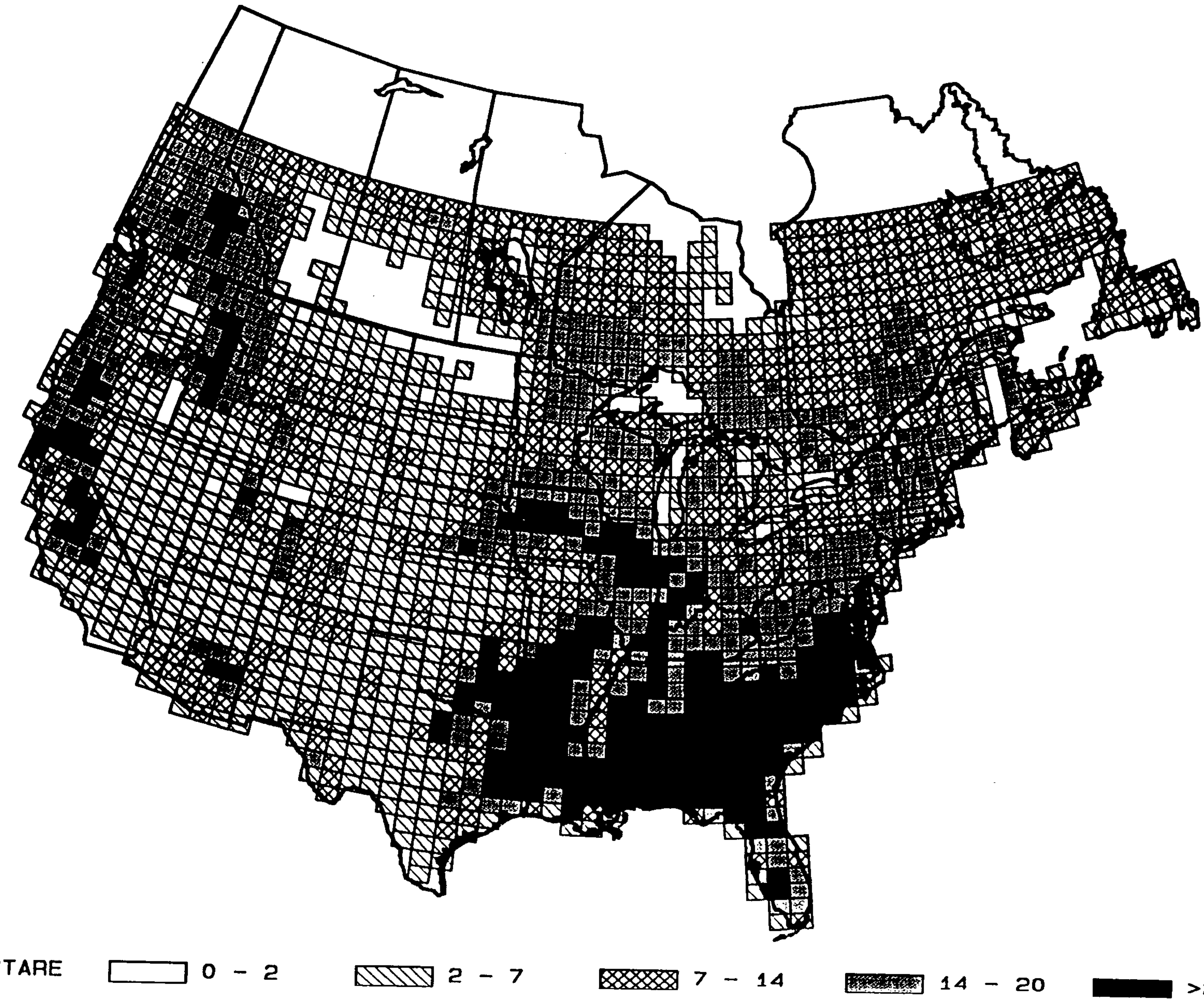
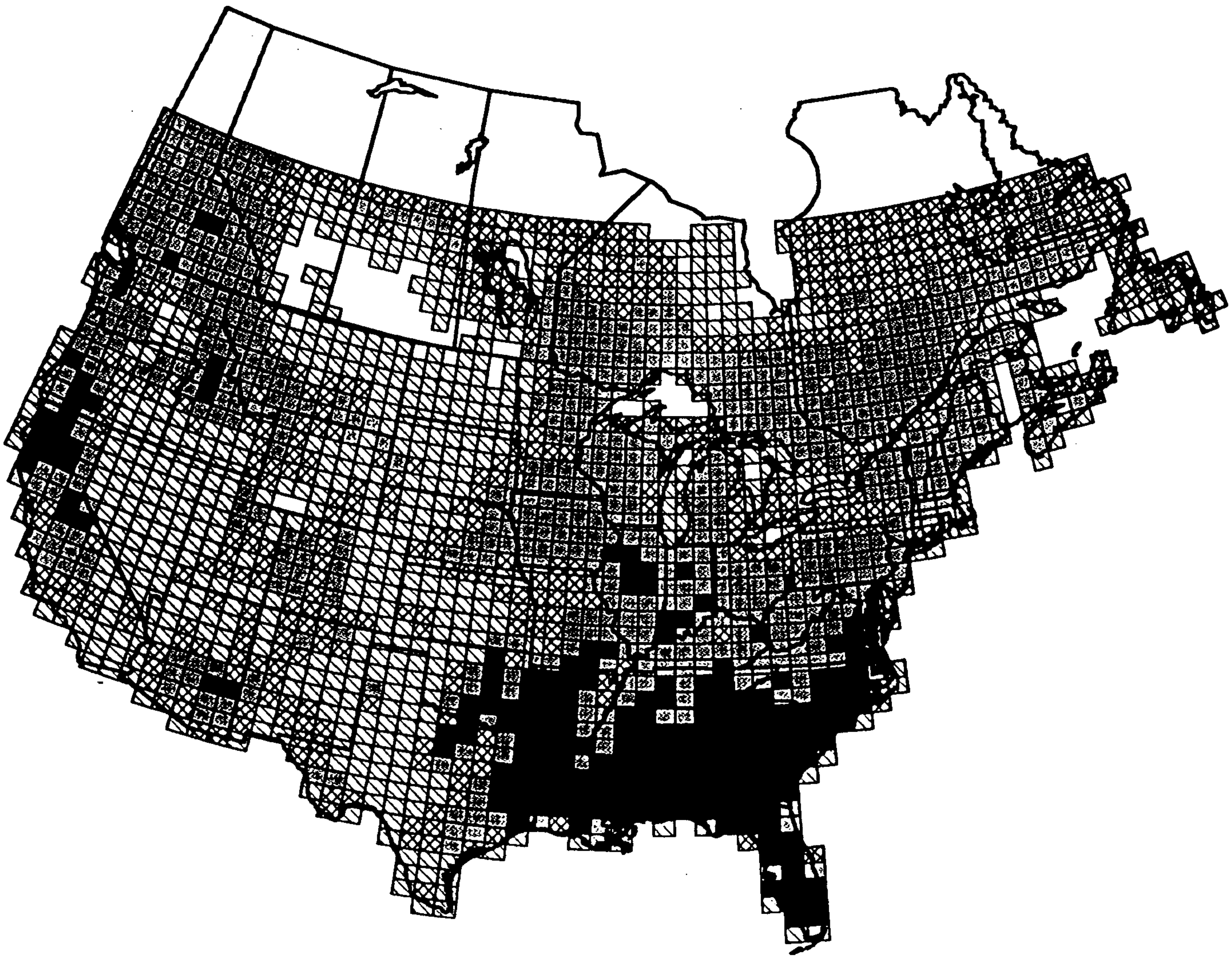


Figure 4-10 Annual Gridded Biogenic Emissions of Total Hydrocarbons



Annual grassland NOx emissions (Figure 4-11) show maxima in the plain States and eastern Texas. These maxima coincide well with grassland areas reported in the Geoecology Data Base.

Seasonal and State/Province Emissions Data

Seasonal state-level totals calculated for the winter months (Tables A-6 and A-10) indicate that States and provinces with the larger land areas generally contain higher State level total biogenic hydrocarbon emissions. In order of decreasing emissions, the States/provinces with the highest biogenic hydrocarbon emissions totals for the winter are: British Columbia (113,211 tons/year), Quebec (108,685 tons/year), Florida (106,263 tons/year), California (80,878 tons/year), and Ontario (74,938 tons/year). Biogenic hydrocarbon emissions from these five States/provinces account for 40% of the total hydrocarbon emissions for the winter season.

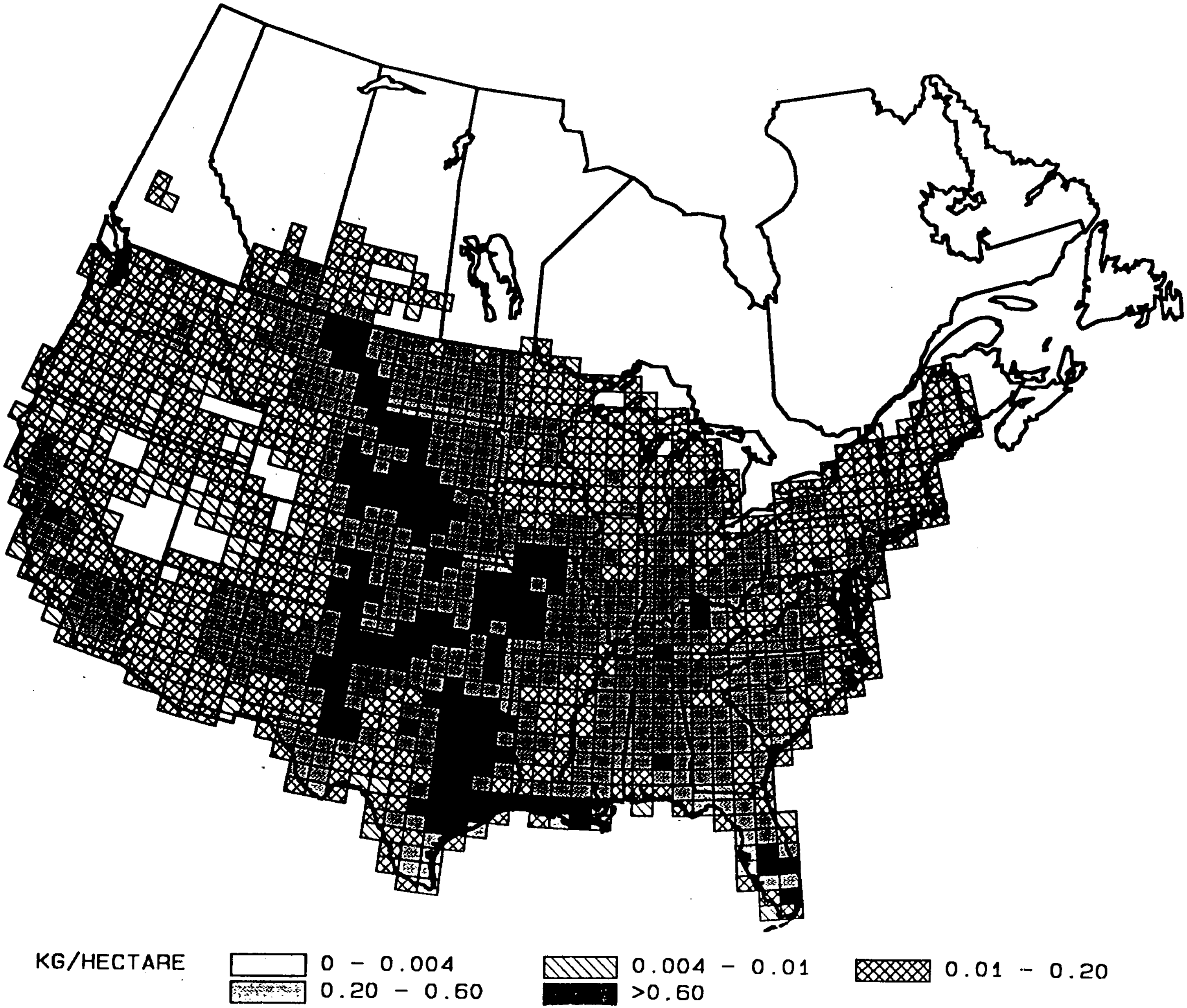
Contributions from each of the individual hydrocarbon species to maximum total hydrocarbon emissions for each of the five States or provinces noted above was evaluated. For British Columbia, Quebec, California, and Ontario, alpha-pinene, other monoterpenes, and unknown hydrocarbons each contribute approximately one third to the total hydrocarbon in winter. In California, isoprene contributes <0.1% while in Florida the contribution of isoprene is about 16%. The Canadian provinces report zero isoprene emissions for the winter. In Florida alpha-pinene and other monoterpenes each contribute just under 20% and the contribution from unknown hydrocarbons is about 50% of the total winter hydrocarbon emissions.

Locations of maxima for each hydrocarbon species during the winter are: Florida for isoprene (71.2% of total isoprene); British Columbia for monoterpenes (9% of total monoterpenes); Quebec for alpha-pinene (11% of total alpha-pinene); Florida for unknown hydrocarbons (12% of total unknown hydrocarbons); and Texas for NO_x (41% of total grassland NO_x). In the U.S., maximum State-level monoterpene and alpha-pinene emissions during the winter are found in California.

Seasonal State-level totals calculated for the spring (Tables A-7 and A-11) indicate that geographic location (e.g., latitude) and total land area are determining factors for States and provinces with maximum biogenic hydrocarbon emissions. In order of decreasing emissions, the States/provinces with the highest biogenic hydrocarbon emissions totals for the spring are: Quebec (365,668 tons/year), Texas (328,309 tons/year), Ontario (305,041 tons/year), Georgia (257,274 tons/year), British Columbia (255,214 tons/year), and Florida (252,376 tons/year). Biogenic hydrocarbon emissions from these six States/provinces account for 32% of the total hydrocarbon emissions for the spring season.

Contributions from each of the four hydrocarbon species analyzed to maximum total hydrocarbon emissions in the spring for each of the six States or provinces noted above were

Figure 4—11 Annual Gridded Biogenic Emissions of Grassland NOx



evaluated. Quebec, Ontario, and British Columbia show similar contributions, of about one third, for alpha-pinene, other monoterpenes, and unknown hydrocarbons. For Quebec and Ontario, there is also a 3% contribution from isoprene. In Texas, Georgia, and Florida, the maximum contribution to total hydrocarbon is from unknown hydrocarbons (43, 50, and 46 percent, respectively). The contributions from alpha-pinene and other monoterpenes are almost equal within each of the three States: alpha-pinene = 18% and monoterpenes = 17% for Texas; alpha-pinene = 10% and monoterpenes = 10% for Georgia; alpha-pinene = 13% and monoterpenes = 13% for Florida.

Locations of maxima by individual hydrocarbon species during the spring are: Georgia for isoprene (10% of total isoprene); Quebec for alpha-pinene and other monoterpenes (10% of total alpha-pinene and 10% of total other monoterpenes); Texas for unknown hydrocarbons (6% of total unknown hydrocarbons); and Texas for grassland NO_x (21% of total grassland NO_x). For the U.S., maximum State-level monoterpenes and alpha-pinene are each found in Texas.

Isoprene values for Canada (Table A-11) for the spring indicate zero values for the western provinces (Manitoba, Saskatchewan, Alberta, and British Columbia). A review of the monthly canopy biomass factors indicated that during the spring there is no growth for oak and deciduous species above row 145 (this corresponds to the U.S.-Canadian border west of Ontario). Therefore, eastern provinces with land area below row 145 may exhibit some isoprene during the spring months, while provinces in western Canada have zero emissions for isoprene.

During the summer months, calculated seasonal State level totals (Tables A-8 and A-12) indicate that total land area is an important determinant for maximum State level biogenic hydrocarbon emissions. In order of decreasing emissions, the States/provinces with the highest biogenic hydrocarbon emissions totals for the summer are: Quebec (1,232,164.8 tons/year), Ontario (1,062,365 tons/year), Texas (664,763 tons/year), British Columbia (637,676 tons/year), and California (570,154 tons/year). Biogenic hydrocarbon emissions from these five States/provinces account for 27% of the total hydrocarbon emissions for the summer.

Contributions from each of the four hydrocarbon species analyzed to the above States/provinces varies for the U.S., but shows similar patterns for the three Canadian provinces. In Quebec, Ontario, and British Columbia, about 10% of the total hydrocarbon emissions are isoprene, about 25% each are monoterpenes and alpha-pinene, and the remaining 40% are unknown hydrocarbons. In California, the breakdown of hydrocarbons is 22% isoprene, 20% monoterpene, 20% alpha-pinene, and 38% unknown hydrocarbons. In Texas, 31% of total hydrocarbons are isoprene, 15% alpha-pinene, 16% other monoterpenes, and 38% an unknown hydrocarbons.

Locations of maxima for individual species for the summer are: Texas for isoprene (7% of total isoprene), Quebec for monoterpenes (11% of total monoterpenes), alpha-pinene (11.5%

of total alpha-pinene), and unknown hydrocarbons (7% of total unknown hydrocarbons), and Texas for grassland NO_x (13% of total grassland NO_x). For the U.S., maximum State level monoterpene and alpha-pinene emissions occur in California and maximum unknown hydrocarbon emissions occur in Illinois.

Seasonal State level totals for the autumn, (Tables A-9 and A-13), indicate that geographic location (e.g., latitude) and total land area are important determinants for maximum State/province level total biogenic hydrocarbon emissions. In order of decreasing emissions, the States/provinces with the highest total biogenic hydrocarbon emissions are: Quebec (474,278 tons/year), Ontario (373,239 tons/year), Texas (321,371 tons/year), Florida (271,348 tons/year), and Georgia (265,150 tons/year). Biogenic hydrocarbon emissions from these five States/provinces account for 28% of the total hydrocarbon emissions for autumn.

Contributions from each of the individual hydrocarbon species to maximum total hydrocarbon emissions for the States/provinces discussed in the previous paragraph indicate similar species distributions among the two Canadian provinces and for the three States. Individual species contributions to total biogenic hydrocarbons however indicate marked differences between the U.S. and Canada for the five maxima. In Quebec and Ontario, a little more than one quarter of the biogenic hydrocarbon emissions are each alpha-pinene and other monoterpenes, about 5% are isoprene, and the remaining 35-40% are unknown hydrocarbons. In Florida and Georgia, about 25% of the biogenic hydrocarbon emissions are isoprene, about 10-15% each are alpha-pinene and other monoterpenes, and approximately 50% are unknown hydrocarbons. In Texas, 20% of the hydrocarbon emissions are comprised of isoprene, alpha-pinene and other monoterpenes each contribute just under 20%, and about 45% are unknown hydrocarbons.

Locations of maxima for individual species for the autumn are: Alabama for isoprene (8.5% of total isoprene), Quebec for monoterpenes, alpha-pinene, and unknown hydrocarbons (11.3% of total monoterpenes; 11.6% of total alpha-pinene; and 6% of total unknown hydrocarbons), and Texas for grassland NO_x (19.4% of total grassland NO_x). In the U.S., maximum State-level monoterpenes occur in California and Texas. Alpha-pinene and unknown hydrocarbon maxima occur in Georgia and Texas.

SECTION 5

SUMMARY AND RECOMMENDATIONS

SUMMARY

The objective of the work documented in this report is to develop county and State-level emissions inventories of biogenic hydrocarbon and NO_x emissions representative of the monthly, seasonal and annual temporal scales. The intended application of these inventories is primarily to support assessment activities. The methodology followed to achieve this objective was to calculate gridded hourly biogenic emissions for a representative day in each month and to sum these emissions to larger temporal and geographic scales. This methodology is closely related to similar work that has been performed by EPA's Atmospheric Research and Exposure Assessment Laboratory (EPA AREAL) to develop gridded emissions inventories of biogenic hydrocarbons for specific episodic cases in support of RADM and ROM model evaluation studies.

Biogenic hydrocarbon emissions have been shown to be strongly influenced by environmental factors such as ambient temperature and solar radiation. To address these dependencies, a Canopy Model was developed by researchers at Washington State University. As part of this current project, diurnal profiles of temperature, solar radiation, wind speed, and relative humidity were developed for use with the Canopy Model. The methodology and detailed processes for developing these data on the appropriate temporal and spatial scales is documented in Section 2 of this report.

Biogenic hydrocarbon emissions were calculated for each hour of a typical day for each month using gridded leaf biomass and land use data, biomass and growth factors, species specific emissions factors, and the Canopy model. A summary of this methodology and the procedures used to temporally and spatially aggregate the data can be found in Section 3 of this report. Use of representative monthly diunal profiles of meteorological data represent a refinement over the monthly and seasonal average meteorological data used in previous studies.

A summary of the resultant emissions data at the seasonal and annual levels is provided in Section 4. The data summaries indicate that biogenic hydrocarbon emissions and NO_x are highest during the summer and lowest during the winter. For the spring and fall, the magnitudes of the biogenic emissions are similar for the U.S. In Canada, biogenic hydrocarbon emissions are higher in the fall than in the spring. Analysis of State-level seasonal totals indicates that during the winter and summer, total State land area appears to be the controlling factor in determining States and provinces with the highest biogenic hydrocarbon emissions magnitudes, although, emissions are also dependent on the canopy foliage biomass. In the spring and fall, land area as well as geographic location appear to be important.

RECOMMENDATIONS

Recommendations for future efforts include additional quality control checks and analyses to evaluate the characteristics and distributions of biogenic hydrocarbon emissions at the monthly, seasonal and annual temporal scales and at the grid, county, and State levels. Specifically, the relationship between forest and other biomass data that is used in the calculations should be reviewed carefully and compared with the resulting emissions estimates. An evaluation of canopy biomass growth factors for the spring should also be undertaken to determine validity of zero isoprene emissions calculated for the western provinces during the spring.

Sensitivity studies to determine the effects of the various biogenic inputs on the emissions calculations should also be undertaken. For example, comparison of data generated from a previous project with the results of this effort have indicated the impacts of monthly canopy biomass factors on biogenic hydrocarbon emissions. This study would allow a more detailed analysis of differences in the current and previous inventories noted in Section 4.

Further research should be conducted to determine if this or a similar methodology could be applied to develop emissions inventories of biogenic hydrocarbons and soil NO_x at global scales in support of global change studies. Additionally, NO_x emissions in the biogenic inventory should be expanded to include other natural sources such as other land use areas, biomass burning, and lightning.

Other possible improvements to the biogenic hydrocarbon and NOx emissions estimation methodology include: the use of updated land use data; investigation of improved growth factors and physiological relationships; identification of unknown hydrocarbon compounds; and expanding the soil NOx emissions algorithms to include other land use types (e.g., forest land and fertilized crop land).

SECTION 6

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APPENDIX A

BIOGENIC EMISSIONS DATA SUMMARIES

KEY TO APPENDIX A TABLES

Column Headings	Description
TSP	total suspended particulate
CA1	calcium, 0.0 2.5 micrometer
CA2	calcium, 2.5 - 10.0 micrometer
CA3	calcium, > 10 micrometers
K1	potassium, 0.0 2.5 micrometer
K2	potassium, 2.5 - 10 micrometer
K3	potassium, > 10 micrometer
MG1	magnesium, 0.0 - 2.5 micrometer
MG2	magnesium, 2.5 - 10 micrometer
MG3	magnesium, > 10 micrometer
NA1	sodium, 0.0 2.5 micrometer
NA2	sodium, 2.5 - 10 micrometer
NA3	sodium, > 10 micrometer
PM1	total particulate, 0.0 2.5 micrometer
PM2	total particulate, 2.5 6.0 micrometer
PM3	total particulate, 6.0 10.0 micrometer
isoprene	isoprene, 2-methyl-1,3-butadiene $CH_2{:}CHC(CH_3){:}CH_2$
alpha-pinene	$C_{10}H_{16}$
unknown hydrocarbons	carbon-containing compounds of unknown structure
NO	nitric oxide, represented as NO
NO_2	nitrogen dioxide, represented as NO_2
total hydrocarbon	the sum of all hydrocarbon
total NO_x	the sum of grassland NO and NO_2 (nitrogen oxides)

All emissions data represented in the Tables of Appendix A are represented in short tons, (2000 pounds). One metric ton equals 1.10231707 short tons.

TABLE A-1 1985 NAPAP Modelers' Emission Inventory Version 2 (Revised) - U.S. Natural Source Particulate Emissions by State (Tons/Year) (continued)

STATE	TSP	CA1	CA2	CA3	K1	K2	K3	MG1
Alabama	572,553	686	7,153	32,664	0	0	0	129
Arizona	1,900,489	740	7,714	35,222	0	0	0	194
Arkansas	490,365	587	6,119	27,940	0	0	0	110
California	2,566,856	1,550	16,164	73,809	0	0	0	371
Colorado	489,823	101	1,054	4,812	0	0	0	33
Connecticut	64,097	77	801	3,657	0	0	0	14
Delaware	11,210	13	138	631	0	0	0	2
District of Columbia	2	0	0	0	0	0	0	0
Florida	400,908	478	4,985	22,761	0	0	0	89
Georgia	1,036,711	1,007	10,506	47,975	0	0	0	192
Idaho	986,397	870	9,078	41,450	0	0	0	177
Illinois	796,581	1,461	15,233	69,556	0	0	0	142
Indiana	2,094,995	4,001	41,720	190,501	0	0	0	469
Iowa	907,590	1,577	16,451	75,117	0	0	0	182
Kansas	1,281,054	1,325	13,819	63,100	0	0	0	263
Kentucky	266,432	317	3,311	15,117	0	0	0	60
Lousiana	347,433	411	4,289	19,584	0	0	0	77
Maine	377,463	452	4,716	21,534	0	0	0	85
Maryland	77,153	92	956	4,363	0	0	0	17
Massachusetts	411,090	488	5,092	23,252	0	0	0	92
Michigan	1,368,943	1,478	15,413	70,381	0	0	0	283
Minnesota	1,350,252	1,531	15,963	72,889	0	0	0	278
Mississippi	970,608	1,162	12,121	55,349	0	0	0	218
Missouri	1,704,624	1,902	19,839	90,589	0	0	0	380
Montana	2,272,633	713	7,438	33,964	0	0	0	345
Nebraska	698,367	757	7,895	36,049	0	0	0	146
Nevada	2,227,309	1,148	11,973	54,672	0	0	0	276
New Hampshire	42,730	51	534	2,438	0	0	0	10
New Jersey	32,798	37	386	1,764	0	0	0	7
New Mexico	1,657,678	931	9,714	44,355	0	0	0	229
New York	1,484,294	673	7,014	32,027	0	0	0	333
North Carolina	171,348	27	286	1,305	0	0	0	30
North Dakota	722,386	662	6,908	31,543	0	0	0	139
Ohio	2,361,063	1,893	19,739	90,134	0	0	0	509
Oklahoma	1,563,998	1,197	12,486	57,015	0	0	0	322
Oregon	2,217,862	286	2,984	13,625	0	0	0	395
Pennsylvania	912,482	1,331	13,875	63,358	0	0	0	100
Rhode Island	64,986	74	774	3,536	0	0	0	14
South Carolina	133,611	20	212	966	0	0	0	4
South Dakota	357,975	353	3,678	16,795	0	0	0	73
Tennessee	449,458	680	7,092	32,383	0	0	0	101
Texas	8,969,735	8,798	91,745	418,929	0	0	0	1,529
Utah	2,135,604	1,494	15,584	71,161	0	0	0	302
Vermont	166,246	199	2,075	9,474	0	0	0	37
Virginia	416,693	253	2,638	12,045	0	0	0	93
Washington	498,903	571	5,957	27,200	0	0	0	109
West Virginia	221,394	257	2,684	12,255	0	0	0	48
Wisconsin	358,524	536	5,589	25,518	0	0	0	77
Wyoming	788,664	150	1,561	7,127	0	0	0	95
TOTAL	51,400,375	45,400	473,454	2,161,889	0	0	0	9,179

TABLE A-1 1985 NAPAP Modelers' Emission Inventory Version 2 (Revised) - U.S. Natural Source Particulate Emissions by State (Tons/Year)

STATE	MG2	MG3	NA1	NA2	NA3	PM1	PM2	PM3
Alabama	1,342	6,126	0	0	0	12,024	50,957	74,432
Arizona	2,018	9,214	0	0	0	39,910	169,144	247,064
Arkansas	1,148	5,241	0	0	0	10,298	43,642	63,747
California	3,872	17,679	0	0	0	53,904	228,450	333,691
Colorado	347	1,583	0	0	0	10,286	43,594	63,677
Connecticut	150	686	0	0	0	1,346	5,705	8,333
Delaware	26	119	0	0	0	235	998	1,457
District of Columbia	0	0	0	0	0	0	0	0
Florida	930	4,248	0	0	0	8,419	35,681	52,118
Georgia	1,999	9,128	0	0	0	21,771	92,267	134,772
Idaho	1,848	8,437	0	0	0	20,714	87,789	128,232
Illinois	1,476	6,739	0	0	0	16,728	70,896	103,555
Indiana	4,888	22,322	0	0	0	43,995	186,455	272,349
Iowa	1,893	8,643	0	0	0	19,059	80,776	117,987
Kansas	2,747	12,541	0	0	0	26,902	114,014	166,537
Kentucky	622	2,840	0	0	0	5,595	23,712	34,636
Lousiana	806	3,679	0	0	0	7,296	30,922	45,166
Maine	885	4,039	0	0	0	7,927	33,594	49,070
Maryland	179	820	0	0	0	1,620	6,867	10,030
Massachusetts	958	4,375	0	0	0	8,633	36,587	53,442
Michigan	2,951	13,476	0	0	0	28,748	121,836	177,963
Minnesota	2,900	13,241	0	0	0	28,355	120,172	175,533
Mississippi	2,274	10,382	0	0	0	20,383	86,384	126,179
Missouri	3,961	18,085	0	0	0	35,797	151,712	221,601
Montana	3,594	16,413	0	0	0	47,725	202,264	295,442
Nebraska	1,525	6,965	0	0	0	14,666	62,155	90,788
Nevada	2,874	13,124	0	0	0	46,773	198,231	289,550
New Hampshire	100	457	0	0	0	897	3,803	5,555
New Jersey	73	334	0	0	0	689	2,919	4,264
New Mexico	2,392	10,924	0	0	0	34,811	147,533	215,498
New York	3,468	15,836	0	0	0	31,170	132,102	192,958
North Carolina	316	1,443	0	0	0	3,598	15,250	22,275
North Dakota	1,450	6,619	0	0	0	15,170	64,292	93,910
Ohio	5,307	24,231	0	0	0	49,582	210,135	306,938
Oklahoma	3,353	15,312	0	0	0	32,844	139,196	203,320
Oregon	4,116	18,796	0	0	0	46,575	197,390	288,322
Pennsylvania	1,039	4,744	0	0	0	19,162	81,211	118,623
Rhode Island	147	671	0	0	0	1,365	5,784	8,448
South Carolina	45	204	0	0	0	2,806	11,891	17,369
South Dakota	760	3,469	0	0	0	7,517	31,860	46,537
Tennessee	1,053	4,809	0	0	0	9,439	40,002	58,430
Texas	15,942	72,795	0	0	0	188,364	798,306	1,166,066
Utah	3,151	14,388	0	0	0	44,848	190,069	277,629
Vermont	389	1,778	0	0	0	3,491	14,796	21,612
Virginia	967	4,415	0	0	0	8,751	37,086	54,170
Washington	1,138	5,195	0	0	0	10,477	44,402	64,857
West Virginia	505	2,308	0	0	0	4,649	19,704	28,781
Wisconsin	808	3,688	0	0	0	7,529	31,909	46,608
Wyoming	996	4,547	0	0	0	16,562	70,191	102,526
TOTAL	95,727	437,108	0	0	0	1,079,408	4,574,633	6,682,049

TABLE A-2 1985 NAPAP Modelers' Emissions Inventory Version 2 (Revised) - U.S. Natural Source Particulate Emissions by EPA Region (Tons/Year)

REGION	TSP	CA1	CA2	CA3	K1	K2	K3	MG1
I	1,126,614	1,342	13,992	63,890	0	0	0	252
II	1,517,092	710	7,400	33,791	0	0	0	340
III	1,638,933	1,946	20,291	92,652	0	0	0	261
IV	4,001,630	4,379	45,666	208,520	0	0	0	823
V	8,330,358	10,899	113,657	518,980	0	0	0	1,758
VI	13,029,209	11,924	124,353	567,822	0	0	0	2,267
VII	4,591,636	5,562	58,003	264,854	0	0	0	971
VIII	6,767,086	3,473	36,223	165,402	0	0	0	987
IX	6,694,654	3,438	35,851	163,703	0	0	0	840
X	3,703,163	1,728	18,018	82,275	0	0	0	681
TOTAL	51,400,375	45,400	473,454	2,161,889	0	0	0	9,179

REGION	MG2	MG3	NA1	NA2	NA3	PM1	PM2	PM3
I	2,629	12,006	0	0	0	23,659	100,269	146,460
II	3,541	16,170	0	0	0	31,859	135,021	197,222
III	2,717	12,406	0	0	0	34,418	145,865	213,061
IV	8,580	39,180	0	0	0	84,034	356,145	520,212
V	18,330	83,696	0	0	0	174,938	741,402	1,082,947
VI	23,641	107,951	0	0	0	273,613	1,159,600	1,693,797
VII	10,125	46,234	0	0	0	96,424	408,656	596,913
VIII	10,297	47,018	0	0	0	142,109	602,271	879,721
IX	8,764	40,017	0	0	0	140,588	595,824	870,305
X	7,102	32,429	0	0	0	77,766	329,581	481,411
TOTAL	95,727	437,107	0	0	0	1,079,408	4,574,633	6,682,049

TABLE A-3 1985 NAPAP Modelers' Emissions Inventory Version 2 (Revised) - U.S. Natural Source Particulate Emissions by Source Category (Tons/Year)

SCC	TSP	CA1	CA2	CA3	K1	K2	K3	MG1
901	36,922,642	40,790	425,381	1,942,380	0	0	0	7,884
902	4,711,540	2,561	26,710	121,963	0	0	0	692
903	9,766,192	2,048	21,363	97,547	0	0	0	603
TOTAL	51,400,375	45,400	473,454	2,161,889	0	0	0	9,179

SCC	MG2	MG3	NA1	NA2	NA3	PM1	PM2	PM3
901	82,224	375,452	0	0	0	775,375	3,286,115	4,799,944
902	7,219	32,963	0	0	0	98,942	419,327	612,500
903	6,284	28,693	0	0	0	205,090	869,191	1,269,605
TOTAL	95,727	437,107	0	0	0	1,079,408	4,574,633	6,682,049

TABLE A-4 1985 NAPAP Modelers' Emissions Inventory Version 2 - Canadian Natural Source Particulate Emissions by Province (Tons/Year)

PROVINCE	TSP	CA1	CA2	CA3	K1	K2	K3	MG1
Newfoundland	224,490	71	102	238	0	0	0	20
Prince Edward Island	44,455	2	4	45	0	0	0	1
Nova Scotia	683,354	31	45	135	0	0	0	10
New Brunswick	406,335	71	103	273	0	0	0	22
Quebec	2,288,654	539	776	2,412	0	0	0	149
Ontario	5,114,660	1,755	2,618	9,869	0	0	0	503
Manitoba	3,126,754	854	1,269	4,261	0	0	0	250
Saskatchewan	7,093,746	1,301	2,336	18,430	0	0	0	462
Alberta	8,586,539	1,294	2,385	20,237	0	0	0	510
British Columbia	1,959,164	524	767	2,320	0	0	0	157
TOTAL	29,528,152	6,442	10,404	58,218	0	0	0	2,083

PROVINCE	MG2	MG3	NA1	NA2	NA3	PM1	PM2	PM3
Newfoundland	29	68	0	0	0	66,205	61,251	29,843
Prince Edward Island	2	24	0	0	0	11,492	10,263	5,201
Nova Scotia	14	49	0	0	0	201,493	189,125	91,992
New Brunswick	31	91	0	0	0	118,517	109,661	53,575
Quebec	222	827	0	0	0	650,840	600,544	295,359
Ontario	789	3,861	0	0	0	1,352,988	1,255,165	628,505
Manitoba	384	1,608	0	0	0	878,744	842,892	413,704
Saskatchewan	920	9,245	0	0	0	1,561,825	1,504,770	788,159
Alberta	1,021	10,402	0	0	0	1,933,040	1,855,012	966,025
British Columbia	233	838	0	0	0	555,123	512,960	252,468
TOTAL	3,645	27,014	0	0	0	7,330,267	6,941,643	3,524,831

TABLE A-5 1985 NAPAP Modelers' Emissions Inventory Version 2 - Canadian Natural Source Particulate Emissions by Source Category (Tons/Year)

SCC	TSP	CA1	CA2	CA3	K1	K2	K3	MG1
41110	996,669	75	57	300	0	0	0	18
41120	217,926	15	11	58	0	0	0	4
42110	279,059	88	126	292	0	0	0	25
42120	72,028	22	31	72	0	0	0	6
42210	13,293,632	4,024	5,768	13,414	0	0	0	1,154
42220	3,303,446	1,005	1,441	3,350	0	0	0	288
42310	4,656,282	326	467	1,086	0	0	0	120
42320	1,468,222	102	146	339	0	0	0	39
43200	5,240,888	786	2,358	39,307	0	0	0	430
TOTAL	29,528,152	6,442	10,405	58,218	0	0	0	2,083

SCC	MG2	MG3	NA1	NA2	NA3	PM1	PM2	PM3
41110	14	71	0	0	0	249,167	119,600	69,767
41120	3	16	0	0	0	54,481	26,151	15,255
42110	36	83	0	0	0	83,718	80,927	39,068
42120	9	21	0	0	0	21,608	20,888	10,084
42210	1,654	3,848	0	0	0	3,988,090	3,855,153	1,861,108
42220	412	959	0	0	0	991,034	957,999	462,482
42310	172	401	0	0	0	1,396,885	1,350,322	651,879
42320	55	128	0	0	0	440,467	425,785	205,551
43200	1,289	21,488	0	0	0	104,818	104,818	209,636
TOTAL	3,645	27,014	0	0	0	7,330,267	6,941,643	3,524,831

TABLE A-6. BIOGENIC EMISSIONS ESTIMATES (TONS) FOR THE UNITED STATES BY STATE, WINTER SEASON

STATE	Isoprene	Monoterpenes	Alpha-Pinene	Unknown HC	NO	NO2	Total HC	Grassland NOx
Alabama	680	5467	5630	7033	14.1	1.3	18810	15.4
Arizona	44	5705	5962	6138	2.7	0.3	17848	2.9
Arkansas	0	5903	6208	6314	0.0	0.0	18425	0.0
California	79	25911	27062	27825	40.6	3.7	80878	44.4
Colorado	0	7845	8694	8392	0.0	0.0	24931	0.0
Connecticut	0	401	441	429	0.0	0.0	1272	0.0
Delaware	0	95	103	102	0.0	0.0	300	0.0
District of Columbia	0	29	31	31	0.0	0.0	90	0.0
Florida	16431	19540	19322	50970	953.8	87.7	106263	1041.5
Georgia	785	8232	8392	10054	33.2	3.1	27463	36.3
Idaho	0	11953	13394	12787	0.0	0.0	38134	0.0
Illinois	0	573	625	612	0.0	0.0	1810	0.0
Indiana	0	714	782	764	0.0	0.0	2260	0.0
Iowa	0	111	124	119	0.0	0.0	354	0.0
Kansas	0	1035	1114	1107	0.0	0.0	3256	0.0
Kentucky	0	1969	2133	2106	0.0	0.0	6208	0.0
Louisiana	1573	10622	10929	13500	523.7	48.2	36623	571.9
Maine	0	3132	3587	3351	0.0	0.0	10070	0.0
Maryland	0	482	521	515	0.0	0.0	1518	0.0
Massachusetts	0	530	587	567	0.0	0.0	1684	0.0
Michigan	0	4534	5170	4850	0.0	0.0	14554	0.0
Minnesota	0	5046	5962	5398	0.0	0.0	16407	0.0
Mississippi	703	4328	4469	5723	13.9	1.3	15224	15.2
Missouri	0	1949	2113	2085	0.0	0.0	6147	0.0
Montana	0	12713	14288	13600	0.0	0.0	40600	0.0
Nebraska	0	506	560	541	0.0	0.0	1608	0.0
Nevada	0	1002	1085	1072	0.0	0.0	3159	0.0
New Hampshire	0	711	805	760	0.0	0.0	2276	0.0
New Jersey	0	443	481	474	0.0	0.0	1398	0.0
New Mexico	0	6179	6563	6610	0.0	0.0	19352	0.0
New York	0	2487	2796	2660	0.0	0.0	7943	0.0
North Carolina	11	5593	5854	5998	1.4	0.1	17455	1.5
North Dakota	0	160	185	171	0.0	0.0	517	0.0
Ohio	0	1177	1294	1259	0.0	0.0	3729	0.0
Oklahoma	0	7974	8425	8530	0.0	0.0	24930	0.0
Oregon	0	21028	22690	22495	0.0	0.0	66214	0.0
Pennsylvania	0	2298	2543	2458	0.0	0.0	7300	0.0
Rhode Island	0	42	46	45	0.0	0.0	134	0.0
South Carolina	98	2875	2956	3207	8.0	0.7	9137	8.7
South Dakota	0	1133	1258	1212	0.0	0.0	3602	0.0
Tennessee	0	2815	2996	3011	0.0	0.0	8822	0.0
Texas	2656	11559	12168	17221	1094.5	100.7	43604	1195.2
Utah	0	3310	3663	3541	0.0	0.0	10513	0.0
Vermont	0	545	619	583	0.0	0.0	1746	0.0
Virginia	3	2101	2260	2253	0.1	0.0	6617	0.1
Washington	0	13494	14716	14436	0.0	0.0	42646	0.0
West Virginia	0	1559	1704	1668	0.0	0.0	4932	0.0
Wisconsin	0	2866	3303	3066	0.0	0.0	9236	0.0
Wyoming	0	6028	6764	6449	0.0	0.0	19241	0.0
TOTAL	23,063	236,703	253,377	294,094	2,686	247	807,237	2933

TABLE A-7. BIOGENIC EMISSIONS ESTIMATES (TONS) FOR THE UNITED STATES BY STATE, SPRING SEASON

STATE	Isoprene	Monoterpenes	Alpha-Pinene	Unknown HC	NO	NO2	Total HC	Grassland NOx
Alabama	73636	18201	18342	102334	1364	126	212513	1490
Arizona	32784	24237	24482	49988	890	82	131492	972
Arkansas	48486	19035	18981	72111	769	71	158613	840
California	25916	56333	56163	86214	1992	183	224626	2176
Colorado	632	23728	23985	28529	1090	100	76874	1190
Connecticut	1981	1164	1197	3869	52	5	8211	57
Delaware	1183	568	604	3517	34	3	5872	37
District of Columbia	243	100	102	435	7	1	880	7
Florida	70732	33174	31797	116673	1739	160	252376	1899
Georgia	78378	25074	24966	128856	1026	94	257274	1121
Idaho	0	31760	32352	33976	0	0	98088	0
Illinois	5817	13683	14820	91232	963	89	125551	1052
Indiana	5798	8273	8868	50308	655	60	73247	715
Iowa	1446	9958	10935	69015	786	72	91355	858
Kansas	3273	9115	9637	24238	2845	262	46263	3107
Kentucky	20237	9664	9992	46359	1093	101	86252	1194
Louisiana	45965	27880	27065	79035	1912	176	179945	2088
Maine	8418	8999	9389	18636	62	6	45441	68
Maryland	4994	2247	2361	12608	118	11	22209	128
Massachusetts	2822	1505	1556	5013	59	5	10896	64
Michigan	7618	14644	15255	31569	367	34	69087	401
Minnesota	5278	24416	25455	51293	626	58	106442	683
Mississippi	47195	14198	14191	66408	1232	113	141993	1345
Missouri	20739	11433	11961	48554	1953	180	92687	2133
Montana	2532	35389	36479	40519	1854	171	114919	2025
Nebraska	1329	8435	9121	39387	1818	167	58272	1985
Nevada	1140	4916	5058	6031	99	9	17145	108
New Hampshire	2012	2062	2125	4753	14	1	10953	15
New Jersey	3100	1543	1596	6000	166	15	12239	181
New Mexico	6394	23515	23606	30927	2154	198	84442	2352
New York	9813	8186	8498	24343	319	29	50841	349
North Carolina	45490	18128	18332	85858	676	62	167808	738
North Dakota	1377	2475	2693	5616	983	90	12161	1073
Ohio	6579	6508	6838	30909	499	46	50834	545
Oklahoma	16065	25691	25429	45586	2448	225	112771	2673
Oregon	1251	39219	39880	43080	26	2	123430	29
Pennsylvania	10302	7478	7761	27204	279	26	52745	305
Rhode Island	272	117	120	443	4	0	952	5
South Carolina	33257	9243	9284	48933	500	46	100716	546
South Dakota	1591	6680	7075	17187	1575	145	32533	1720
Tennessee	21801	10677	10753	42664	847	78	85896	924
Texas	72934	56694	58000	140681	10030	923	328309	10953
Utah	1915	11101	11175	13897	38	4	38087	42
Vermont	1852	1661	1723	4170	28	3	9406	30
Virginia	25487	7914	8180	42411	523	48	83992	571
Washngton	2178	25590	26315	29456	86	8	83538	93
West Virginia	7471	4633	4688	15201	165	15	31993	180
Wisconsin	6260	12312	12791	31277	246	23	62640	269
Wyoming	574	17133	17488	18971	539	50	54166	588
TOTAL	796,547	736,690	749,466	2,016,271	47,547	4,374	4,298,974	51,921

TABLE A-8. BIOGENIC EMISSIONS ESTIMATES (TONS) FOR THE UNITED STATES BY STATE, SUMMER SEASON

STATE	Isoprene	Monoterpenes	Alpha-Pinene	Unknown HC	NO	NO2	Total HC	Grassland NOx
Alabama	195530	31272	30188	180644	2203	203	437634	2406
Arizona	88440	50325	48722	107024	2223	205	294512	2428
Arkansas	180083	38117	35988	156604	1527	140	410792	1668
California	125507	118253	112029	214364	4552	419	570154	4971
Colorado	33474	63757	61719	109468	6230	573	268419	6803
Connecticut	6651	2900	2819	12825	161	15	25195	175
Delaware	3860	1457	1468	9715	82	8	16500	90
District of Columbia	837	231	223	1123	15	1	2415	17
Florida	128562	46354	43188	165028	2280	210	383132	2490
Georgia	194368	41772	39925	221838	1636	151	497904	1787
Idaho	30587	87198	82397	120965	840	77	321147	917
Illinois	21864	37578	38727	257778	2332	215	355946	2547
Indiana	21202	23316	23838	150275	1678	154	218630	1833
Iowa	4840	35134	36757	248436	2222	204	325167	2426
Kansas	16783	26182	26122	73687	7527	692	142774	8220
Kentucky	66311	20830	20627	110180	2409	222	217947	2631
Louisiana	117808	44517	41472	128703	2725	251	332500	2975
Maine	31601	22739	22151	69182	275	25	145674	300
Maryland	17024	5558	5556	35056	297	27	63194	324
Massachusetts	9097	3752	3665	17046	192	18	33560	210
Michigan	36798	40119	39446	127857	1616	149	244220	1765
Minnesota	21460	64505	63894	183873	2544	234	333731	2779
Mississippi	129153	24437	23302	114707	1928	177	291599	2106
Missouri	83423	27816	27645	127630	4686	431	266514	5117
Montana	32953	95805	92732	135387	10468	963	356877	11430
Nebraska	8411	32417	33406	152303	7273	669	226537	7942
Nevada	15093	25366	25456	33645	335	31	99561	366
New Hampshire	10360	5146	4995	19691	73	7	40193	79
New Jersey	10267	3870	3792	17805	434	40	35734	474
New Mexico	29092	54798	53368	77924	7102	653	215182	7755
New York	39216	21952	21691	93863	1258	116	176722	1374
North Carolina	130077	34220	33145	177384	1386	127	374825	1513
North Dakota	5944	10129	10627	24397	4052	373	51097	4424
Ohio	23479	18299	18512	101788	1518	140	162077	1658
Oklahoma	70714	56954	53105	106524	5655	520	287296	6175
Oregon	31366	91145	86723	124967	1280	118	334200	1398
Pennsylvania	39906	19193	19000	95389	965	89	173487	1054
Rhode Island	624	270	261	1180	10	1	2336	11
South Carolina	84103	15866	15264	86514	814	75	201747	889
South Dakota	9198	24587	25053	73128	6741	620	131966	7361
Tennessee	80232	21778	20956	97903	1808	166	220869	1975
Texas	206118	103820	101305	253520	16913	1556	664763	18468
Utah	32215	35011	33719	60195	350	32	161140	383
Vermont	7590	4357	4252	16222	119	11	32421	130
Virginia	83492	17190	17041	107494	1253	115	225217	1369
Washngton	17938	55693	53841	78741	1224	113	206213	1336
West Virginia	26306	9721	9442	43521	511	47	88990	558
Wisconsin	27182	32979	32592	116198	985	91	208951	1075
Wyoming	18487	52251	50678	73313	4018	370	194728	4387
TOTAL	2,605,623	1,700,934	1,652,823	5,113,006	128,725	11,842	11,072,386	140,567

TABLE A-9. BIOGENIC EMISSIONS ESTIMATES (TONS) FOR THE UNITED STATES BY STATE, AUTUMN SEASON

STATE	Isoprene	Monoterpenes	Alpha-Pinene	Unknown HC	NO	NO2	Total HC	Grassland NOx
Alabama	71706	19783	19827	112017	1534	141	223333	1676
Arizona	23014	21015	21209	41686	655	60	106923	716
Arkansas	49188	19789	19659	77784	860	79	166420	939
California	26683	58539	58431	94984	2272	209	238638	2481
Colorado	703	22119	22406	25919	1014	93	71148	1108
Connecticut	2180	1375	1407	5318	74	7	10281	81
Delaware	1014	654	689	4094	38	4	6451	42
District of Columbia	208	112	113	485	7	1	919	8
Florida	68933	37067	35219	130128	1975	182	271348	2157
Georgia	70567	27084	26859	140641	1157	106	265150	1263
Idaho	3336	29901	30831	36384	178	16	100452	194
Illinois	5510	16037	17218	108123	1100	101	146887	1201
Indiana	5624	10277	10935	64229	800	74	91066	874
Iowa	1264	12999	14352	91571	948	87	120185	1035
Kansas	3205	10438	10943	28418	3284	302	53003	3586
Kentucky	19459	10453	10730	50584	1203	111	91226	1313
Louisiana	41415	28572	27678	80427	2037	187	178092	2224
Maine	7706	10119	10454	22051	85	8	50330	92
Maryland	5037	2655	2773	15741	147	14	26206	161
Massachusetts	2944	1738	1789	6589	84	8	13060	92
Michigan	8416	17378	18095	46241	645	59	90130	704
Minnesota	4510	23034	24480	57715	712	65	109738	777
Mississippi	44600	14950	14856	69185	1313	121	143592	1433
Missouri	19320	12439	12914	53704	2178	200	98378	2379
Montana	3321	29617	31109	35461	1820	167	99508	1988
Nebraska	1398	10363	11305	50731	2326	214	73798	2540
Nevada	1317	5536	5830	7078	38	4	19761	42
New Hampshire	2154	2192	2254	5660	19	2	12260	21
New Jersey	2921	1854	1899	7673	207	19	14347	226
New Mexico	4545	20573	20689	26505	1768	163	72312	1931
New York	10426	9497	9864	32436	504	46	62224	550
North Carolina	42202	20003	20162	97842	803	74	180208	877
North Dakota	971	2036	2258	4630	847	78	9895	925
Ohio	7504	8643	9081	45238	745	69	70466	814
Oklahoma	17850	27015	26644	50240	2815	259	121749	3074
Oregon	5726	39901	40714	49840	342	31	136181	374
Pennsylvania	13020	9192	9515	40088	461	42	71815	503
Rhode Island	225	134	136	514	5	0	1009	5
South Carolina	29351	9802	9827	52570	561	52	101549	613
South Dakota	1296	6684	7215	19666	1639	151	34861	1790
Tennessee	21715	11347	11359	45818	921	85	90238	1005
Texas	65241	57034	58400	140696	10377	955	321371	11332
Utah	1135	9901	9964	12045	25	2	33045	28
Vermont	1518	1797	1851	4486	30	3	9652	33
Virginia	23794	8730	9000	48775	624	57	90299	682
Washngton	2813	25083	25864	30606	249	23	84366	272
West Virginia	8804	5250	5302	19925	247	23	39282	270
Wisconsin	5978	12797	13440	38453	340	31	70668	371
Wyoming	1487	16171	16731	19090	822	76	53478	897
TOTAL	763,255	759,680	774,284	2,250,082	52,837	4,861	4,547,301	57,698

TABLE A-10. BIOGENIC EMISSIONS ESTIMATES (TONS) FOR CANADA BY PROVINCE, WINTER SEASON

PROVINCE	Isoprene	Monoterpenes	Alpha-Pinene	Unknown HC	NO	NO2	Total HC	Grassland NOx
Newfoundland	0.0	11980.8	14325.9	12816.7	0.0	0.0	39123.5	0.0
Nova Scotia	0.0	4545.7	5125.5	4862.8	0.0	0.0	14534.0	0.0
New Brunswick	0.0	1936.0	2240.6	2071.1	0.0	0.0	6247.8	0.0
Quebec	0.0	33158.0	40055.3	35471.3	0.0	0.0	108684.6	0.0
Ontario	0.0	22882.3	27576.5	24478.7	0.0	0.0	74937.5	0.0
Manitoba	0.0	4166.9	5097.9	4457.6	0.0	0.0	13722.3	0.0
Saskatchewan	0.0	3485.3	4215.5	3728.5	0.0	0.0	11429.2	0.0
Alberta	0.0	10333.1	11968.6	11054.0	0.0	0.0	33355.7	0.0
British Columbia	0.0	35537.4	39657.2	38016.7	0.0	0.0	113211.3	0.0
TOTAL	0.0	128,025.4	150,263.1	136,957.4	0.0	0.0	415,245.9	0.0

TABLE A-11. BIOGENIC EMISSIONS ESTIMATES (TONS) FOR CANADA BY PROVINCE, SPRING SEASON

PROVINCE	Isoprene	Monoterpenes	Alpha-Pinene	Unknown HC	NO	NO2	Total HC	Grassland NOx
Newfoundland	378.8	32668.8	35667.7	35187.0	0.14	0.01	103902.2	0.15
Nova Scotia	3527.3	9302.3	9804.4	13209.6	0.14	0.01	35843.6	0.15
New Brunswick	2173.8	5126.7	5411.6	7444.6	0.04	0.00	20156.7	0.04
Quebec	11328.5	109281.9	117818.9	127238.6	0.68	0.06	365667.9	0.74
Ontario	8929.3	90301.3	95555.7	110255.2	0.68	0.06	305041.4	0.74
Manitoba	0.0	19033.7	20086.5	20361.7	0.00	0.00	59481.9	0.00
Saskatchewan	0.0	14764.9	15507.5	15795.0	0.01	0.00	46067.4	0.01
Alberta	0.0	30406.1	31740.6	32527.5	0.00	0.00	94674.2	0.00
British Columbia	0.0	82353.2	84761.7	88098.8	0.00	0.00	255213.8	0.00
TOTAL	26,337.7	393,238.9	416,354.5	450,117.9	1.69	0.14	1,286,049.0	1.83

TABLE A-12. BIOGENIC EMISSIONS ESTIMATES (TONS) FOR CANADA BY PROVINCE, SUMMER SEASON

PROVINCE	Isoprene	Monoterpenes	Alpha-Pinene	Unknown HC	NO	NO2	Total HC	Grassland NOx
Newfoundland	29152.0	92741.2	93000.1	130411.7	1.6	0.1	345305.0	1.7
Nova Scotia	12348.2	23783.1	23124.6	42565.9	0.7	0.1	101821.9	0.7
New Brunswick	7710.0	13658.3	13272.3	25096.9	0.3	0.0	59737.5	0.3
Quebec	124871.0	312548.3	309090.2	485655.3	4.2	0.4	1232164.8	4.6
Ontario	98896.8	264847.4	259101.9	439518.6	3.8	0.4	1062364.7	4.1
Manitoba	32071.7	59927.3	58331.9	104908.4	4.5	0.4	255239.3	5.0
Saskatchewan	27871.0	43477.7	42655.4	81775.1	1093.4	100.6	195779.2	1194.0
Alberta	30020.5	70541.9	69423.2	110548.0	1650.1	151.8	280533.5	1801.9
British Columbia	59481.6	167980.2	162619.0	247595.2	51.6	4.8	637676.1	56.4
TOTAL	422,422.8	1,049,505.5	1,030,618.7	1,668,075.0	2,810.2	258.5	4,170,622.0	3,068.7

TABLE A-13. BIOGENIC EMISSIONS ESTIMATES (TONS) FOR CANADA BY PROVINCE, AUTUMN SEASON

PROVINCE	Isoprene	Monoterpenes	Alpha-Pinene	Unknown HC	NO	NO2	Total HC	Grassland NOx
Newfoundland	6188.7	41977.8	44973.0	51903.7	0.7	0.1	145043.2	0.8
Nova Scotia	2957.8	12331.6	12654.8	17573.7	0.4	0.0	45517.8	0.5
New Brunswick	1758.3	6290.4	6510.1	9190.3	0.1	0.0	23749.0	0.1
Quebec	25629.4	132876.7	141151.9	174621.0	2.0	0.2	474278.9	2.2
Ontario	19559.3	100374.4	106162.4	147142.8	1.8	0.2	373238.8	2.0
Manitoba	5825.9	19260.3	20511.4	27380.9	0.9	0.1	72978.4	1.0
Saskatchewan	5117.9	13095.7	14071.3	19680.9	207.7	19.1	51965.7	226.8
Alberta	5777.1	23713.5	25474.1	31267.6	322.7	29.7	86232.3	352.4
British Columbia	11100.0	68605.5	71912.8	86214.2	11.5	1.1	237832.4	12.6
TOTAL	83,914.3	418,525.8	443,421.6	564,974.9	547.8	50.4	1,510,836.6	598.2

APPENDIX B

REGIONAL EMISSIONS PROCESSING FOR THE RADM: BIOGENIC SOURCES

APPENDIX B CONTENTS

FIGURES

TABLES

EMISSIONS PROCESSING FOR THE REGIONAL ACID DEPOSITION MODEL (RADM)

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BIOGENIC SOURCES

Hydrocarbon emissions influence the formation of acid deposition through the intricately-coupled atmospheric chemistry of sulfur dioxide, nitrogen oxides, and reactive organic hydrocarbons. Biogenic hydrocarbon emissions emanate from living surface vegetation--trees, shrubs, grasses, and agricultural crops--and from decaying leaf litter and vegetation in fresh and salt water. Hydrocarbon emissions from biogenic sources have been estimated to equal or exceed those from anthropogenic sources on a total-mass basis. Thus, biogenic hydrocarbon emission rates have become an important input requirement for regional acid deposition models such as the Regional Acid Deposition Model (RADM).

The calculation of biogenic hydrocarbon emission rates requires four basic components:

- estimates of the biomass density of each vegetative class in each grid cell,
- an adjustment of biomass density to account for season,
- emission factors for the vegetation classes in the modeling region, and
- empirical relationships that allow for adjusting the emission factors based on the values of specific environmental parameters, such as temperature, solar intensity, soil conditions, and elevation.

We show the procedure that we use to calculate the hourly grid-specific emissions for the RADM in Figure 1, and describe it below. Our procedure provides the flexibility to update vegetation-specific emission factors and allows for evaluating the importance of an individual vegetative species in the modeling domain. We calculate the hourly emission rate for an individual grid cell and a specific hydrocarbon compound (or group of compounds) by adjusting the vegetation-specific emission factors for canopy (forest) and noncanopy (nonforest) areas to reflect variations in the meteorological episode being modeled, and then summing the canopy and noncanopy emissions.

3.1 BIOMASS DENSITY BY VEGETATION CLASS

Data from the Oak Ridge National Laboratory (ORNL) Geoecology Data Base (Olson, 1980) form the basis of the U.S. biogenic emissions inventory for the RADM. The database contains county-level land use data for the classes of natural vegetation, agricultural crops, urban areas, and water. Table 1 lists examples of vegetative species included in the biogenic emissions inventory system by vegetation class.

TABLE 1. VEGETATION CLASSES IN THE BIOGENIC EMISSIONS INVENTORY SYSTEM

Vegetation class	Examples
	CANOPY (FOREST)
Natural vegetation:	
Oak	Oregon oakwoods, oak savanna, oak-hickory
Other deciduous	Elm-ash, northern hardwoods, beech-maple
Coniferous	Cypress savanna, Douglas fir, conifer bog
	NONCANOPY (NONFOREST)
Natural vegetation:	
Scrubland	Creosote bush, chaparral, coastal sagebrush
Grassland	Fescue-oatgrass, northern cordgrass, prairie
Agricultural crops:	Alfalfa, barley, corn, cotton, hay, oats, peanuts, potatoes, rice, rye, sorghum, soybeans, tobacco, wheat, miscellaneous crops
Urban area:	Urban grass, urban trees
Water (fresh and salt):	Inland lakes
Barren area:	Tundra, ice, alpine meadows, desert

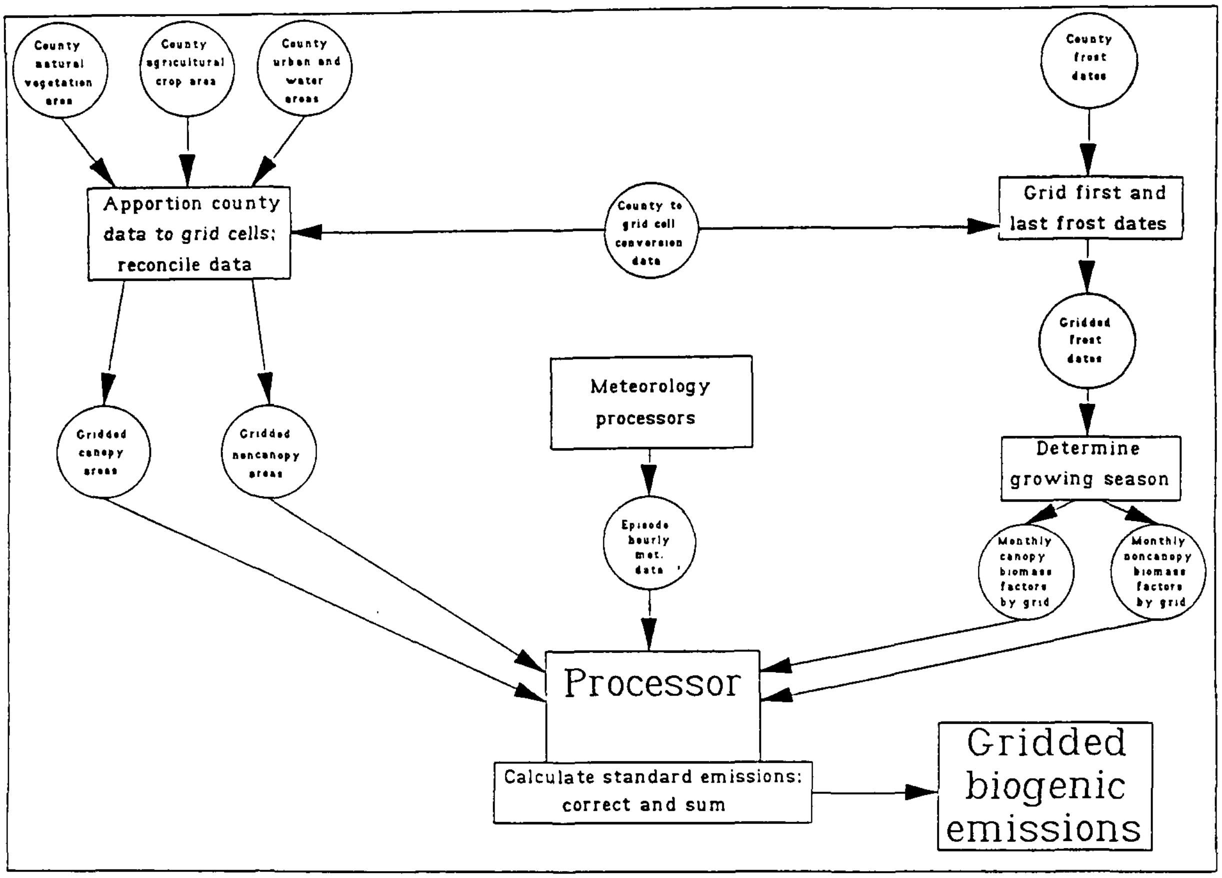

Figure 1. Biogenic emissions inventory system.

The Landsat data set (Page, 1980), which reports data in standard NAPAP grid cells, and vegetation data from Matthews (1984) form the basis of the Canadian biogenic emissions inventory. For the portion of Canada south of 55° N latitude, we used the Landsat data set to determine the types of vegetation present by land use class (Page, 1980). However, the Landsat data set contains no data for areas north of 55° N latitude. If you require data north of this latitude, you can use the vegetation, land-use, and seasonal albedo data sets of Matthews (1984). Note that the Matthews data specify only one vegetation type for each 1° latitude by 1° longitude square.

3.1.1 Natural Vegetation Area

The ORNL Geoecology Potential and Adjusted Vegetation Data File uses Kuchler's vegetation codes (001-106) to identify natural vegetation. We categorized these into the five natural vegetation classes: oak forests, other deciduous forests, coniferous forests, scrubland, and grassland.

For Canada, we assigned the vegetation types within the Matthews (1984) and the Landsat (Page, 1980) data sets to one of the above five natural vegetation classes. We calculated the area allocated to each class in each NAPAP grid cell. However, there was no direct correspondence to the oak class for either data set. Therefore, we allocated a zero area to this class.[1]

Oak, other deciduous, and coniferous forests are categorized as canopy (forest) vegetation classes. Canopy emissions are determined by biomass density, a measure of the dry leaf biomass per unit area (kg/ha). Table 2 presents the biomass density for the three canopy vegetation classes.

TABLE 2. FOREST BIOMASS DENSITY ESTIMATES

	Forest biomass density (kg/ha) by canopy vegetation class		
Forest biomass class	Oak	Other deciduous	Coniferous
Deciduous high isoprene	1,850	600	390
Deciduous low isoprene	600	1,850	260
Deciduous nonisoprene	600	900	260
Coniferous nonisoprene	700	1,350	5,590

Source: Lamb *et al.*, 1987.

For a single canopy class, we use four forest biomass classes to describe the mix of forest vegetation, including underwood, within that class. All oaks (and some other deciduous tree species) that emit more than 10 $\mu g_{isoprene}/(g_{biomass} \cdot h)$ at temperatures near 30 °C are grouped together as high isoprene emitters. All deciduous tree species with an emission rate less than 10 $\mu g_{isoprene}/(g_{biomass} \cdot h)$ are considered low isoprene emitters. Deciduous and coniferous tree species that do not emit isoprene make up the two remaining forest biomass classes.

Natural vegetation areas of scrubland and grassland are noncanopy (nonforest) vegetation classes. For these vegetation classes, as well as the agricultural crop class, we determine hydrocarbon emissions using emission factors expressed as a function of land area. Thus, biomass density is not calculated directly.

1. A percentage of the deciduous areas could be allocated to the oak class if that percentage is known.

3.1.2 Agricultural Crop Area

The agricultural crop data are from the ORNL Geoecology Crop Areas and Yields Data File. The crops included in the biogenic emissions inventory are: alfalfa, barley, corn, cotton, hay, oats, peanuts, potatoes, rice, rye, sorghum, soybeans, tobacco, wheat, and miscellaneous crops.

For Canada, neither the Matthews (1984) data set nor the Landsat (Page, 1980) data set assigned specific agricultural classes. Therefore, we made agricultural class assignments along latitude and longitude lines (see Figure 2), using cash crop data by province from atlases. Where only the broad crop category "grain" was listed, the area was assigned 25% wheat and 75% oats, since oats, barley, and rye all have the same emission factor.

Where wheat was specifically listed, the area was assigned 75% wheat and 25% oats. Where no specific crop was listed, the area was assigned to the miscellaneous crops class.

3.1.3 Urban Area

The ORNL Geoecology Land Areas Data File specifies urban, rural, road, water, and federal land areas. Urban areas include suburban areas if the same area has not been included as agricultural crops or natural vegetation.

To account for hydrocarbon emissions from grass and trees in an urban area, we used the results from two studies. Zimmerman (1979) showed that residential areas made up 14.6% of an urban area. Winer *et al.* (1983) showed that trees covered 9.7% of an urban area, and that ground cover comprised more than 17.1% of the area. For purposes of RADM modeling, we assume that 20% of an urban area is covered by grasses; a further 20% is covered by trees, where this area is evenly distributed among oak, other deciduous, and coniferous categories.

Note that the Matthews data set does not define urban areas.

3.1.4 Water and Barren Area

Water areas are also determined from the ORNL Geoecology Land Areas Data File (for the United States) and the Landsat data set (for Canada). Oceans and the Great Lakes are not included in the biogenic emissions inventory. However, smaller water areas such as lakes and rivers are included if the grid cell they are in is not 100% water. Also included in the biogenic emissions inventory are any barren areas, such as tundra, ice, alpine meadows, and desert. Areas of water and barren land are used only in reconciliation of the total area for the county and the grid cell.

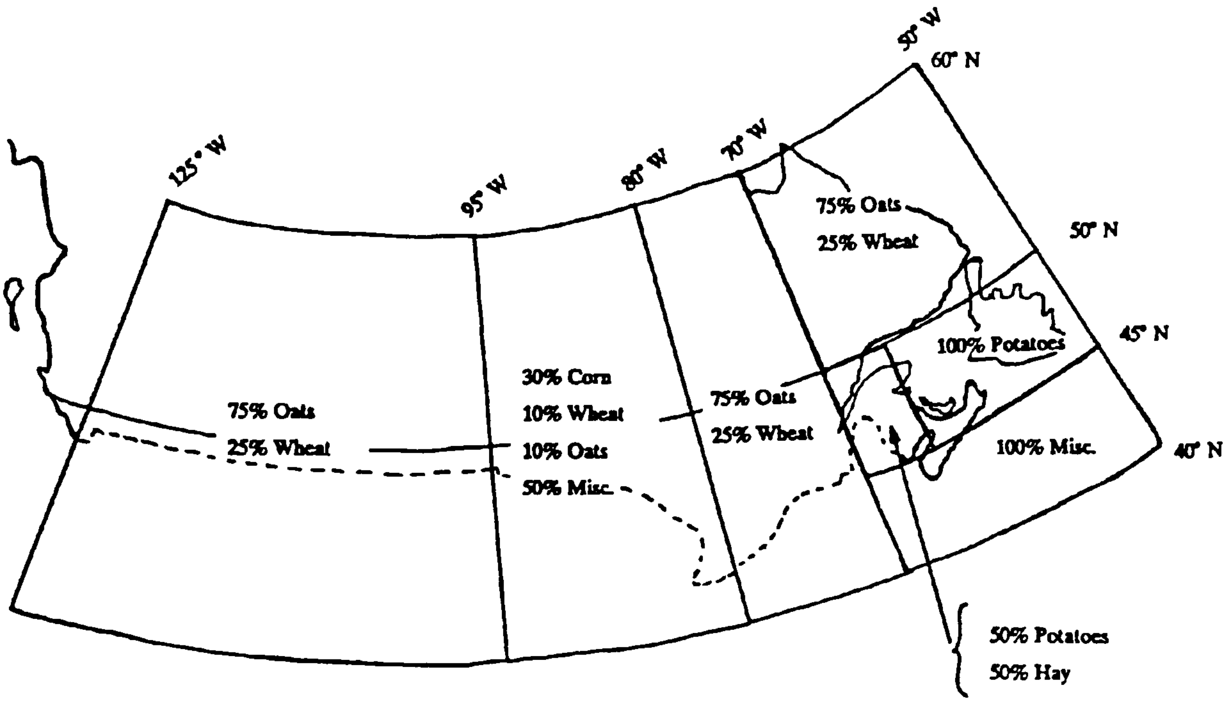

Figure 2. Agricultural class assignments.

3.2 ADJUSTMENT OF BIOMASS DENSITY

3.2.1 Growing Season

We used first and last frost dates to determine the growing season for vegetation. We acquired these data from (1) the ORNL Geoecology Growing Season Data File for the United States and (2) seasonal data for Canada (Kaplan, N., U.S. Environmental Protection Agency, personal communication, January 4, 1989). For simplicity, we assume that deciduous (i.e., nonconiferous) vegetation is at full biomass between the last frost date and the first frost date and at zero biomass for the rest of the year. We assume that coniferous vegetation is at full biomass over the entire year.

3.2.2 Layering of Forest Biomass

We vary the canopy biomass as a function of canopy height to simulate forest structure. We assume that deciduous forest biomass classes (including high isoprene, low isoprene, and nonisoprene) have a canopy height of 15 m, while the coniferous nonisoprene biomass class has a canopy height of 20 m.

Table 3 presents the height and the estimated fraction of biomass for each layer (B. Lamb, Washington State University, personal communication, 1989).

TABLE 3. LAYERS FOR FOREST BIOMASS CLASSES

Layer variable name	Layer height, m	Fraction of biomass by layer
	DECIDUOUS (High Isoprene, Low Isoprene, Nonisoprene)	
LA1	3.75 - 5.25	0.00
LA2	5.25 - 6.75	0.00
LA3	6.75 - 8.25	0.02
LA4	8.25 - 9.75	0.11
LA5	9.75 - 11.25	0.22
LA6	11.25 - 12.75	0.35
LA7	12.75 - 14.25	0.22
LA8	14.25 - 15.00	0.09
	CONIFEROUS	
LA9	5.0 - 7.0	0.025
LA10	7.0 - 9.0	0.050
LA11	9.0 - 11.0	0.150
LA12	11.0 - 12.0	0.215
LA13	12.0 - 15.0	0.215
LA14	15.0 - 17.0	0.165
LA15	17.0 - 19.0	0.120
LA16	19.0 - 20.0	0.050

Source: B. Lamb, Washington State University, personal communication, 1989.

3.3 EMISSION FACTORS

Vegetation-specific emission factors are available for the following hydrocarbon compounds: isoprene, α-pinene, other identified monoterpenes (excluding α-pinene), and other unidentified hydrocarbons. Emission rates of the unidentified hydrocarbons can be estimated. The reactivity of the unidentified hydrocarbons is uncertain; we assume that about 95% of the unidentified compounds are reactive, and are evenly split between terpenoid and oxygenated compounds.

3.3.1 Canopy

Table 4 lists the compound-specific emission factors [in units of $\mu g_{compound}/(g_{biomass} \cdot h)$] for the forest biomass classes.

The canopy emission factors are standardized to 30 °C using the temperature relationship of Tingey (1981). Each emission factor represents the geometric mean emission rate for a forest biomass class (B. Lamb, Washington State University, personal communication, 1988).

The compound-specific emission factor by vegetation class (oak, other deciduous, or coniferous) is the product of the forest biomass density for the vegetation class (from Table 2) and the canopy emission factor for the hydrocarbon compound (from Table 4), summed over the four forest biomass classes.

TABLE 4. CANOPY EMISSION FACTORS AT 30 °C

Hydrocarbon compound	Forest biomass class	Canopy emission factor, $[\mu g_{compound}/(g_{biomass} \cdot h)]$
Isoprene	Deciduous high isoprene	14.69
	Deciduous low isoprene	6.60
	Deciduous nonisoprene	0.00
	Coniferous nonisoprene	0.00
α-pinene	Deciduous high isoprene	0.13
	Deciduous low isoprene	0.05
	Deciduous nonisoprene	0.07
	Coniferous nonisoprene	1.13
Other identified monoterpenes	Deciduous high isoprene	0.11
	Deciduous low isoprene	0.05
	Deciduous nonisoprene	0.07
	Coniferous nonisoprene	1.29
Other unidentified hydrocarbons	Deciduous high isoprene	3.24
	Deciduous low isoprene	1.76
	Deciduous nonisoprene	1.91
	Coniferous nonisoprene	1.38

Source: B. Lamb, Washington State University, personal communication, 1988.

3.3.2 Noncanopy

Table 5 lists the noncanopy emission factors [$\mu g_{compound}/(m^2 \cdot h)$], and the hydrocarbon compound-specific emission composition (%) for the noncanopy vegetation classes.

Emission rates for a specific hydrocarbon compound can be calculated by multiplying the surface land area (for each vegetation class) by the appropriate emission factor and the fraction of hydrocarbon compound composition.

TABLE 5. NONCANOPY EMISSION FACTORS AT 30 °C AND ESTIMATED PERCENT COMPOSITION OF EMISSIONS

		Estimated emissions composition (%)			
Noncanopy vegetation class	Noncanopy emission factor, [$\mu g_{compound}/(m^2 \cdot h)$]	Isoprene	α-pinene	Other mono-terpenes	Other unidentified hydrocarbons
Natural Vegetation:					
Grass	281.0	20	25	25	30
Scrub*	189.0	20	25	25	30
Agricultural Crops:					
Alfalfa	37.9	50	10	10	30
Barley †	37.9	20	25	25	30
Corn	3,542.0	0	10	10	80
Cotton †	37.9	20	25	25	30
Hay	189.0	20	25	25	30
Oats †	37.9	20	25	25	30
Peanuts	510.0	20	25	25	30
Potatoes	48.1	20	25	25	50
Rice	510.0	20	25	25	30
Rye †	37.9	20	25	25	30
Sorghum	39.4	20	25	25	30
Soybeans	22.2	100	0	0	0
Tobacco	294.0	0	10	10	80
Wheat	30.0	50	10	10	30
Misc. crops †	37.9	20	25	25	30
Water: ‡					
Barren Area: ‡					

Source: B. Lamb, Washington State University, personal communication, 1988.

* Emission factor is assumed to equal the hay emission factor.

† Emission factor is assumed to equal the alfalfa emission factor.

‡ Used only in the reconciliation of land area.

3.4 ADJUSTMENT OF EMISSION FACTORS

3.4.1 Tingey Temperature and Solar Intensity Corrections

Several studies have shown the effects of temperature and solar intensity on hydrocarbon emissions. We adjust the gridded compound-specific emission factors for variations in temperature and solar intensity with Tingey's curves (Tingey, 1981). Tingey's laboratory work with slash pine and live oak has yielded logarithmic equations to describe the increase in isoprene emissions due to the combined effect of temperature and solar intensity, and the increase in nonisoprene emissions due to temperature only. These equations are listed below.

For isoprene emissions,

$$E_{adj} = E_{30} \cdot \frac{10^{\left\{\frac{a}{1+\exp[-b(T-c)]} \quad d\right\}}}{e}$$

where: E_{adj} is the adjusted emission factor at temperature T [$\mu g_{isoprene}/(g_{biomass} \cdot h)$],

E_{30} is the emission factor at 30 °C [$\mu g_{isoprene}/(g_{biomass} \cdot h)$], and

T is the hourly ambient temperature (°C), used as a surrogate for leaf temperature.

Table 6 lists the equation coefficients *a*, *b*, *c*, *d*, and *e* for four levels of light intensity ($\mu E/m^2$, where: μE represents micro-einsteins, a unit of light energy). For light intensities not listed, we used linear interpolation to calculate adjusted emission factors. Note that the biogenic emissions inventory system for the RADM uses cloud cover data to attenuate light intensity values on an hourly basis.

TABLE 6. ISOPRENE TEMPERATURE AND SOLAR INTENSITY ADJUSTMENT COEFFICIENTS

	Isoprene equation coefficient (unitless)				
Light intensity [$\mu E/(m^2 \cdot s)$] *	*a*	*b*	*c*	*d*	*e*
800	1.200	0.400	28.30	0.796	1.00
400	0.916	0.239	29.93	0.462	1.95
200	0.615	0.696	32.79	0.077	4.75
100	0.437	0.312	31.75	0.160	10.73

Sources: Tingey, 1981, and Pierce *et al.*, 1990.

* μE represents micro-einsteins, a unit of light energy.

The coefficients for light intensity of 800 $\mu E/m^2$ were modified from Tingey's values to match a light intensity of 400 $\mu E/m^2$ for temperatures of less than 29 °C. Also, the original Tingey equation expressed emissions in terms of $\mu g_{carbon\,mass}/dm^2$ leaf area; the isoprene equation presented above includes unit conversions (68/60 represents the ratio of isoprene mass to carbon mass; 1.205 is the number of grams of biomass per square decimeter of leaf area).

For nonisoprene emissions (α-pinene, other identified monoterpenes, and other unidentified hydrocarbons),

$$E_{adj} = E_{30} \cdot \exp(a[T-30])$$

where: E_{adj} is the adjusted emission factor at temperature T [$\mu g_{nonisoprene}/(g_{biomass} \cdot h)$],

E_{30} is the emission factor at 30 °C [$\mu g_{nonisoprene}/(g_{biomass} \cdot h)$], and

T is the hourly ambient temperature (°C), used as a surrogate for leaf temperature.

The emission factor in Tingey's equation was expressed in units of $\mu g_{carbon\,mass}/(g_{biomass} \cdot h)$. The nonisoprene equation presented above has been converted to units of $\mu g_{compound}/(g_{biomass} \cdot h)$ using the ratio 136/120, i.e., the ratio of nonisoprene mass (as α-pinene) to carbon mass. Table 7 lists the coefficient a of the nonisoprene adjustment equation by hydrocarbon compound.

TABLE 7. NONISOPRENE TEMPERATURE ADJUSTMENT COEFFICIENTS

Hydrocarbon compound	Nonisoprene equation coefficient (unitless) a
α-pinene	0.067
Other identified monoterpenes (excluding α-pinene)	0.0739
Other unidentified hydrocarbons	0.0739

Source: Tingey, 1981 and Pierce *et al.*, 1990.

3.4.2 Layered Correction Factors for Forest Biomass Classes

A canopy model has been developed by the Laboratory for Atmospheric Research at Washington State University (Gay, 1987). It is used to adjust emission factors for the four forest biomass classes (deciduous high isoprene, deciduous low isoprene, deciduous nonisoprene, and coniferous nonisoprene).

Typical leaf biomass profiles are assumed for the deciduous and coniferous forest types (as discussed in Section 3.2.2). The leaf area indices corresponding to these biomass profiles are apportioned into eight vertical layers for each forest type.

The canopy model utilizes hourly meteorological data for the episode, including ambient temperature, solar radiation, relative humidity, and wind speed. Meteorological input data are assumed to represent the top of the canopy. Within each layer and for each of the two forest types, the canopy model uses an iterative approach to compute the leaf-radiation balance of a typical leaf's surface. Solar radiation is exponentially reduced through the layers with the rate being a function of the biomass distribution. The rate of solar attenuation increases more rapidly for the photosynthetically-active region of the solar spectrum than for the rest of the spectrum, since leaves preferentially absorb visible light (Baldocchi *et al.*, 1984).

Both the total solar spectrum and the visible spectrum subset are calculated over the eight layers of the hypothetical canopies. The calculated total solar radiation is used to compute the leaf temperature at each level using the radiation balance equation of Gates and Papian (1971).

The final output from this process consists of leaf temperatures and photosynthetically-active radiation for the eight layers in the two forest types. We then use these data when applying the Tingey correction factors.

3.5 CALCULATION OF BIOGENIC EMISSIONS

For the forest biomass classes, we multiply the layered biomass by the canopy emission factors to arrive at the layered standardized emissions. These emissions are then adjusted by the layered Tingey correction factors and we sum the results to produce canopy emissions.

For the noncanopy vegetation classes, we multiply the biomass area by the noncanopy emission factors to arrive at the standardized emissions. These emissions are then adjusted using the Tingey curves to produce noncanopy emissions. The canopy and noncanopy emissions are then summed for each grid cell.

3.6 QUALITY CONTROL

Quality control efforts by the EPA have focused on reconciling land area values. The sum of the areas allocated to all the vegetation classes in a county (natural vegetation, agricultural crops, urban, water, and barren areas) must equal the total area of the county. Similarly, the sum of the areas allocated to all the vegetation classes in one grid cell must equal the total area of the grid cell. Thus, we account for all the land area in a county or grid cell.

New or revised emission factors resulting from further studies of hydrocarbon emissions from vegetative species will be incorporated into the biogenic emissions inventory system.

3.7 REFERENCES

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APPENDIX C

GRID PLOTS OF INTERPOLATED METEOROLOGICAL DATA FOR SELECT MONTHS

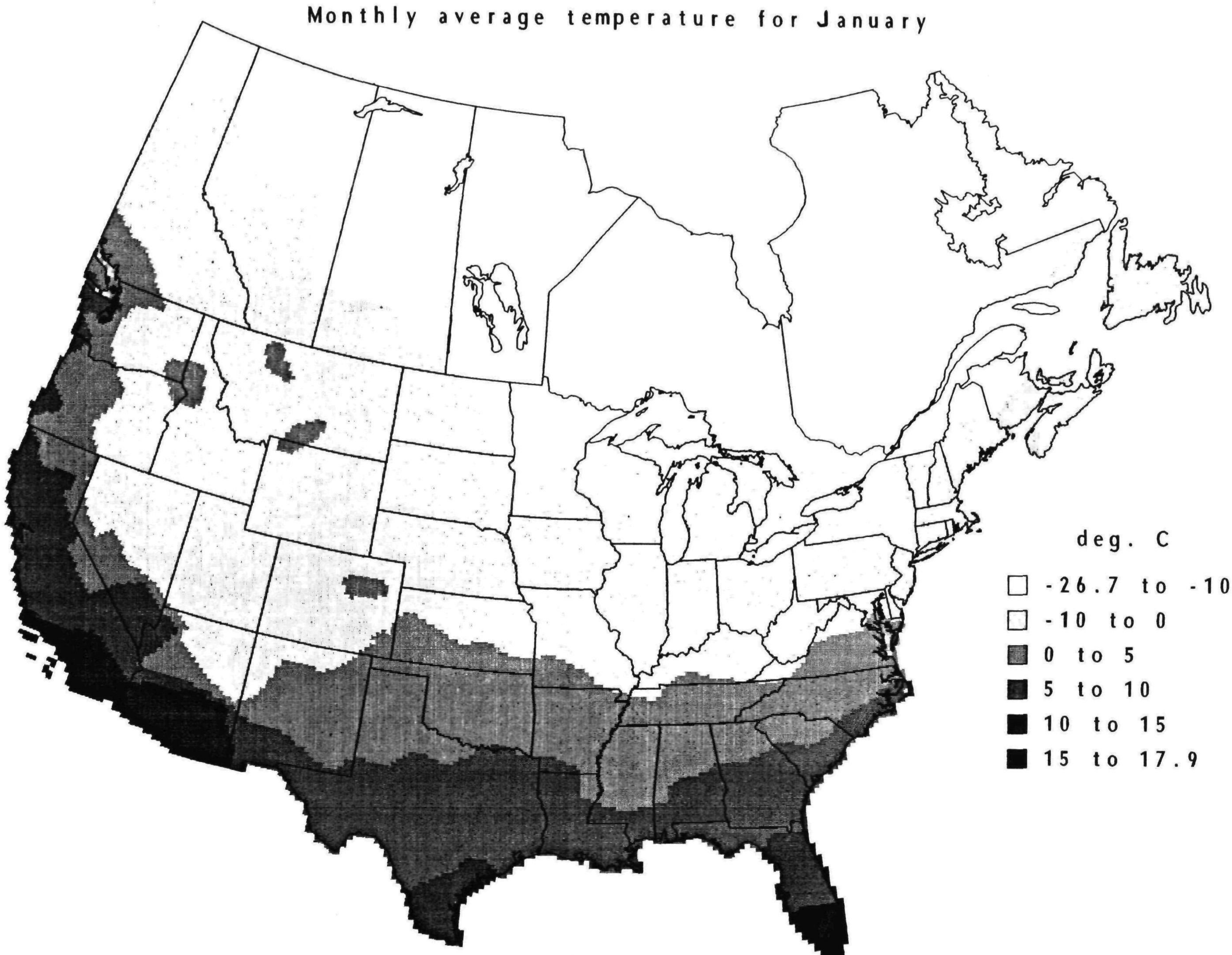
Monthly average temperature for January
deg. C
-26.7 to -10
-10 to 0
0 to 5
5 to 10
10 to 15
15 to 17.9

Figure C-1.

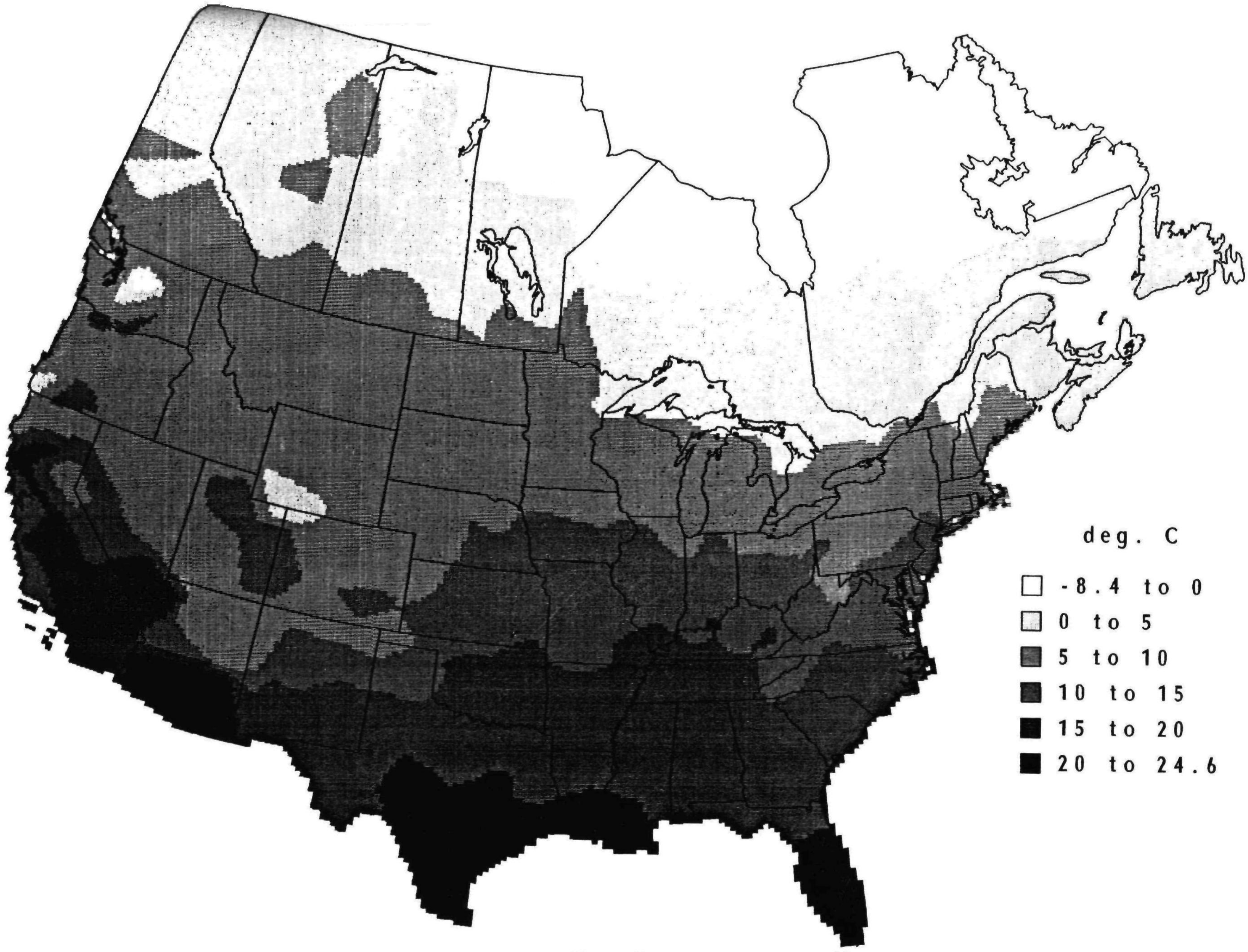

Figure C-2.

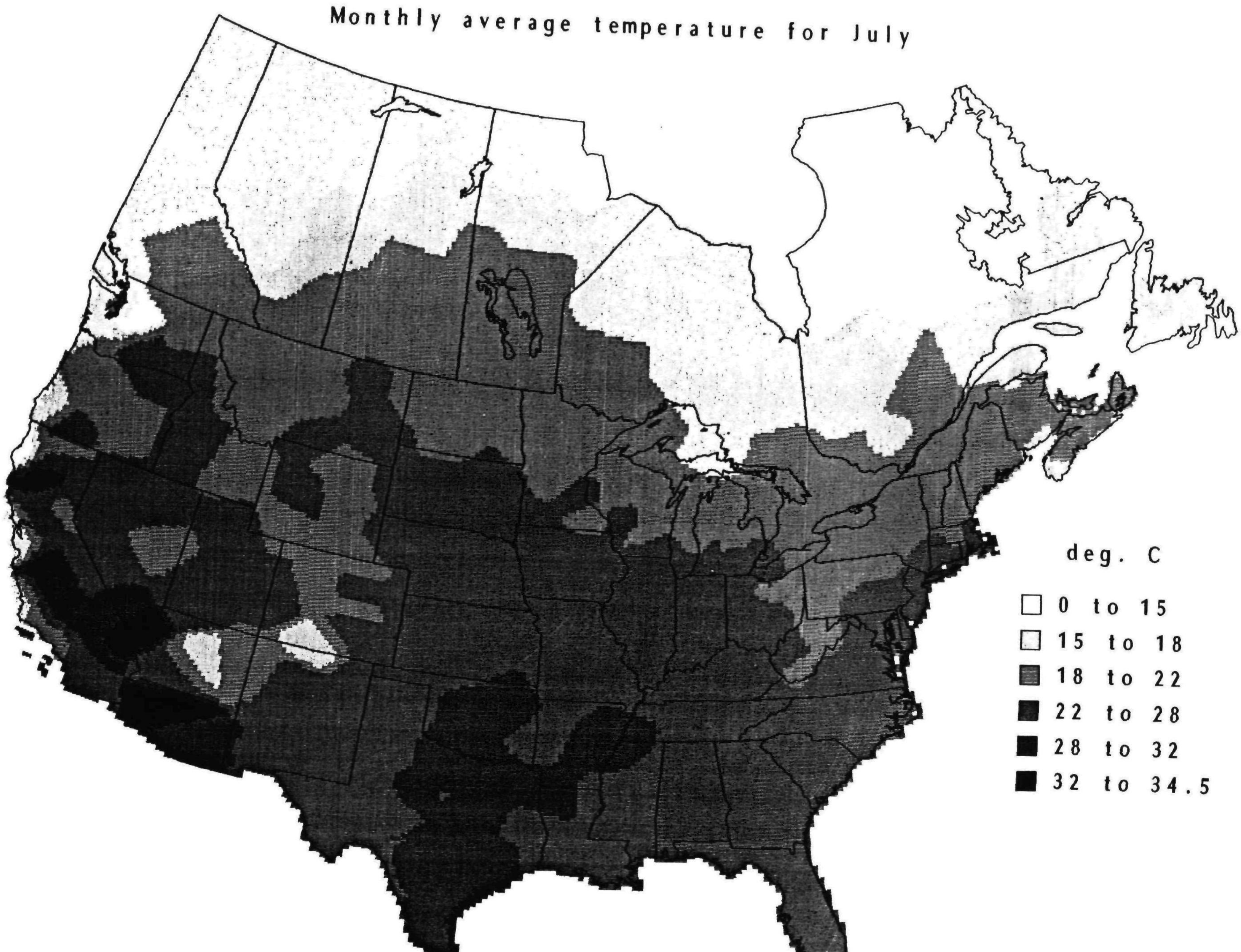
Monthly average temperature for July
deg. C
0 to 15
15 to 18
18 to 22
22 to 28
28 to 32
32 to 34.5

Figure C-3.

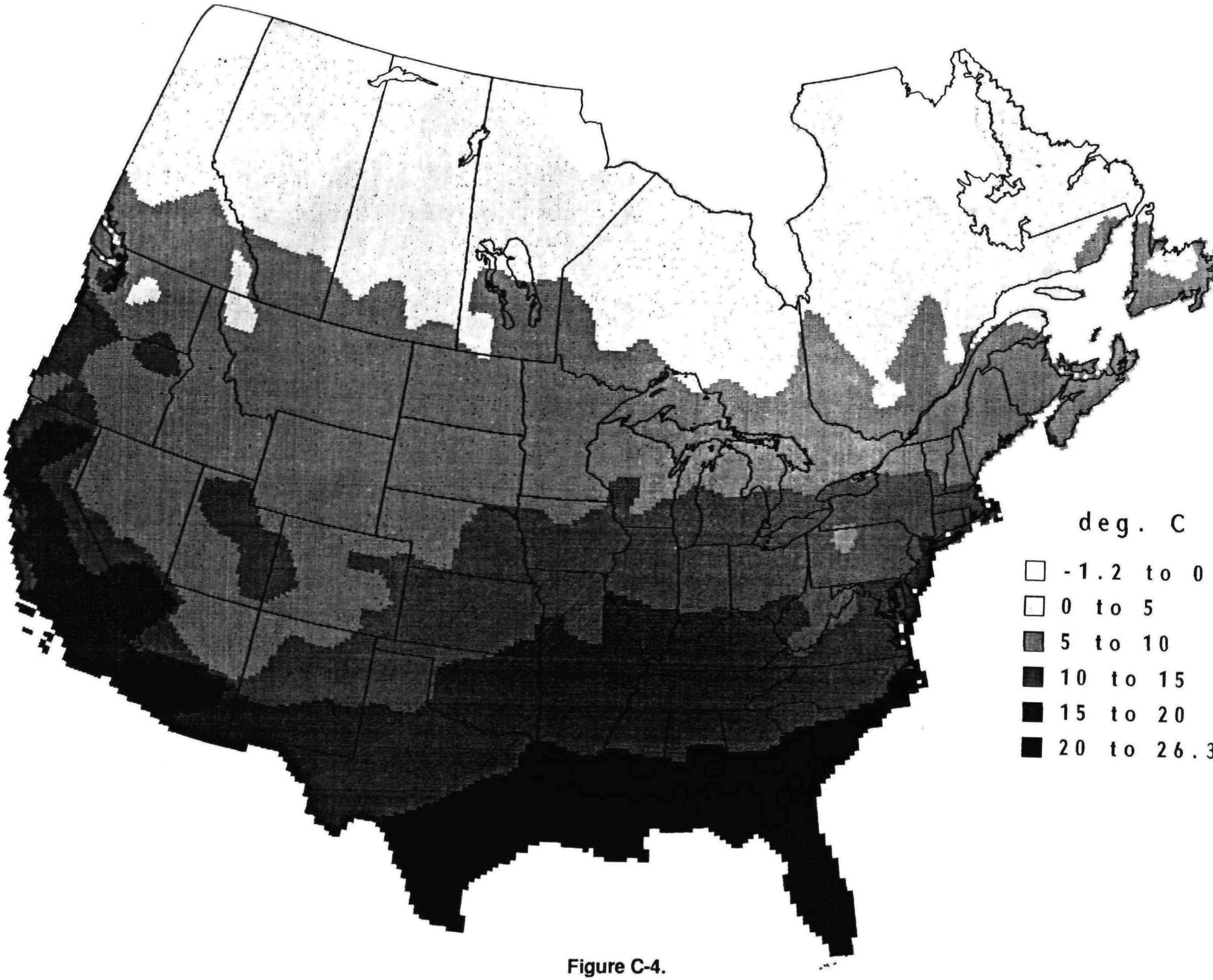

Figure C-4.

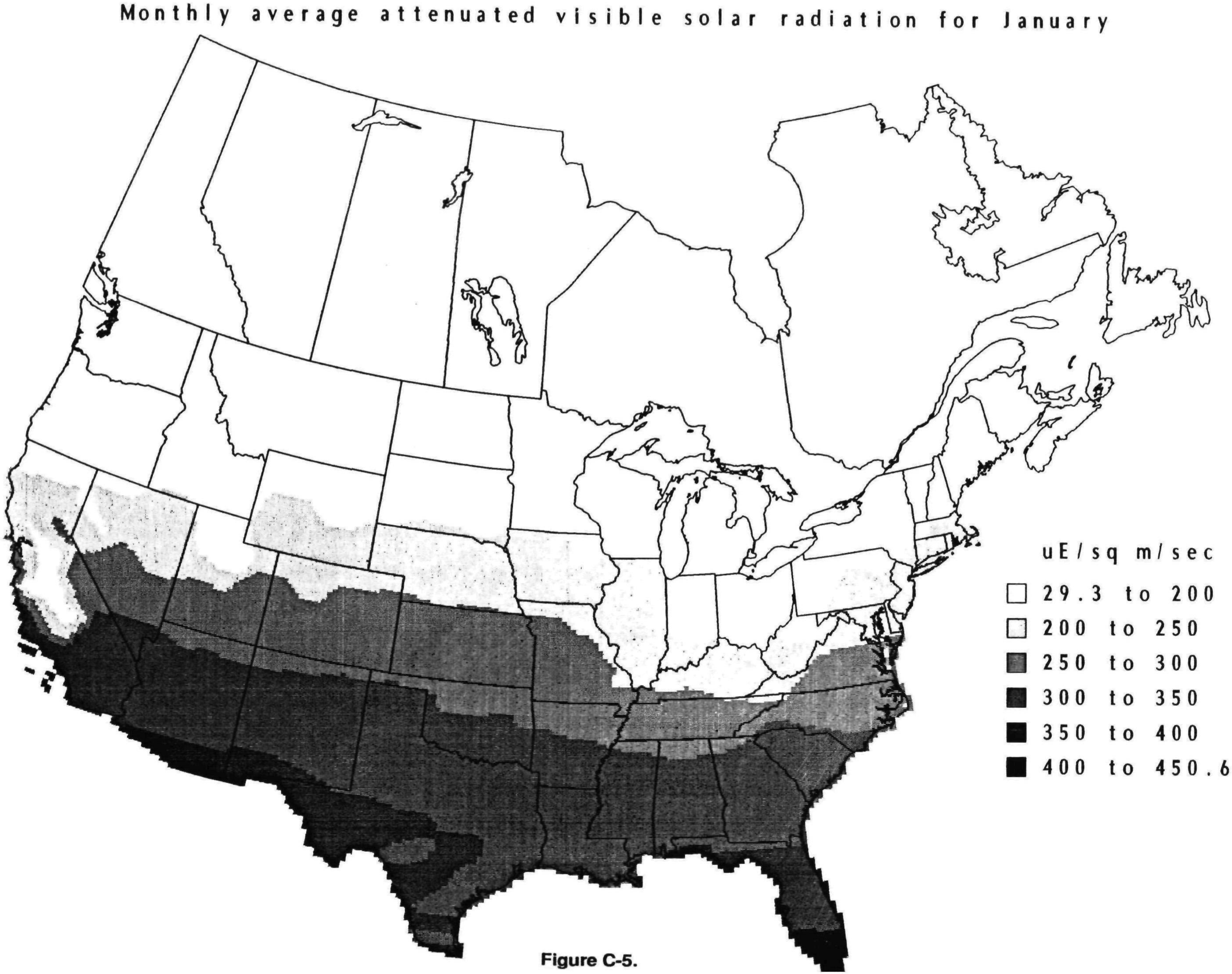
Monthly average attenuated visible solar radiation for January
uE/sq m/sec
29.3 to 200
200 to 250
250 to 300
300 to 350
350 to 400
400 to 450.6

Figure C-5.

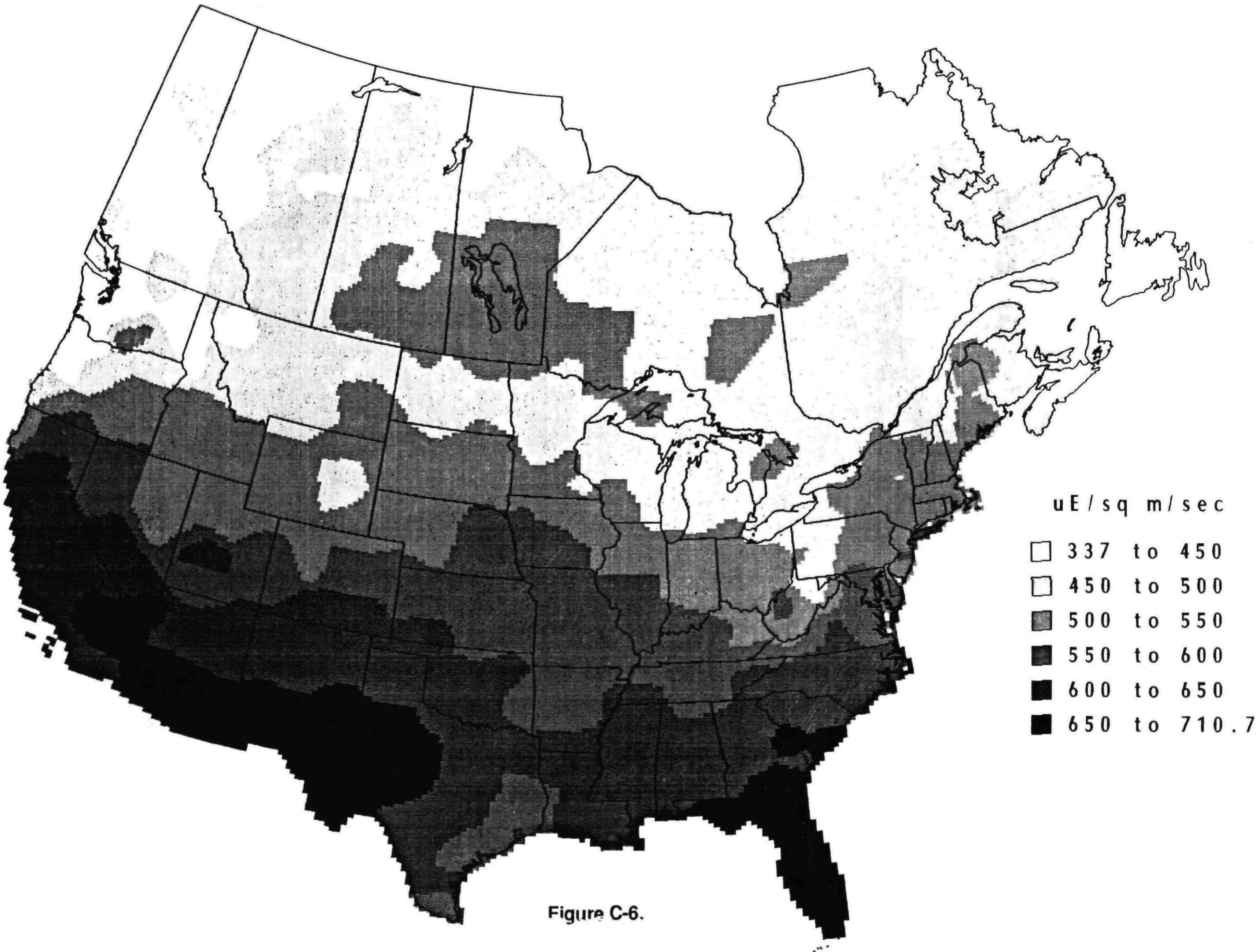
uE / sq m / sec
337 to 450
450 to 500
500 to 550
550 to 600
600 to 650
650 to 710.7

Figure C-6.

Monthly average attenuated visible solar radiation for July

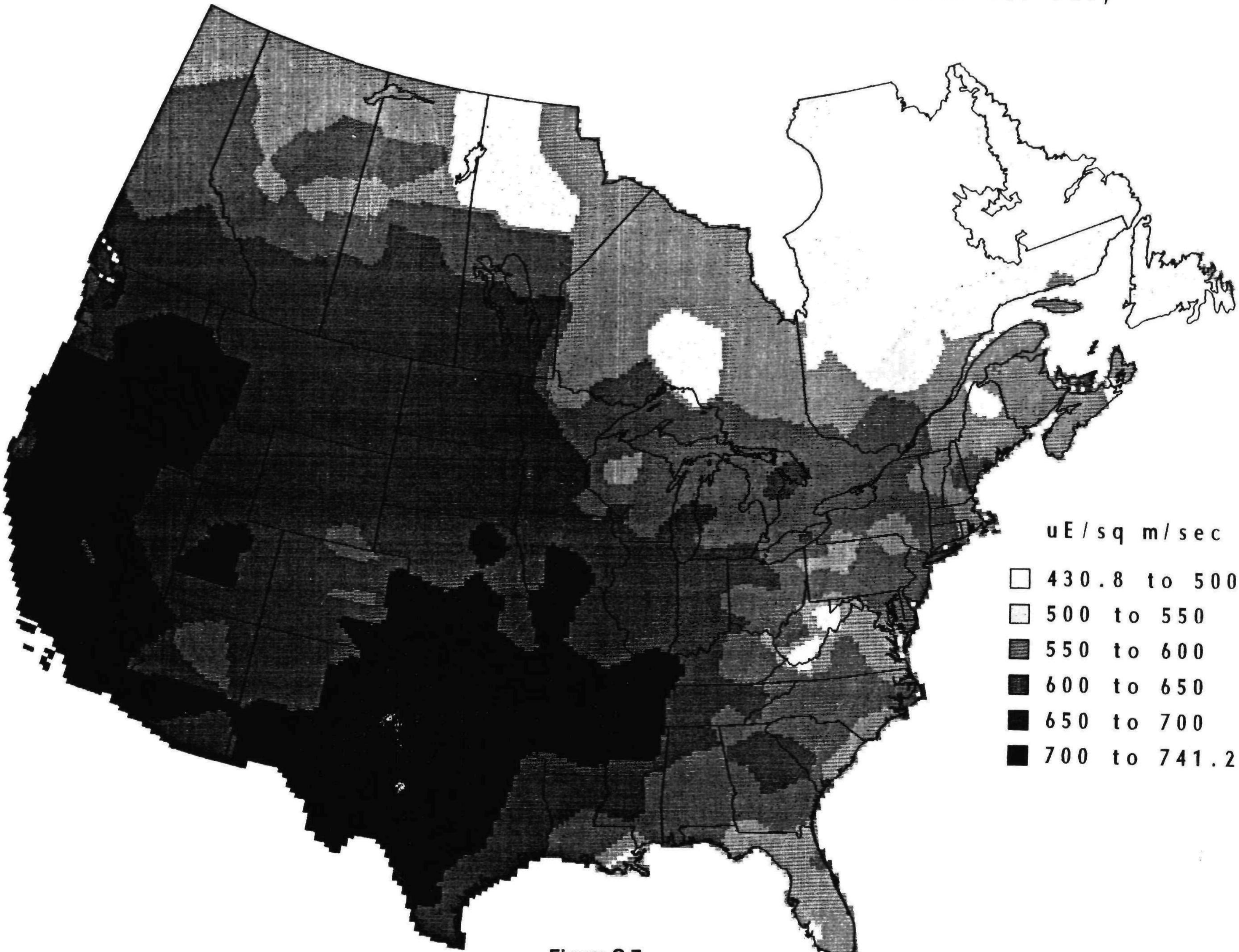

Figure C-7.

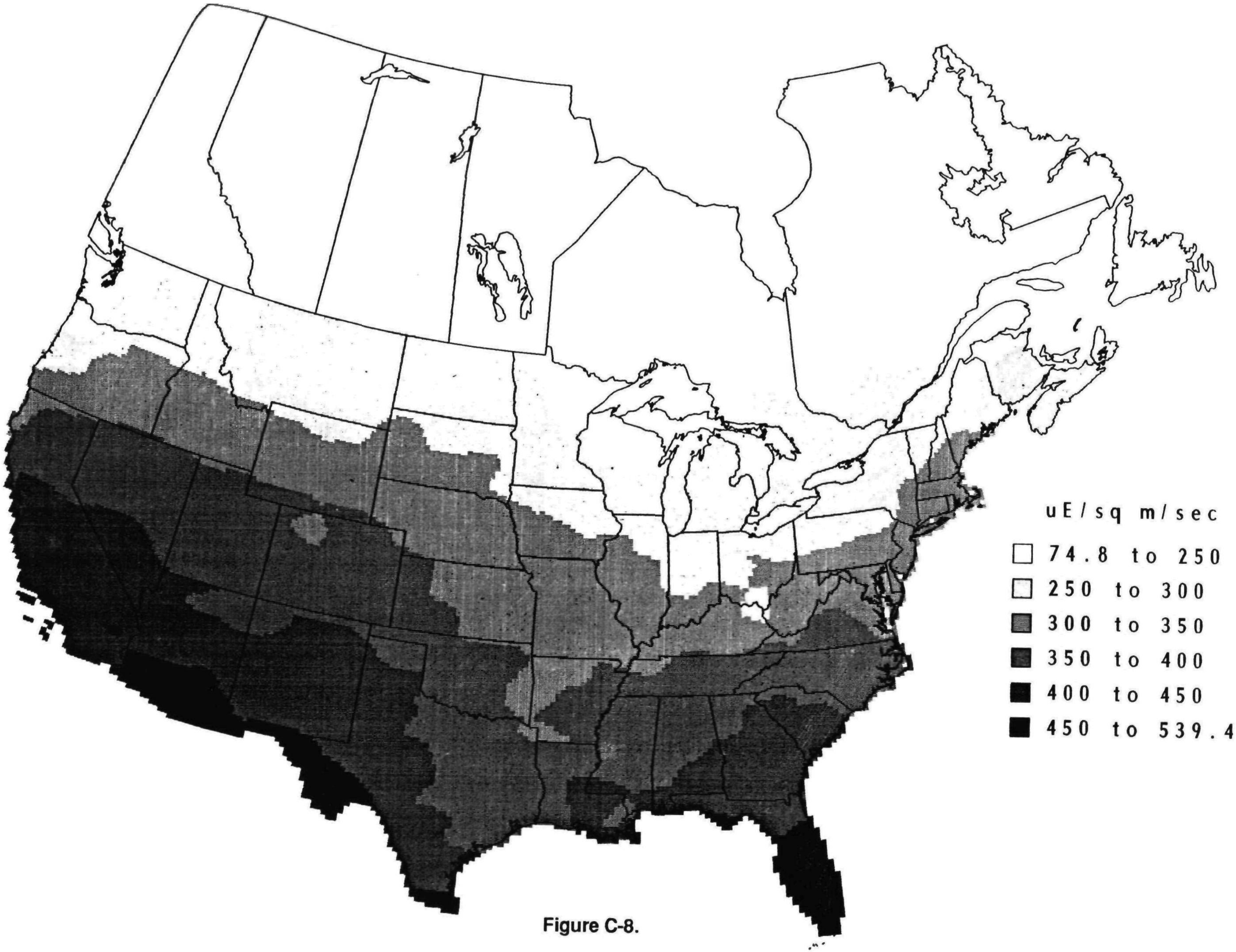
uE/sq m/sec
74.8 to 250
250 to 300
300 to 350
350 to 400
400 to 450
450 to 539.4

Figure C-8.

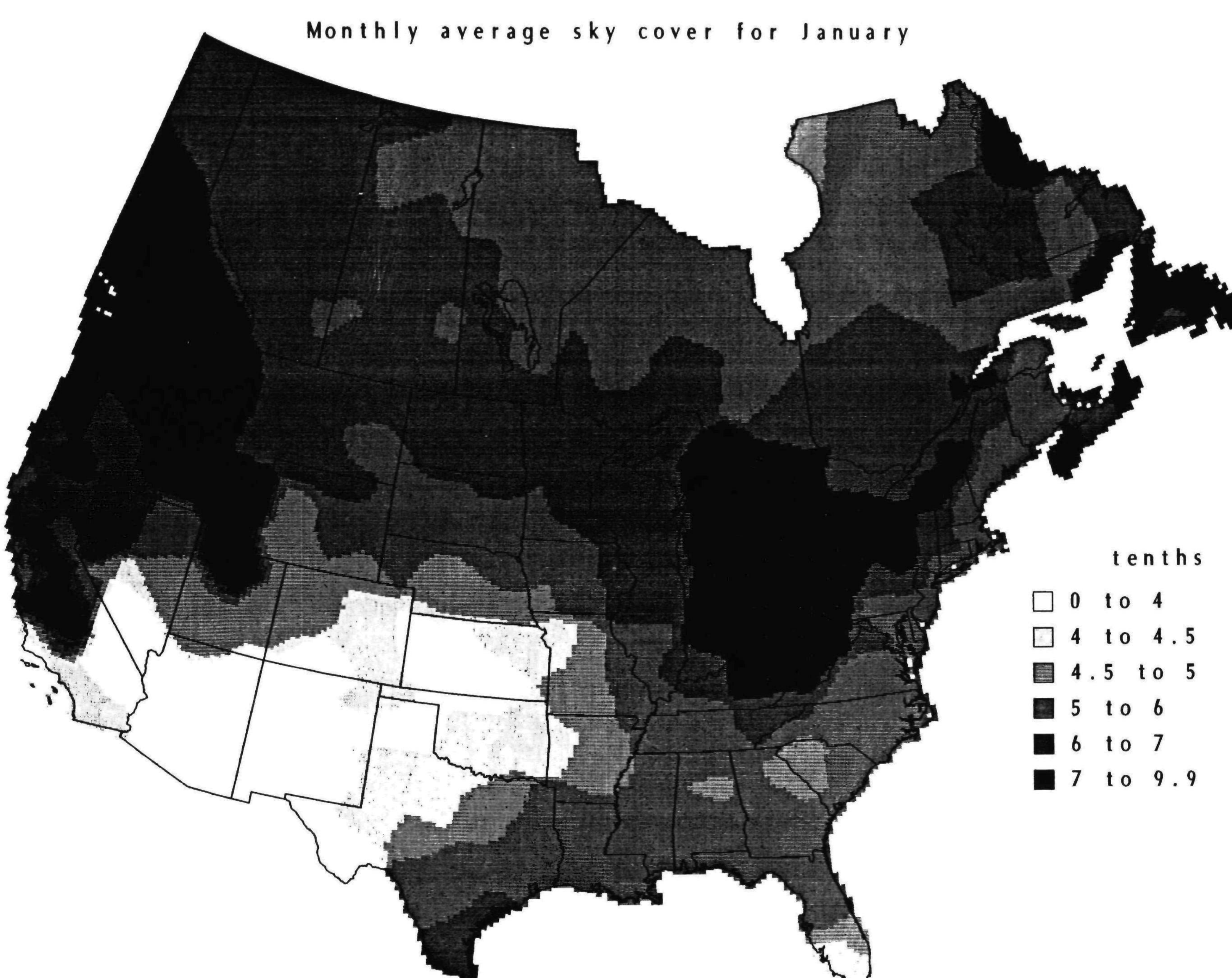
Monthly average sky cover for January
tenths
0 to 4
4 to 4.5
4.5 to 5
5 to 6
6 to 7
7 to 9.9

Figure C-9.

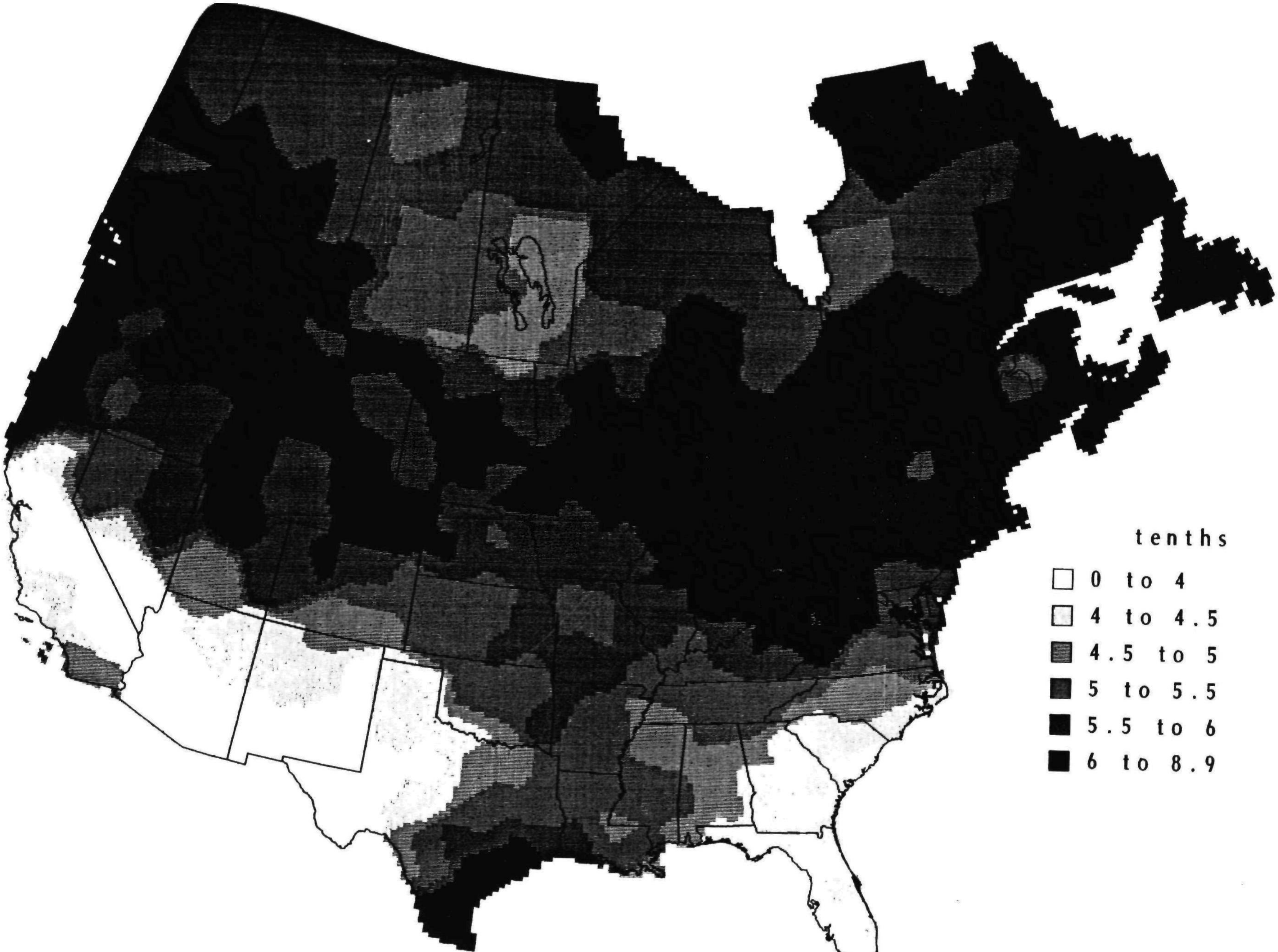

Figure C-10.

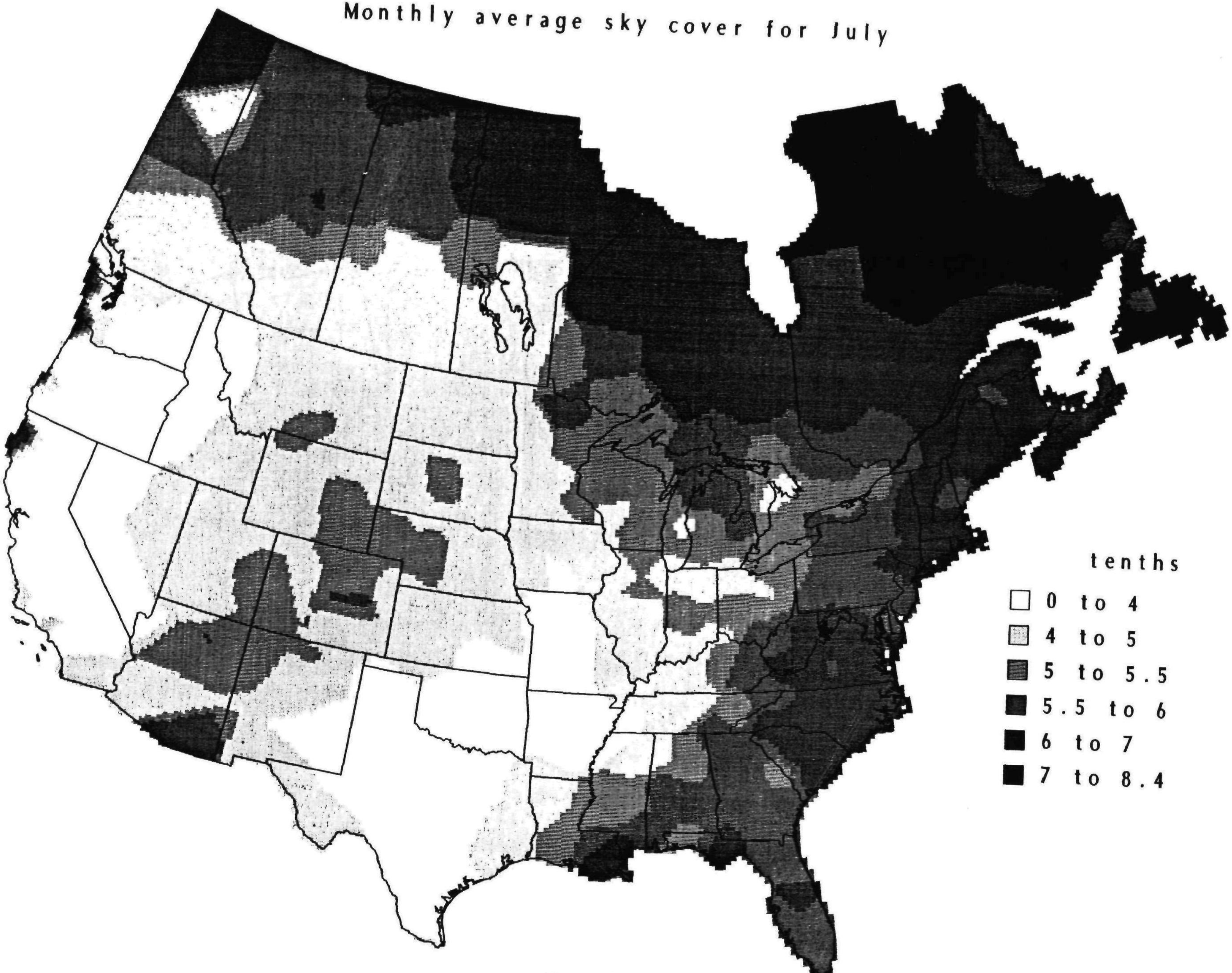
Monthly average sky cover for July
tenths
0 to 4
4 to 5
5 to 5.5
5.5 to 6
6 to 7
7 to 8.4

Figure C-11.

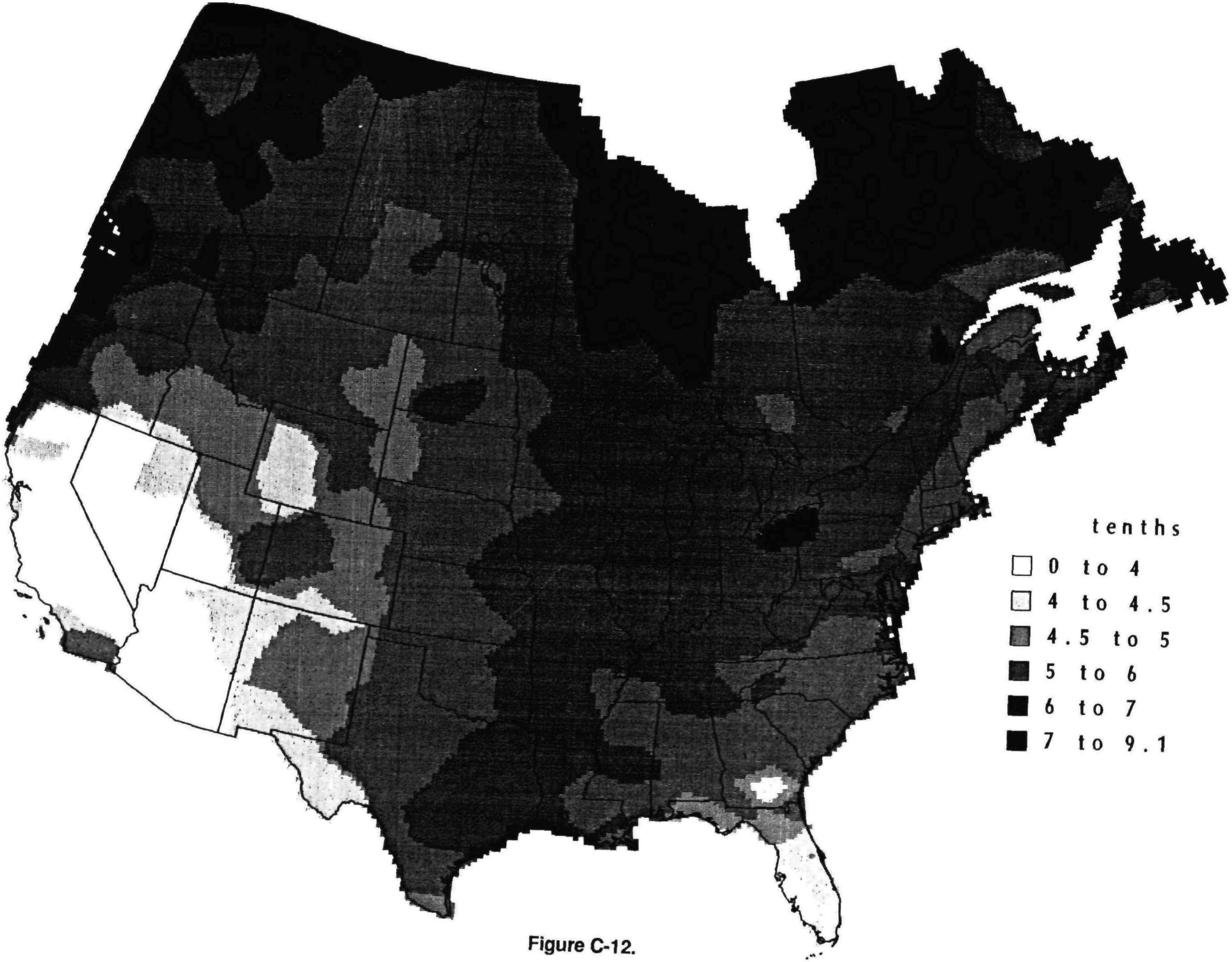

Figure C-12.

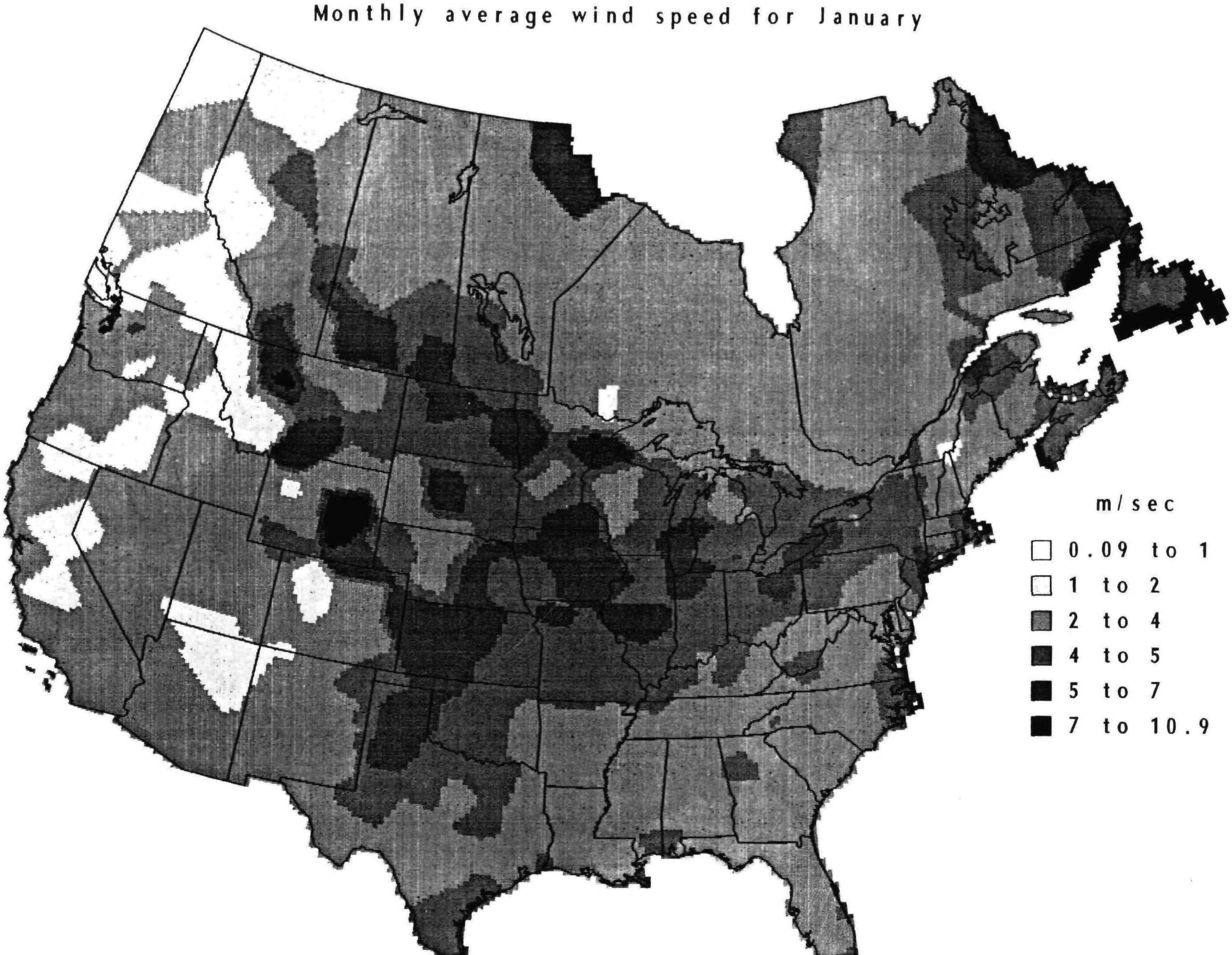
Monthly average wind speed for January
m/sec
0.09 to 1
1 to 2
2 to 4
4 to 5
5 to 7
7 to 10.9

Figure C-13.

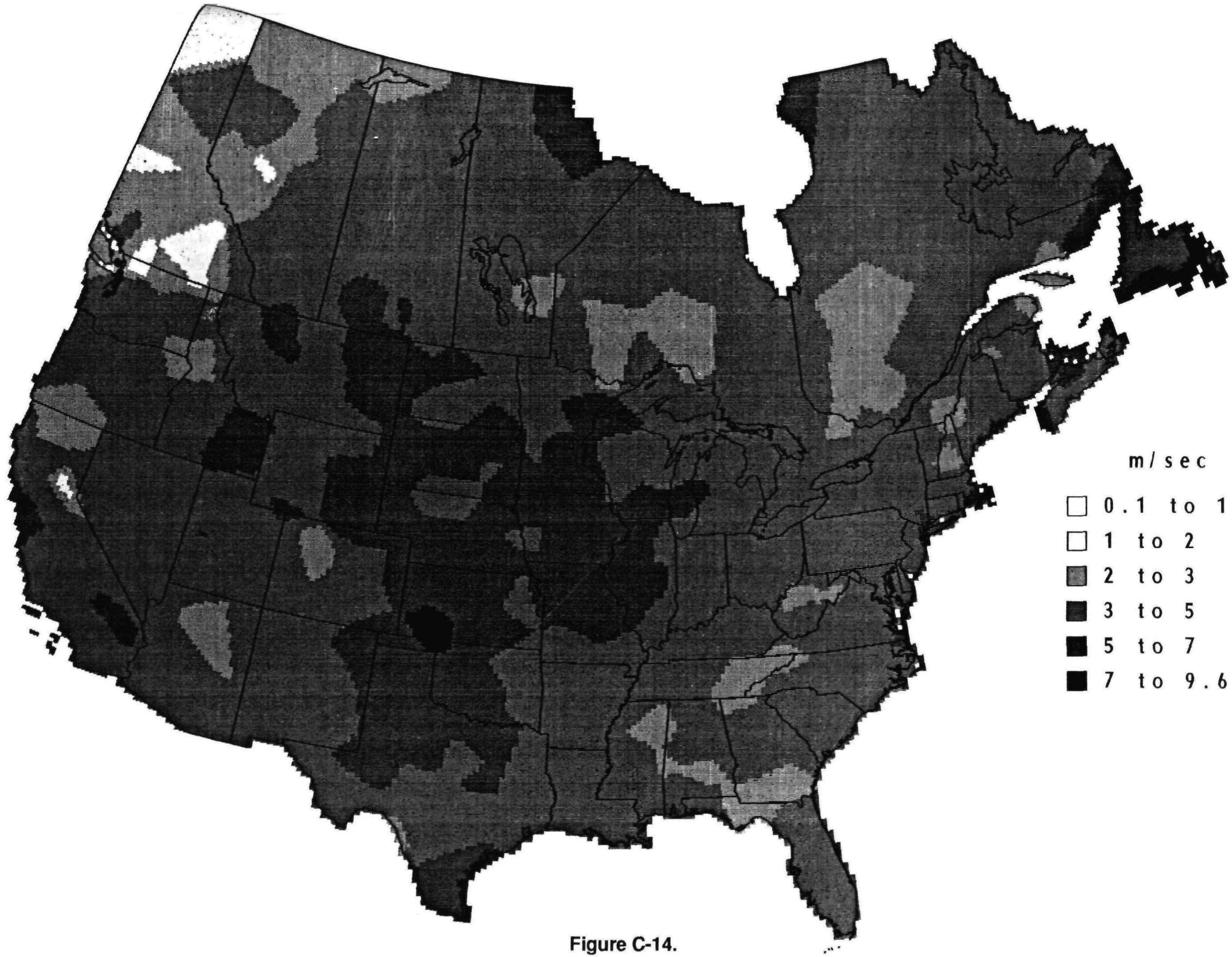

Figure C-14.

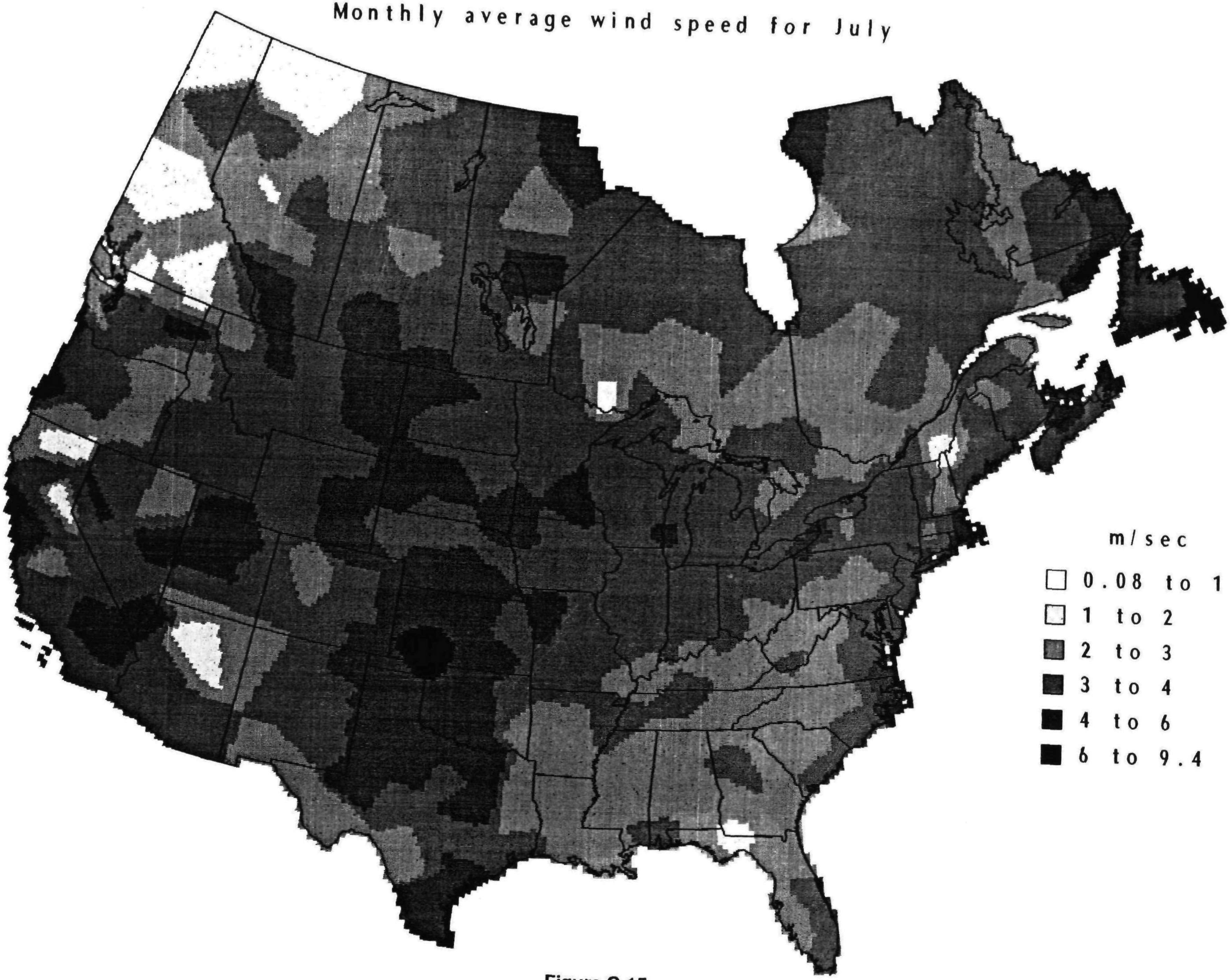
Monthly average wind speed for July
m/sec
0.08 to 1
1 to 2
2 to 3
3 to 4
4 to 6
6 to 9.4

Figure C-15.

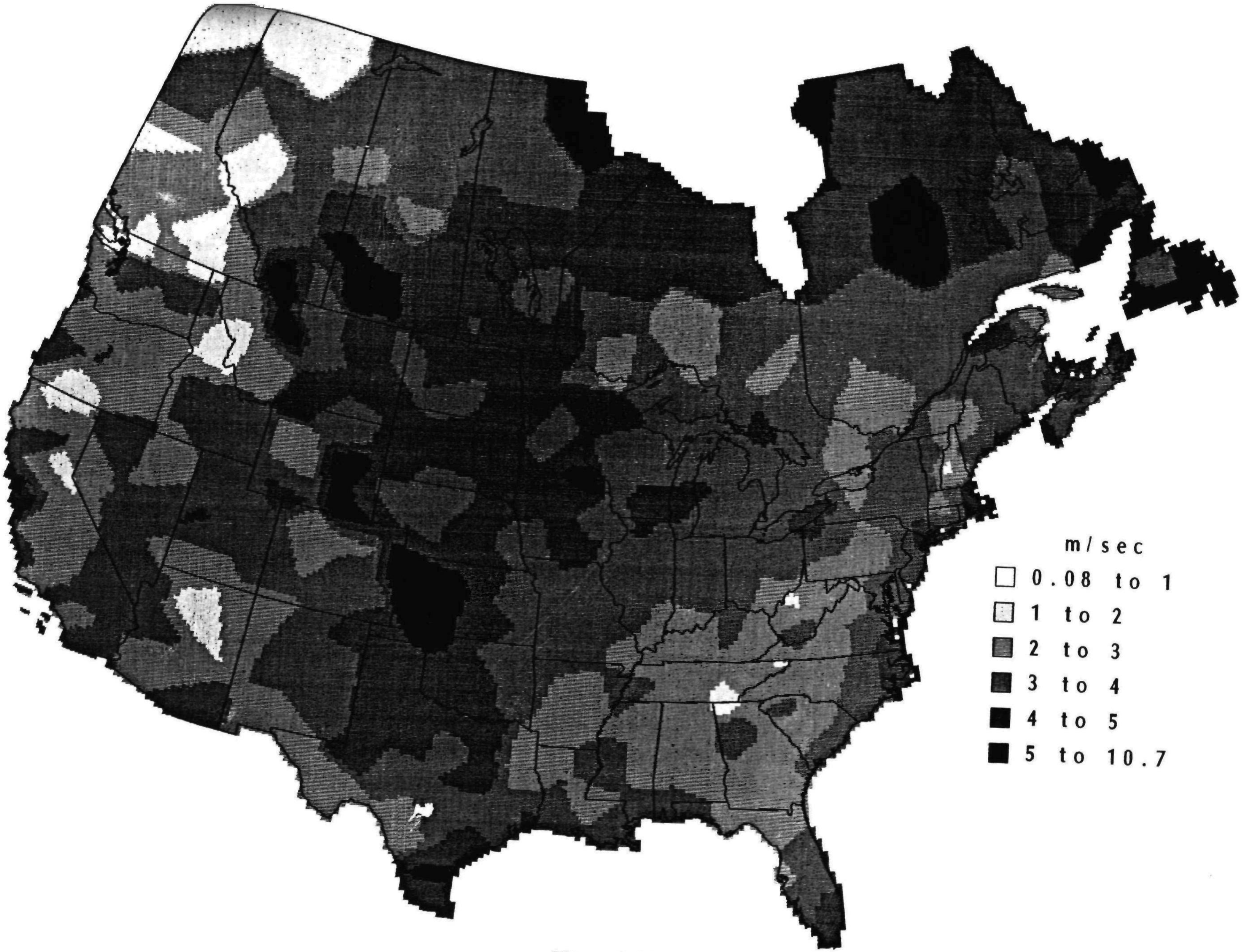

Figure C-16.

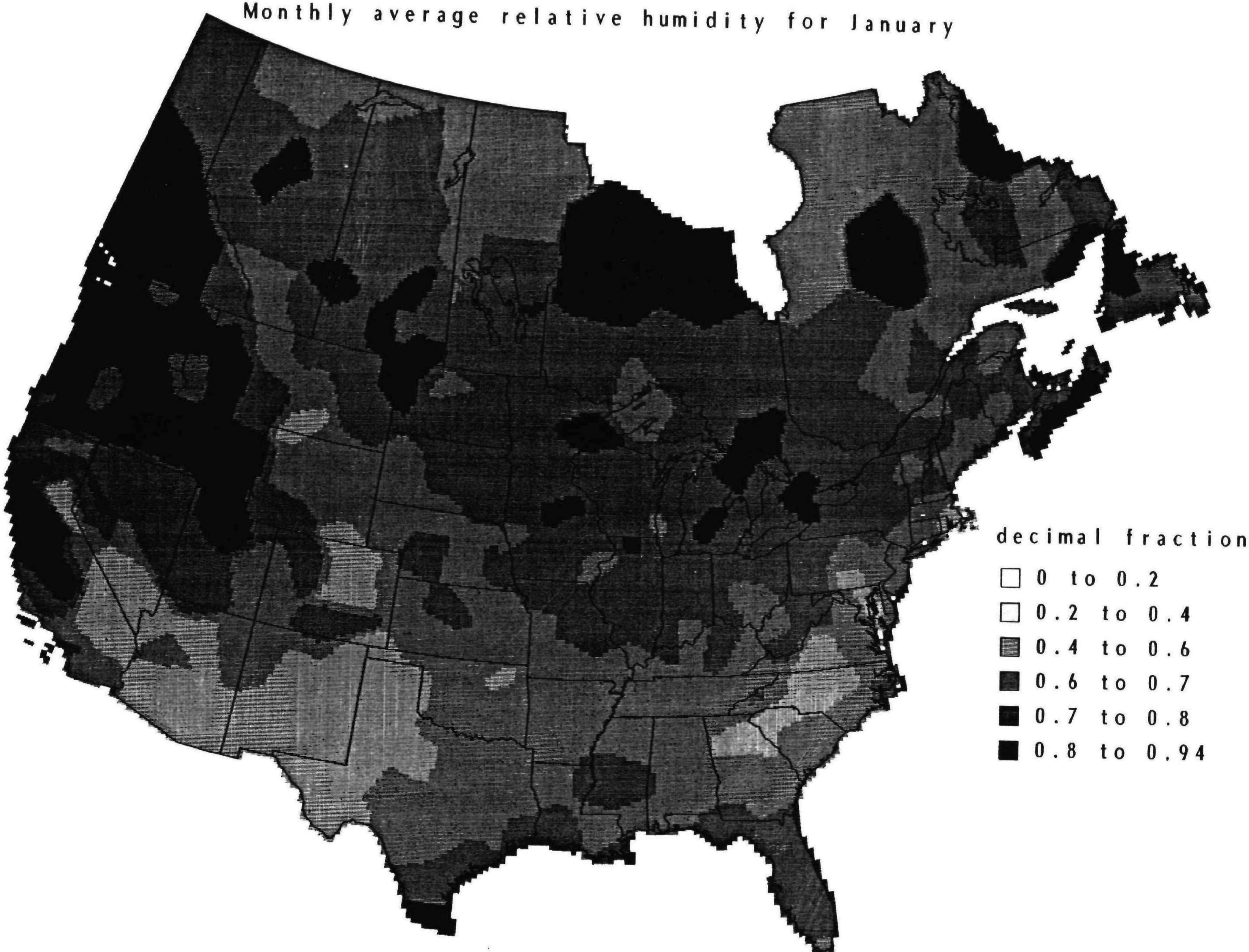
Monthly average relative humidity for January
decimal fraction
0 to 0.2
0.2 to 0.4
0.4 to 0.6
0.6 to 0.7
0.7 to 0.8
0.8 to 0.94

Figure C-17.

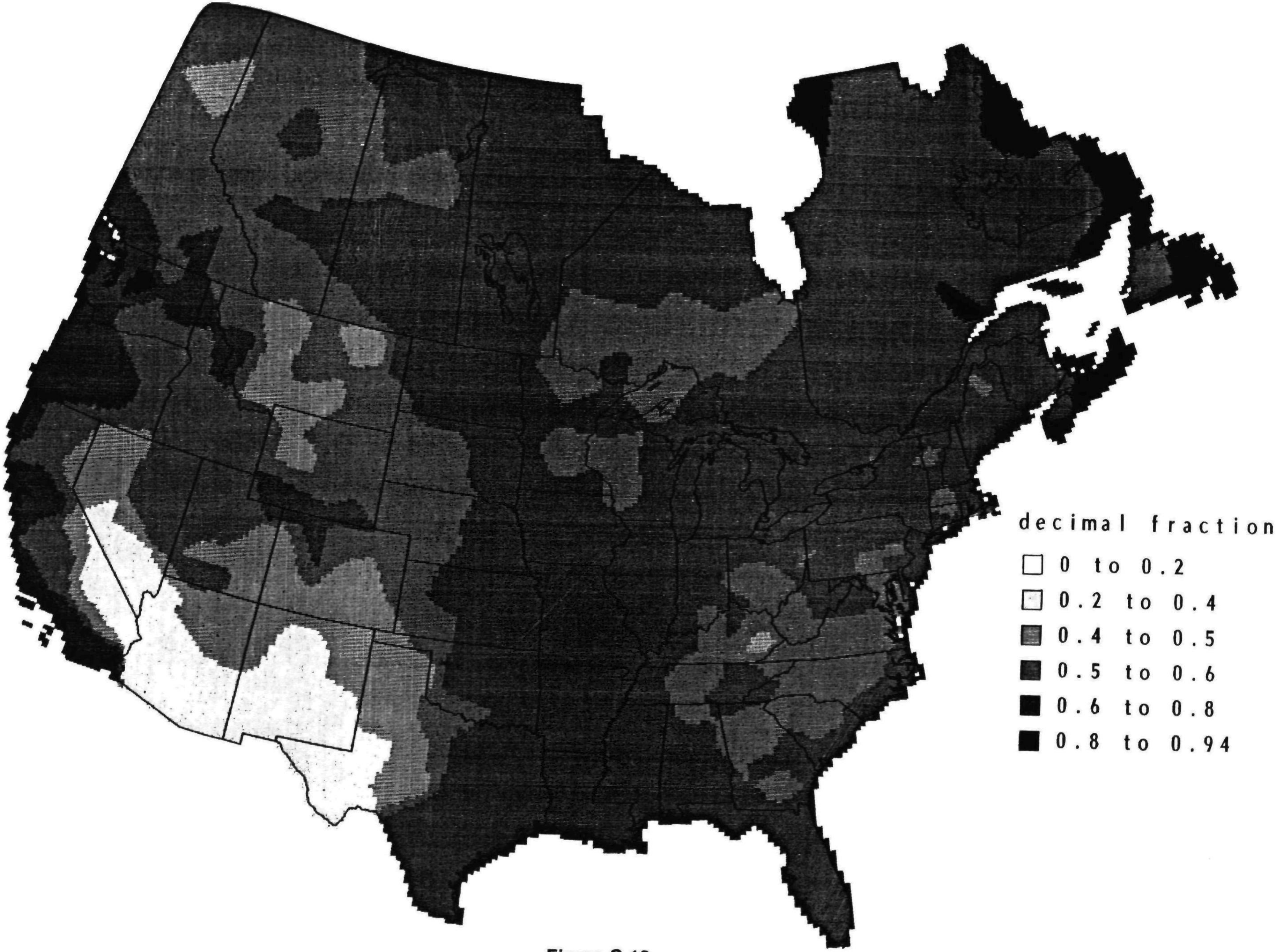
decimal fraction
0 to 0.2
0.2 to 0.4
0.4 to 0.5
0.5 to 0.6
0.6 to 0.8
0.8 to 0.94

Figure C-18.

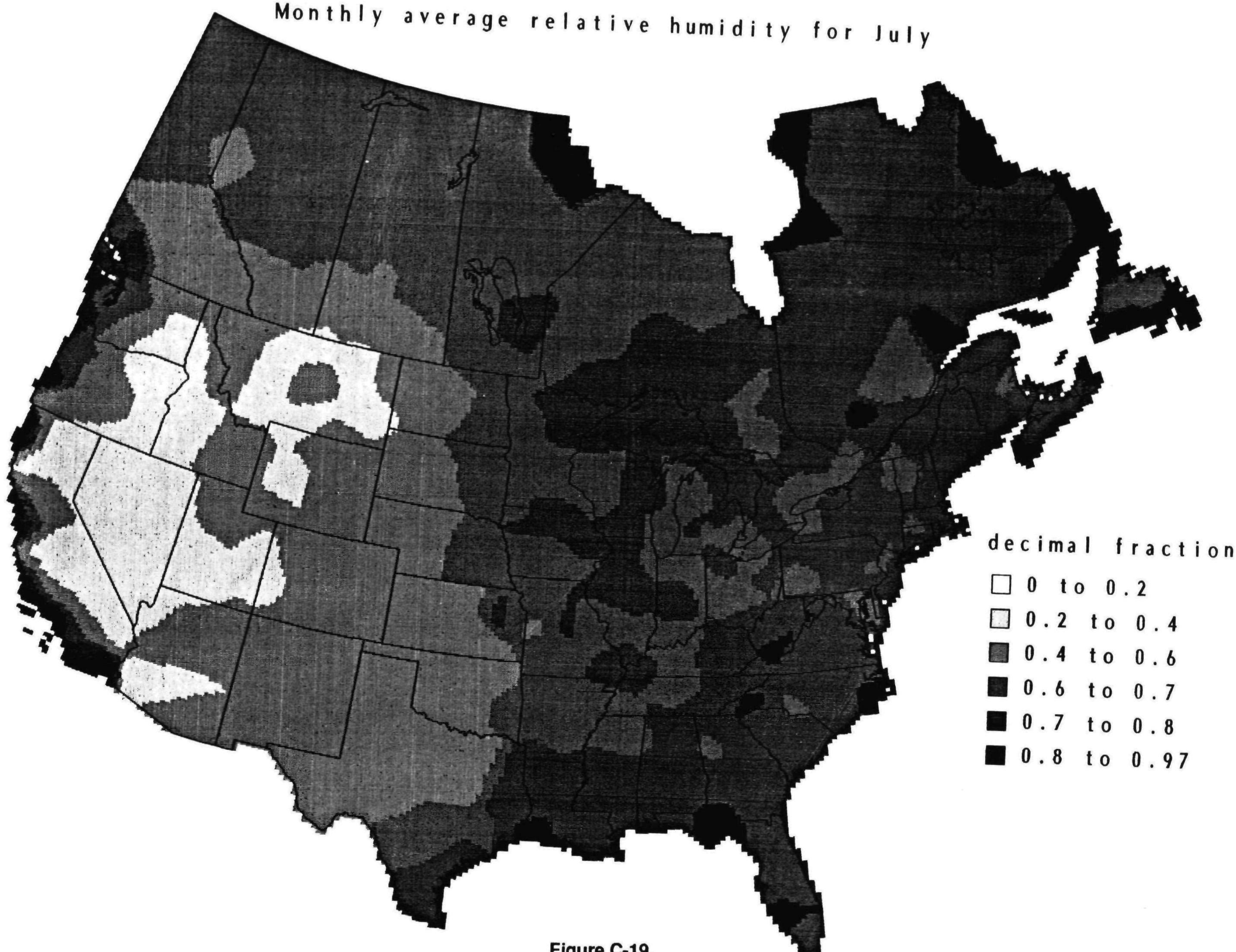
Monthly average relative humidity for July
decimal fraction
0 to 0.2
0.2 to 0.4
0.4 to 0.6
0.6 to 0.7
0.7 to 0.8
0.8 to 0.97

Figure C-19.

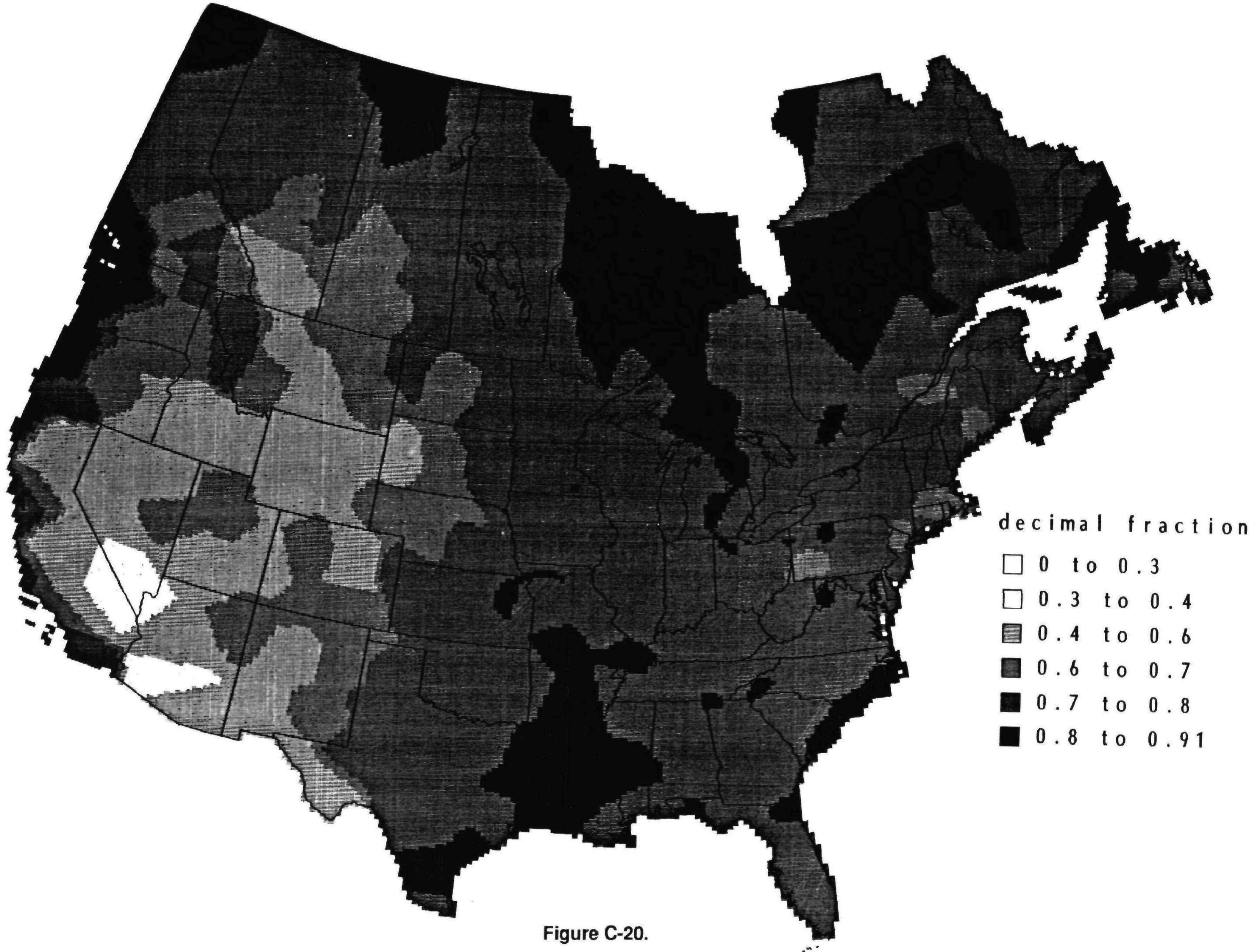
decimal fraction
0 to 0.3
0.3 to 0.4
0.4 to 0.6
0.6 to 0.7
0.7 to 0.8
0.8 to 0.91

Figure C-20.

APPENDIX D

BIOGENIC EMISSIONS AND SOLAR RADIATION SOURCE CODE LISTINGS

SOLENGY.FORT

```
      PROGRAM SOLENGY

C************************************************************************
C
C  THIS ROUTINE GENERATES A FILE OF HOURLY GRIDDED SOLAR ENERGY
C  GIVEN THE SUN'S ZENITH ANGLE AND A RANGE OF SOLAR WAVELENGTHS.
C
C   INPUT FILES:
C
C  CONTROL FILE TO WITH YEAR STARTMONTH DAY NHOURS STARTHOUR (CNTRL)
C  SOLAR ENERGY AS A FUNCTION OF ZENITH ANGLE AND WAVELENGTH (SOLARFLUX)
C  LAT & LONG OF THE CENTERPOINTS OF THE RADM GRID CELLS (LATLON)
C  (NOTE: LONGITUDE IS NEGATIVE FOR WESTERN HEMISPHERE IE. N. AMERICA)
C
C
C  OUTPUT FILE:
C
C      HOURLY GRIDDED SOLAR ENERGY (SOLAR)
C        - IN TWO FORMATS: MICROEINSTEINS/M2-SEC & CAL-GM/CM2-SEC
C
C 2/89-BRG-BASED ON THE ROM PROGRAM, MODIFIED TO WORK WITH THE RADM GRID
C  argument list description:
C
C     INPUT ARGUMENTS:
C
C        PRES     SURFACE AIR PRESSURE (ASSUMED TO BE 980 MB)
C        IMONTH - MONTH (FROM 1 TO 12)
C        IDAY     DAY OF THE MONTH (1 - 31)
C        IYEAR  - YEAR (SUCH AS 88)
C        IHOUR  - LOCAL STANDARD TIME (1 - 24)
C        LAT    - LATITUDE (DEGREES)
C        LONG   - LONGITUDE (DEGREES)
C
C     OUTPUT ARGUMENTS:
C
C        TOTAL  - TOTAL SOLAR RADIATION, DIFFUSE AND DIRECT (LY/MIN)
C        PAR    - VISIBLE SOLAR RADIATION (UE/M**2-S)
C
C     INTERNAL ARGUMENTS:
C
C        DIRCTO - DIRECT INCIDENT SOLAR RADIATION (W/M**2)
C        A      - SOLAR CONSTANT AT SEA-LEVEL, VARIES BY DAY (W/M**2)
C        ADAY   - FIXED VALUES OF A USED IN THE TABLE LOOK UP
C        B      - INVERSE AIR MASS, VARIES BY DAY (ATM**-1)
C        BDAY   - FIXED VALUES OF B USED IN THE TABLE LOOK UP
C        PRESO  - STD SEA-LEVEL PRESSURE (1013 MB)
C        ZENITH - ZENITH ANGLE COMPUTED AS FUNCTION OF JULIAN DAY, TIME
C                 TIME ZONE, LAT, AND LONGITUDE. (RADIANS)
C        DFUSE  - DIFFUSE SOLAR RADIATION (W/M**2)
C        C      - CONSTANT WHICH ACCOUNTS FOR WATER VAPOR, VARIES BY
C                 JULIAN DAY (UNITLESS)
C        CDAY   - FIXED VALUES OF C USED IN THE TABLE LOOK UP
C        IDAY   - FIXED VALUES OF JULIAN DAY CORRESPONDING TO ADAY,
```

```
C                BDAY, AND CDAY
C       WM2LY    CONVERSION OF W/M**2 TO LY/MIN (0.001433)
C       LY2UE  - CONVERSION OF LY/MIN TO UE/M**2-S, ASSUMES THAT
C                VISIBLE PORTION OF SPECTRUM IS 400 NM TO 700 NM
C                AND THE REPRESENTATIVE WAVELENGTH IS 500 NM
C                THUS USED ONLY FOR PAR (2916.)
C       DAYINC - DAY INCREMENT USED IN INTERPOLATING BETWEEN DAYS
C       EXPA     EXP FUNCTION WITH ZENITH ANGLE AND AIR MASS
C       CATTEN   CLOUD ATTENUATION (UNITLESS), FROM 0 TO 1
C       ANGLE  - SOLAR ANGLE (DEGREES)
C       DG2RD    CONVERSION OF DEGREES TO RADIANS (0.0174533)
C
C***********************************************************************

      IMPLICIT NONE

      CHARACTER*12 INFILE, OUTFILE

      INTEGER*4 YEAR, SMTH, SDAY, STHR, NHRS, ICOL, IROW, IHR, IWAVE1,
     &          IWAVE2, M, J, I, JMO(12), JDAY, NCOL, NROW, OCOL, OROW,
     &          EOF, HOUR

C SET UP FOR 300X210 NAPAP GRID WITH ORIGIN AT 1,1

      PARAMETER (NCOL=300,NROW=210,OCOL=1,OROW=1)

C     Following two lines commented out 03/01/91 Shannon L. Parker
C
C     REAL*4 WAVE, WAVE1, WAVE2, FLUXC(52,10), FLUXE(52,10), ZENITH,
C    &       FCTOT, FETOT, Z(10), ZX, FC, FE

      REAL*4 WAVE, WAVE1, WAVE2, ZENITH,
     &       total, par, Z(10), ZX, FC, FE

      REAL*4 LAT(300,210), LON(300,210)

      PARAMETER (WAVE  = 290.0, WAVE1 = 400.0, WAVE2 = 690.0)

C
      DATA INFILE /'LATLON'/
      DATA OUTFILE /'SOLAR'/
      DATA Z /0.,10.,20.,30.,40.,50.,60.,70.,78.,86./
      DATA JMO/0,31,59,90,120,151,181,212,243,273,304,334/
C
C...OTHER DECLARATIONS
C
      REAL DRCTO, CN, A, ADAY(14), B, BDAY(14), PRES, PRESO, ZENITH,
     &     C, CDAY(14), DFUSE, TOTAL, PAR, LY2UE, WM2LY, DG2RD,
     &     DAYINC, EXPA, CATTEN, ANGLE
      INTEGER NDAY(14), JDAY, I
      DATA NDAY/  1, 21, 52, 81,112,142,173,
     &          203,234,265,295,326,356,366/
      DATA ADAY/1203.,1202.,1187.,1164.,1130.,1106.,1092.,
     &          1093.,1107.,1136.,1136.,1190.,1204.,1203./
```

```
      DATA BDAY/.141,.141,.142,.149,.164,.177,.185,
     &          .186,.182,.165,.152,.144,.141,.141/
      DATA CDAY/.103,.103,.104,.109,.120,.130,.137,
     &          .138,.134,.121,.111,.106,.103,.103/
      DATA WM2LY/0.001433/, LY2UE/2916./, CN/1./,
     &     DG2RD/0.0174533/, PRES0/1013./, PRES/980./
      ELEV = 0.
C
C     READ PARAMETERS FROM CONTROL RECORD.
C
C     YEAR   = START YEAR
C     SMTH   = START MONTH
C     SDAY   = START DAY
C     STHR   = START HOUR
C     NHRS   = NUMBER OF HOURS TO PROCESS
C
      OPEN(UNIT = 11, FORM='FORMATTED',STATUS='OLD',ACTION='READ')
      READ (11,500,ERR=400) YEAR, SMTH, SDAY, NHRS, STHR
      PRINT *, YEAR, SMTH, SDAY, STHR, NHRS
C
C     COMPUTE JULIAN DAY FORMAT USING JULIAN ROUTINE.
C
        JDAY = SDAY + JMO(SMTH)
        IF (MOD(YEAR,4).EQ.0.AND.SMTH.GT.2) JDAY = JDAY + 1

C
C     READ THE SOLAR ENERGY CONSTANTS
C
      CALL FLXEIN (FLUXC,FLUXE)
C
C     COMPUTE START/END WAVELENGTH INDEX.
C     THE WAVELENGTH INDEX  RANGES FROM 1 TO 52.
C
C    Following two lines commented out 03/01/91    Shannon L. Parker
C     IWAVE1 = (WAVE1 - WAVE) / 10.0  + 1
C     IWAVE2 = (WAVE2 - WAVE) / 10.0  + 1
C
C READ IN ALL RECORDS - LAT & LON FOR 300X210
C
      OPEN(UNIT = 10, FORM='FORMATTED',STATUS='OLD',ACTION='READ')
      READ(10,100,IOSTAT=EOF) ICOL, IROW, LAT(ICOL,IROW), LON(ICOL,IROW)
      DO WHILE (EOF.NE.-1)
      READ(10,100,IOSTAT=EOF) ICOL, IROW, LAT(ICOL,IROW), LON(ICOL,IROW)
      END DO
      CLOSE (10)
C
        OPEN (UNIT = 12, FORM='UNFORMATTED',STATUS='NEW')
c    &   RECL=6)
C
C  ********* THE HOUR LOOP STARTS HERE.
C
      IHR = STHR                ! STARTING HOUR
      HOUR = 1                  ! NUMBER THE HOURS FROM 1 TO NHRS
      DO WHILE (NHRS .GT. 0)
```

```
C
C     INTERPOLATE FOR THE SOLAR ENERGY GIVEN WAVELENGTH AND ZENITH ANG.
C
       DO IROW = OROW,NROW + OROW - 1
         DO ICOL = OCOL,NCOL + OCOL - 1
C
C           CALCULATE THE ZENITH ANGLE FOR THIS HOUR
C
            CALL SOLRADT(JDAY,IHR,LAT(ICOL,IROW),LON(ICOL,IROW),ZENITH)
C
C     IF ZENITH ANGLE IS OUT OF RANGE OF TABLE, THEN DON'T CALCULATE
C     ANY SOLAR FLUX - ELSE GET THE SOLAR ENERGY IN BOTH SETS OF UNITS
C
C           FIND THE RANGE THE ZENITH ANGLE IS IN
C
            J = 2
            DO WHILE (ZENITH .GE. Z(J) .AND. J .LT. 10)
              J = J + 1
            END DO
            ZX = (ZENITH - Z(J-1)) / (Z(J)   Z(J-1))
C
C           INITIALIZE THE SOLAR ENERGY TO ZERO

C           CHANGED 03/01/91        Shannon L. Parker
C
C           FETOT = 0.0
C           FCTOT = 0.0
C
            PAR   = 0.0
            total = 0.0
C
C          LOOP THROUGH ALL WAVELENGTHS, CALCULATING ENERGY AT EACH
C          WE WILL BE USING 400 NM TO 690 NM WAVELENGTHS
C
C           DO M = IWAVE1,IWAVE2
C             FC = FLUXC(M,J-1) + (FLUXC(M,J) - FLUXC(M,J-1)) * ZX
C             FE = FLUXE(M,J-1) + (FLUXE(M,J) - FLUXE(M,J-1)) * ZX
C              IF (FC .GT. 0.0) FCTOT = FCTOT + FC
C              IF (FE .GT. 0.0) FETOT = FETOT + FE
C           END DO
C
C   Comput radiation section added 03/01/91     Shannon L. Parker
C...COMPUTE DIRECT RADIATION
C      FIRST, PERFORM THE TABLE LOOK UP
      DO 10 I = 1, 14
         IF (JDAY .LE. NDAY(I)) GO TO 20
10    CONTINUE
      PRINT *,'ERROR IN TABLE LOOKUP, JDAY OUT OF RANGE'
      STOP
C
20    IF (I .LT. 1 .OR. I .GT. 14) THEN
         PRINT *,'ERROR, DAY INDEX OUT OF RANGE'
         STOP
      ENDIF
```

```
      IF (NDAY(I) .EQ. 1) THEN
         A = ADAY(1)
         B = BDAY(1)
         C = CDAY(1)
      ELSE
         DAYINC = FLOAT(JDAY-NDAY(I-1))/FLOAT(NDAY(I)-NDAY(I-1))
         A = ADAY(I-1) + (ADAY(I)-ADAY(I-1))*DAYINC
         B = BDAY(I-1) + (BDAY(I)-BDAY(I-1))*DAYINC
         C = CDAY(I-1) + (CDAY(I)-CDAY(I-1))*DAYINC
      ENDIF
C
C...CHECK RANGE OF EXP
      IF (PRES .LT. 100.) STOP 'ERROR IN SFC PRES, ITS TOO LOW'
      IF (ZENITH .GT. 1.55) THEN
         EXPA = 0.
      ELSE
         EXPA = EXP(-B*(PRES/PRES0)/COS(ZENITH))
      ENDIF
      DRCT0 = CN*A*EXPA
      DFUSE = C*DRCT0
      TOTAL = DRCT0*COS(ZENITH) + DFUSE
      TOTAL = TOTAL*WM2LY
C...VISIBLE IS ASSUMED TO CONSIST OF 50% OF THE TOTAL
      PAR   = TOTAL*0.5*LY2UE
C     WRITE OUT THE AMOUNTS FOR THIS HOUR & GRID CELL
C     ***Following line changed 03/01/91     Shannon L. Parker
C        WRITE(12) ICOL, IROW, HOUR, FCTOT, FETOT
          WRITE(12) ICOL, IROW, HOUR, total, par
        END DO
      END DO
C
C     PREP FOR NEXT HOUR AND CHECK FOR A CHANGE OF DAY.
C
      PRINT 510, JDAY, IHR
      IHR  = IHR + 1
      HOUR = HOUR + 1
      NHRS = NHRS - 1
      IF (IHR .GT. 23) THEN
        IHR = 0
        JDAY = JDAY + 1
      ENDIF
C
C **** END OF HOUR LOOP
C
      END DO
      PRINT 502
        CLOSE (11)
      STOP
C
C     ERROR PROCESSING
C
400   PRINT 503
      CALL EXIT
401   PRINT 504
```

```
      CALL EXIT
402   PRINT 505
      CALL EXIT
C
100     FORMAT(1X,I4,I4,F9.3,F9.3)
500   FORMAT(5(I5))
502   FORMAT(1X,'PROCESSING COMPLETE. ')
503   FORMAT(1X,'***ERROR*** READING CONTROL RECORD')
504   FORMAT(1X,'EOF ENCOUNTERED READING SOLAR ENERGY FILE')
505   FORMAT(1X,'***ERROR*** READING SOLAR ENERGY FILE')
507   FORMAT()
508   FORMAT(' ',10F11.5)
510   FORMAT(1X,'...Data written for DAY ',I5,' HOUR ',I2,'...')
      END

C  ***Following subroutine commented out   03/01/91   Shannon L. Parker
C
      SUBROUTINE FLXEIN(FLUXC,FLUXE)
C******************************************************************
C
C   THIS PROGRAM CONVERTS PETERSON'S ACTINIC FLUX UNITS FROM
C   PHOTONS/CM2-SEC TO MICOREINSTEINS/M2-SEC & TO LANGLEY-MIN
C    (CAL-GM/CM2-SEC)
C
C   NOTE: AMOUNTS IN FLUX DATA FILE NEED TO MULTIPLIED BY 10E15
C******************************************************************
C     REAL*4    XJ(52,10), WL, A, B, C, FLUXC(52,10), FLUXE(52,10)
C
C     INTEGER*4 I, J, K
C
C     CHARACTER*12 INFILE
C
C  CONVERSION E: (PHOTONS/CM2-SEC) / (6.02252E17 PHOTONS/MICROEINSTIN)
C               * (1.0E4 CM2/M2)
C               = MICOREINSTEINS/M2-SEC
C
C  CONVERSION C: (PHOTONS/CM2-SEC) * (.2389 CAL/J) * (6.63E-34 JSEC/PHO
C               * (3E10 CM/SEC) * (60SEC/MIN) / (WAVELENGTH CM)
C               = LANGLEY-MIN OR CAL-GM/CM2-MIN
C
C     DATA A/6.02252E17/, B/1.0E4/, C/2.851E-15/
C     DATA INFILE/'SOLARFLUX'/
C
C   READ ACTINIC FLUXES
C
C    OPEN(UNIT = 14, FORM='FORMATTED',STATUS='OLD',ACTION='READ')
C
C     DO  I=1,52
C       READ(14,100) (XJ(I,J), J=1,10)
C100     FORMAT(10F10.7)
C     END DO
C     CLOSE (14)
C
C    CONVERT FLUX TO BOTH SETS OF UNITS
```

```
C
C     DO K=1,10
C       DO J=1,52
C         WL = 290 + (J-1) * 10      !DETERMINE WAVELENGTH IN NM
C         FLUXE(J,K) = XJ(J,K) * 1.0E15 / A * B
C         FLUXC(J,K) = XJ(J,K) * 1.0E15 * C / WL
C       END DO
C     END DO   .
C     RETURN
C     END

      SUBROUTINE SOLRADT(JDAY, HR, DLAT, DLON, ZEANGL)

C     THIS SUBROUTINE CALCULATES THE SOLAR ANGLES GIVEN A
C     PARTICULAR LOCATION AND TIME OF YEAR.  THE METHOD USED
C     IS THAT PRESENTED BY HOLTSLAG AND VAN ULDEN (1983).
C     IT THEN CALCULATES THE SOLAR RADIATION AT THE GROUND
C     FOR VARIOUS TIMES OF THE YEAR AND LOCATIONS.  THIS SHCEME
C     WAS ADAPTED FROM "P15G" OF ROM AFTER KONDRATYEV, (1969).
C
C     2/89 - BRG MODIFIED TO BETTER INTERFACE WITH THE CALCULATION OF
C            SOLAR INTENSITY FOR THE RADM GRID
C     ********************************************************
        IMPLICIT NONE

      REAL*4    SINLAT, COSLAT, COSHR, SINDEC, COSDEC
      REAL*4    RAD2, SCLHGT, RADIUS, SCH2, RSX2
      PARAMETER (SCLHGT=8000., RADIUS=6.37E+06)
      PARAMETER (RAD2=RADIUS*RADIUS, SCH2=SCLHGT*SCLHGT)
      PARAMETER (RSX2=RADIUS*SCLHGT*2.0)

      INTEGER*4 JDAY, HR
      REAL*4    RJDAY, HOUR, LAT, LON, ZEANGL, DLAT, DLON
      REAL*4    PI, SOLDEC, HRANGL, SOLELV, SL
      PARAMETER (PI=3.14159265)

      REAL*4    DG2RAD, RAD2DG
      PARAMETER (DG2RAD=PI/180., RAD2DG=180./PI)

C     ********************************************
C     SUBROUTINE PARAMETERS
C     JDAY  - JULIAN DATE TO PROCESS
C     HR   - HOUR TO PROCESS IN GMT
C     DLAT    - LATITUDE OF THIS CELL IN DEGREES
C     DLON    - LONGITUDE OF THIS CELL IN DEGREES
C             WESTERN HEMISPHERE (IE. NORTH AMERICA) IS NEGATIVE
C     ZEANGL - ZENITH ANGLE IN DEGREES
C
C     DEFINITIONS USED BY SOLAR RADIATION ROUTINES
C
C     PI      - CONSTANT "PI"
C     DG2RAD - CONSTANT TO CONVERT DEGREES TO RADIANS
C     RAD2DG - CONSTANT TO CONVERT RADIANS TO DEGREES
C     SOLDEC - SOLAR DECLINATION ANGLE IN RADIANS
```

```
C     HRANGL - SOLAR HOUR ANGLE IN RADIANS
C     SOLELV - SOLAR ELEVATION IN RADIANS
C
C     *********************************************
C SET THE DAY AND HOUR INTO REAL NUMBERS
C
       RJDAY = JDAY
       HOUR = HR
C
C TO CSLCULATE THE ZENITH ANGLE, THE LAT & LON NEED TO BE RADIANS
C
        LAT = DLAT * DG2RAD
        LON = -DLON * DG2RAD

C     CALCULATE SOLAR LONGITUDE

      SL = 4.871 + DG2RAD*RJDAY + 0.033*SIN(DG2RAD*RJDAY)

C     CALCULATE SOLAR DECLINATION

      SOLDEC = ASIN(0.398*SIN(SL))

C     CALCULATE HOUR ANGLE

      HRANGL = -LON + 0.043*SIN(2*SL) -
     &         0.033*SIN(DG2RAD*RJDAY) + 0.262*HOUR - PI

C     CALCULATE VARIOUS TRIG FUNCTION VALUES

      SINLAT = SIN(LAT)
      COSLAT = COS(LAT)
      COSHR = COS(HRANGL)
      SINDEC = SIN(SOLDEC)
      COSDEC = COS(SOLDEC)

C     CALCULATE THE SOLAR ELEVATION

      SOLELV = ASIN( SINDEC*SINLAT + COSDEC*COSLAT*COSHR )

C     CALCULATE THE ZENITH ANGLE

      ZEANGL = PI/2.0 - SOLELV

C RETURN THE ZENITH ANGLE IN DEGREES

      ZEANGL = ZEANGL * RAD2DG

      RETURN
      END
```

BIOMASS.SAS

```
************************************************************************
*   RUNSTREAM TO EXECUTE PROGRAM BIO.BIOMASS.SAS
*
*   BIOMASS.SAS SELECTS MONTH SPECIFIC BIOMASS FOR CANOPY
*   VEGETATION  LAND AREA FOR NONCANOPY VEGETATION AND CALCULATES
*   THE GRIDDED BIOMASS AND LAND AREA FOR EACH MONTH USING GROWTH
*   FACTORS.  THE INPUT/OUTPUT FILES ARE:
*
*       IN1:  THE EPISODE TO BE RUN (THE MONTH TO CALC BIOMASS FOR)
*       IN2:  GROWTH FACTORS FOR NONCANOPY VEGETATION
*       IN3:  BIOMASS GROWTH FACTORS FOR CANOPY (FOREST) VEGETATION
*       IN4:  GRID ORIGIN AND BOUNDARIES
*       IN5:  GRIDDED CANOPY VEGETATION AREA
*       IN6:  GRIDDED URBAN TREE AREA
*       IN7:  GRIDDED NONCANOPY VEGETATION AREA
*
*      OUT1:  BIOMASS FOR CANOPY
*      OUT2:  BIOMASS FOR URBAN TREES
*      OUT3:  LAND COVERAGE FOR NONCANOPY
*********************************************************************
*;
OPTIONS SOURCE MPRINT;
* BIOMASS.SAS;
* -----------------------------------------------------------*
|    CALCULATES THE BIOMASS FOR CANOPY, NON-CANOPY, AND URBAN
|    TREES.
* -----------------------------------------------------------*;
* LGM 7/89   IBM/TSO VERSION;
* BRG 6/89   CMS VERSION;
* BRG 5/89   BIOGENIC EMISSIONS PROCESSING VERSION 2.1;
* REVISED CANOPY MODEL FOR RADM;
* BRG 3/89   BIOGENIC EMISSIONS PROCESSING VERSION 2.0;
* IMPLEMENTATION OF THE CANOPY MODEL;
* BRG 12/88   BIOGENIC EMISSIONS PROCESSING VERSION 1.0;
*;
* -----------------------------------------------------------*
|        CALCULATE BIOMASS FOR SPECIFIC MONTH
]
] CALCULATE THE BIOMASS AMOUNTS BY TYPE OR BIOMASS AREAS BY
] TYPE. FIND THIS EPISODE'S GROWTH FACTORS & BIOMASS FACTORS
* -----------------------------------------------------------*;
DATA EPISODE;
SET IN1.EPISODE;
 LENGTH MONTH 4.;
OKEEP MONTH;
 PUT 'EPISODE MONTH IS ' MONTH;
DATA GROWTH;           * GET APPRO MONTH'S GROWTH FACTORS;
 MERGE EPISODE(IN=INEPS) IN2.NCBIOFC;
 BY MONTH;
 LENGTH DEFAULT=4;
 IF INEPS;
DATA CNPYBF;     * GET APPRO MONTH'S BIOMASS FACTORS-FOR FOREST;
 MERGE EPISODE(IN=INEPS) IN3.CNPBIOFC;
 BY MONTH;
```

```
 LENGTH DEFAULT=4;
 IF INEPS;
DATA _NULL_;
  SET IN4.EPSHDR;             * GET REGION COORDINATES;
  CALL SYMPUT('XORIGIN',X_ORIGIN);
  CALL SYMPUT('YORIGIN',Y_ORIGIN);
  CALL SYMPUT('XMAX',X_MAX);
  CALL SYMPUT('YMAX',Y_MAX);
* -------------------------------------------------------------*
|       CALCULATE CANOPY BIOMASS
* -------------------------------------------------------------*;
DATA OUT1.GCPBIO;       * CALCULATE THE BIOMASS FOR CANOPY;
 MERGE CNPYBF IN5.GCNPY(IN=A);
 BY COL ROW;
 LENGTH DEFAULT=4;
 ARRAY VEG(3) OAK DECD CONF;
 ARRAY BIOFAC1(4) OAKHI OAKLI OAKNI OAKCF;
 ARRAY BIOFAC2(4) DECDHI DECDLI DECDNI DECDCF;
 ARRAY BIOFAC3(4) CONFHI CONFLI CONFNI CONFCF;
 ARRAY BIOCAT(4) BIOMHI BIOMLI BIOMNI BIOMCF;
* BIOMASS CATEGS. HIGH ISOP, LOW ISOP, NO ISOP, CONF - 8 CANOPY;
 ARRAY LAYHI(8) BIOHI1-BIOHI8;
 ARRAY LAYLI(8) BIOLI1-BIOLI8;
 ARRAY LAYNI(8) BIONI1-BIONI8;
 ARRAY LAYCF(8) BIOCF1-BIOCF8;
* BIOMASS LAYER FACTORS FOR DECD & CONF FOREST FROM B.L. CANOPY;
 ARRAY LAYDECD(8) LAI1-LAI8;
 ARRAY LAYCONF(8) LAI9-LAI16;
 IF _N_ = 1 THEN DO;
   LAI1=0; LAI2=0; LAI3=0.02; LAI4=0.11; LAI5=0.22;
   LAI6=0.35; LAI7=0.22; LAI8=0.09;
   LAI9=0.025; LAI10=0.05; LAI11=0.15; LAI12=0.215;
   LAI13=0.215; LAI14=0.165; LAI15=0.12; LAI16=0.05;
   RETAIN LAI1-LAI16;
 END;
 IF A;
* WINDOW FOR CURRENT REGION;
 IF COL >= &XORIGIN AND COL <= &XMAX AND
    ROW >= &YORIGIN AND ROW <= &YMAX;
* IF ALL ZERO THEN DROP THIS COL ROW;
 IF OAK <= 0 AND DECD <= 0 AND CONF <= 0 THEN DELETE;
 DO J = 1 TO 4;         * CALC BIOMASS FOR EMISS CATEGORY & VEG;
   BIOCAT(J) = 0;
   BIOCAT(J) + SUM(VEG(1) * BIOFAC1(J),
                   VEG(2) * BIOFAC2(J),
                   VEG(3) * BIOFAC3(J));
 END;
 DO I = 1 TO 8; * LAYER THE BIOMASS IN CANOPY LAYERS;
     LAYHI(I) = BIOCAT(1) * LAYDECD(I);
     LAYLI(I) = BIOCAT(2) * LAYDECD(I);
     LAYNI(I) = BIOCAT(3) * LAYDECD(I);
     LAYCF(I) = BIOCAT(4) * LAYCONF(I);
 END;
 KEEP COL ROW BIOHI1-BIOHI8 BIOLI1-BIOLI8 BIONI1-BIONI8
```

```
      BIOCF1-BIOCF8;
* ------------------------------------------------------------*
|       CALCULATE URBAN TREE BIOMASS
* ------------------------------------------------------------*;
DATA OUT2.GUTBIO;       * CALCULATE THE BIOMASS FOR CANOPY;
 MERGE CNPYBF IN6.GUTREE(IN=A);
 BY COL ROW;
 LENGTH DEFAULT=4;
 ARRAY VEG(3) OAK DECD CONF;
 ARRAY BIOFAC1(4) OAKHI OAKLI OAKNI OAKCF;
 ARRAY BIOFAC2(4) DECDHI DECDLI DECDNI DECDCF;
 ARRAY BIOFAC3(4) CONFHI CONFLI CONFNI CONFCF;
 ARRAY BIOCAT(4) BIOHI BIOLI BIONI BIOCF;
 IF A;
* WINDOW FOR CURRENT REGION;
 IF COL >= &XORIGIN AND COL <= &XMAX AND
    ROW >= &YORIGIN AND ROW <= &YMAX;
* IF ALL ZERO THEN DROP THIS COL ROW;
 IF OAK <= 0 AND DECD <= 0 AND CONF <= 0 THEN DELETE;
 DO J = 1 TO 4;        * CALC BIOMASS FOR EMISS CATEGORY & VEG;
   BIOCAT(J) = 0;
   BIOCAT(J) + SUM(VEG(1) * BIOFAC1(J),
                   VEG(2) * BIOFAC2(J),
                   VEG(3) * BIOFAC3(J));
 END;
 KEEP COL ROW BIOHI BIOLI BIONI BIOCF;
* ------------------------------------------------------------*
|       CALCULATE NON-CANOPY AREAS
* ------------------------------------------------------------*;
DATA OUT3.GNCBIO;       * CALCULATE THE AREAS FOR NON-CANOPY;
 MERGE GROWTH IN7.GNCNPY(IN=A);
 BY COL ROW;
 LENGTH DEFAULT=4;
 ARRAY VEG(19) GRASS SCRUB URB_GRSS WATER ALFA BARL CORN COTT
  CRP_MS HAY OATS PEANUT POTAT RICE RYE SORG SOYBN TOBAC WHEAT;
 IF A;
* WINDOW FOR CURRENT REGION;
 IF COL >= &XORIGIN AND COL <= &XMAX AND
    ROW >= &YORIGIN AND ROW <= &YMAX;
* IF ALL ZERO THEN DROP THIS COL ROW;
 IF GRASS <= 0 AND SCRUB <= 0 AND URB_GRSS <= 0 AND WATER <= 0
 AND ALFA <= 0 AND BARL <= 0 AND CORN <= 0 AND COTT <= 0 AND
 CRP_MS <= 0 AND
 HAY <= 0 AND OATS <= 0 AND PEANUT <= 0 AND POTAT <= 0 AND RICE
  <= 0 AND SORG <= 0 AND TOBAC <= 0 AND WHEAT <= 0 THEN DELETE;
 DO N = 1 TO DIM(VEG);
   VEG(N) = VEG(N) * BIOFAC;    * KEEP AREA OR SET TO ZERO;
 END;
 DROP BIOFAC N;
 *;
 PROC PRINT DATA=OUT1.GCPBIO(OBS=100);
 TITLE 'BIOMASS DATA FOR CANOPY VEGETATION';
 PROC PRINT DATA=OUT2.GUTBIO(OBS=100);
 TITLE 'BIOMASS DATA FOR URBAN TREES';
```

```
 PROC PRINT DATA=OUT3.GNCBIO(OBS=100);
 TITLE 'BIOMASS DATA FOR NONCANOPY VEGETATION';
*;
```

CORRECT2.SAS

```
**********************************************************************
* RUNSTREAM TO EXECUTE PROGRAM BIO.CORRECT.SAS
*
* CORRECT.SAS USES GRIDDED METEOROLOGICAL DATA TO CALCULATE HOURLY
* CANOPY AND NONCANOPY CORRECTION FACTORS BASED ON TEMP., W.S., SOLAR
* RAD., AND R.H.  THE INPUT/OUTPUT FILES ARE AS FOLLOWS:
*
*     IN1:  GRIDDED HOURLY TEMPERATURE DATA
*     IN2:  GRIDDED HOURLY SOLAR RADIATION DATA
*     IN3:  GRIDDED HOURLY WIND SPEED DATA
*     IN4:  GRIDDED HOURLY RELATIVE HUMIDITY DATA
*
*    OUT1:  CANOPY EMISSION CORRECTION FACTORS
*    OUT2:  NONCANOPY EMISSION CORRECTION FACTORS
*
* NOTE: FOR THIS VERSION, INPUT DATA SETS IN SAS DATA STEPS WERE
* CHANGED TO INFILE.TEMP AND INFILE.RELH TO MATCH THE SAS
* LIBRARY DATA SETS CREATED (THESE SHOULD HAVE BEEN INFILE.BIOTEMP
* AND INFILE.BIORELH).  NOTE THAT INFILE.BIOWIND (VERSION 2) AND
* INFILE.BIOSOLR WERE NOT CHANGED AS THESE WERE PROPOERLY CREATED.
*     ........LGM 3/91
*
*****************************************************************
* OPTIONS SOURCE MPRINT;
*  CORRECT.SAS;
*-----------------------------------------------------------------*
|    PROVIDE METEOROLOGY VALUES FOR THE CANOPY PART OF THE MODEL   |
|    AND THEN OUTPUT CANOPY TINGEY CORRECTION VALUES.              |
*-----------------------------------------------------------------*;
* LGM 3/91 - CHANGE INFILE.WIND TO INFILE.BIOWIND FOR VERSION 2;
* LGM 6/90 - CHANGE INFILE.BIOTEMP TO INFILE.TEMP, INFILE.BIOWIND;
*  TO INFILE.WIND AND CHANGE INFILE.BIORELH TO INFILE.RELH;
* LGM 6/90 - INCORPORATE NEW NOX EMISSION FACTORS;
* LGM 7/89 - IBM/TSO VERSION;
* BRG 6/89 - CMS VERSION;
* BRG 5/89 - BIOGENIC EMISSIONS PROCESSING VERSION 2.1;
* REVISED CANOPY MODEL FOR RADM;
* BRG 3/89 - BIOGENIC EMISSIONS PROCESSING VERSION 2.0;
* IMPLEMENTATION OF THE CANOPY MODEL;
* BRG 12/88 - BIOGENIC EMISSIONS PROCESSING VERSION 1.0;
*;
DATA OUT1.CNPEMFAC(KEEP=COL ROW HOUR MONODE1-MONODE8 MONOCF1-MONOCF8
                                     ALPHDE1-ALPHDE8 ALPHCF1-ALPHCF8
                                     ISOPDE1-ISOPDE8 ISOPCF1-ISOPCF8);
*;
*;
   LENGTH DEFAULT=4;
*  MERGE IN1.BIOTEMP IN2.BIOSOLR IN3.BIOWIND IN4.BIORELH;
   MERGE IN1.TEMP IN2.BIOSOLR IN3.BIOWIND IN4.RELH;
   BY COL ROW HOUR;
*........................ ARRAYS....................................;
   ARRAY LAI (16)   LAI1 - LAI16;
   ARRAY ZI(16)     ZI1-ZI16;
```

```
   ARRAY CAFV(16)   CAFV1-CAFV16;
   ARRAY CAFT(16)   CAFT1-CAFT16;
   ARRAY WADJ(8)    WADJ1-WADJ8;
   ARRAY CHIGHT(2)  CHIGHT1-CHIGHT2;
* HOURLY EMISSION CORRECTION FACTORS - FOR BIOMASS TYPE - 8 LAYERS;
   ARRAY MONO(16) MONODE1-MONODE8 MONOCF1-MONOCF8;
   ARRAY ALPH(16) ALPHDE1-ALPHDE8 ALPHCF1-ALPHCF8;
   ARRAY ISOP(16) ISOPDE1-ISOPDE8 ISOPCF1-ISOPCF8;
*
*........................ PROGRAM VARIABLES........................
*;
   IF _N_ = 1 THEN DO;
      LAI1=0; LAI2=0; LAI3=0.02; LAI4=0.11;
      LAI5=0.22; LAI6=0.35; LAI7=0.22; LAI8=0.09;
      LAI9=0.025; LAI10=0.05; LAI11=0.15; LAI12=0.215;
      LAI13=0.215; LAI14=0.165; LAI15=0.12; LAI16=0.05;
      CAFT1=0.339; CAFT2=0.339; CAFT3=0.339; CAFT4=0.346;
      CAFT5=0.389; CAFT6=0.493; CAFT7=0.717; CAFT8=0.908;
      CAFT9=0.195; CAFT10=0.204; CAFT11=0.221; CAFT12=0.283;
      CAFT13=0.404; CAFT14=0.575; CAFT15=0.755; CAFT16=0.921;
      CAFV1=0.0799; CAFV2=0.0799; CAFV3=0.0799; CAFV4=0.0840;
      CAFV5=0.1106; CAFV6=0.1918; CAFV7=0.4604; CAFV8=0.7984;
      CAFV9=0.0221; CAFV10=0.0244; CAFV11=0.0295; CAFV12=0.0526;
      CAFV13=0.1204; CAFV14=0.2754; CAFV15=0.5198; CAFV16=0.8249;
      ZI1=3.75; ZI2=5.25; ZI3=6.75; ZI4=8.25;
      ZI5=9.75; ZI6=11.25; ZI7=12.75; ZI8=14.25;
      ZI9=5.0; ZI10=7.0; ZI11=9.0; ZI12=11.0;
      ZI13=12.0; ZI14=15.0; ZI15=17.0; ZI16=19.0;
      WADJ1=1.0; WADJ2=1.0; WADJ3=1.0; WADJ4=1.0;
      WADJ5=1.0; WADJ6=0.1846; WADJ7=0.6846; WADJ8=0.917;
      K1=0.0162; K2=0.026; LLENTH=10.0;
      CHIGHT1=15; CHIGHT2=20;
*;
      RETAIN LAI1-LAI16 CAFT1-CAFT16 ZI1-ZI16 WADJ1-WADJ8 K1 K2 LLENTH
             CHIGHT1-CHIGHT2 CAFV1-CAFV16;
   END;
*;
   TAIR = TEMP + 273;
* 8.132E-11 = STEFAN BOL. CONSTANT;
   GROUNDO = 8.132E-11*((TAIR)**4);
*;
   TRATE =  0.06;
   IF SOLARC <= 0.0 THEN TRATE = -0.06;
*;
* SET LOWER LAYERS TO ZERO FOR DECID - NO BIOMASS THERE;
MONODE1 = 0.0;
MONODE2 = 0.0;
ISOPDE1 = 0.0;
ISOPDE2 = 0.0;
ALPHDE1 = 0.0;
ALPHDE2 = 0.0;
*;
DO CNTYPE = 0 TO 1;
*;
```

```
*.. NO TLEAF CALCULATIONS FOR THESE CNTYPES: USE TEMPERATURE VALUES..;
*;
   DO I = 8 TO 1 BY -1;
*......................BIOMASS......................................;
*;
      IF LAI(CNTYPE*8+I) = 0 THEN GO TO OUTLOOP2;
      TLEAFAA=0.0;
      SOLAR=0.0;
*;
*...OUTLOOP FOR ZERO VERTICAL BIOMASS TO SAVE COMPUTER TIME USAGE ;
*...CONVERSION FROM G BIOM/M2 GROUND TO KGRAM BIOM/M2 TO M2 LEAF AREA/M2
*   GROUND LINDE1 BACK TO CM2 L A/M2 UNDERSTORY DISTRIBUTION NOT
*  ACCOUNTED FOR IN VERTICAL............................................;
*...FINAL UNITS *** GRAMS BIOMASS/VERTICAL/M**2 GROUND................;
*;
*.........................SOLARZ....................................;
*... K = 0.42 IS AN ESTIMATED EXTINCTION COEFF FOR VISIBLE SPECTRUM;
*... K = 0.18 IS AN ESTIMATED EXTINCTION COEFF FOR THE TOTAL SPECTRUM;
*;
*... ADD IN IR FROM GROUND PLUS 10% REFLECTANCE BACK UP ;
*... ASSUME IR ATTENUATED INVERSELY TO CANOPY HT. BY BIOMASS ;
*;
      GROUND = GROUNDO*(1-CAFT(CNTYPE*8+I));
      SOLAN = SOLARC * (1.1 * CAFT(CNTYPE*8+I)) + GROUND;
      SOLAR = 1.1*CAFV(CNTYPE*8+I)*SOLARE;
*;
*...LINDEX=M2 LEAF AREA(ONE SIDE ONLY)/M2 GROUND, SUMMED FROM TOP DOWN;
*...FINAL UNITS ***  CALORIES/CM**2-MIN ;
*;
*.................... TEMPZ:  FROM TOP DOWN (-) ......................;
      TCHANG = TRATE*(CHIGHT(CNTYPE+1) - ZI(CNTYPE*8+I));
      TEMPC = TAIR - TCHANG;
*;
*... FINAL UNITS ***  DEGREES KELVIN ;
*;
*.......................... HUMIDITY................................;
*... SATURATION VAPOR PRESSURE  (MILLIBARS) ;
*;
      SVP1 = 4.9283*LOG10(TEMPC);
      SVP  = 10**((-2937.4/TEMPC)-SVP1+23.5518);
*;
      IF TEMPC > 283 THEN
         DELTAH = 7.0;
      ELSE
         DELTAH = 1.5;
*;
*... RELATIVE HUMIDITY FROM HOURLY FILES ;
*;
      HUMID = (RELH*SVP) + (DELTAH/CHIGHT(CNTYPE+1))*
                          (CHIGHT(CNTYPE+1) - ZI(CNTYPE*8+I));
*... FINAL UNITS ***  MILLIBARS ;
*;
*............................. WINDSZ.............................;
*... CALCULATION IN TWO PARTS:  UPPER CANOPY WIND IS LOGARITHMIC ;
```

```
*... LOWER CANOPY IS LINEAR ;
*... CALCULATION OF HEIGHT WHERE WINDSPEED ENDS LOG DIST. ;
*... IE. GOES BELOW 0.1 M/SEC, IS ASSUMED TO BE 0.1M/SEC FOR THE REST ;
*... LOWER CANOPY VALUES FOR WINDSPEED: ASSIGNED ARBITRARY DUE ;
*... LACK OF UNDERSTORY DATA ;
*;
     IF I < 6 THEN WINDC = 0.1;
*... UPPER CANOPY LOGARITHMIC DETERMINATION OF WINDSPEED ;
*... LOGARITHMIC WIND FORMULA ;
     ELSE DO;
        WINDC = WIND * WADJ(I);
        IF WINDC < 0.1 THEN WINDC = 0.1;
     END;
*... FINAL UNITS ***  METERS/SEC ;

*..................... LEAF SIZES ****(CM) .......................;
*;
     LWIDTH =  5.0;
     IF CNTYPE = 1 THEN LWIDTH = 1.0;
*;
*... REVERSAL OF LEAF ORIENTATION WITH RESPECT TO WIND ;
*...................... TLEAFZ..................................;
*... NEWTON BISECTIONAL METHOD OF SOLVING EQUATION ;
*... A)  PRECALCULATIONS/CONVERSIONS (T CON. IN PROGRAM) ;
*;
        WINDSCM = WINDC*100;
*... LEAF RESISTANCE IN MIN/CM;
*;
        LRESIS = (0.03233 / ((0.01 + SOLAN - GROUND)**0.99)) + 0.025;
*;
        VAPOR1 = 0.0002165 *SVP/TEMPC;
        RELHUM1 = HUMID/SVP;
        IF RELHUM1 > 1.0 THEN RELHUM1 = 1.0;
*;
        L2 = LRESIS + (K2*
               (LWIDTH**0.2*LLENTH**0.35/WINDSCM**0.55));
        Q = SOLAN * 0.5;
*;
        TLEAFAA = TEMPC; LEFTA =TEMPC + 20;
        RIGHTA = TEMPC - 20;
*;
        CONTIN: ZERO = 0;
*;
        DO N = 1 TO 3 BY 1;
           IF N = 1 THEN TLEAFA = LEFTA;
           IF N = 2 THEN TLEAFA = RIGHTA;
           IF N = 3 THEN TLEAFA = TLEAFAA;
*... VAPOR DENSITY FOR LEAF TEMPS ;
*... SATURATION VAPOR DENSITIES (G/CM*3) ;
*... SATURATION VAPOR PRESSURE  (MILLIBARS) ;
*;
           SVP1 = 4.9283*LOG10(TLEAFA);
           SVP = 10**((-2937.4/TLEAFA)-SVP1+23.5518);
*... SATURATION VAPOR DENSITY (GRAMS/CM3) ;
```

```
*;
          VAPOR2 = 0.0002165*SVP/TLEAFA;
*;
*... LATENT HEAT OF VAPORIZATION (CAL/GRAM H2O ;
*;
          LHV = 597 - (0.57*(TLEAFA - 273));
          L1 = (VAPOR2 - RELHUM1*VAPOR1);
          L3 = LHV*(L1/L2);
*;
*... IR RADIATION BY LEAF, ATTENUATED BY CANOPY ;
*;
          RI1 = 0.95*8.132E-11*(TLEAFA)**4;
          R1 = RI1*(1-CAFT(CNTYPE*8+I));
          C1 = K1*((WINDSCM/LLENTH)**0.5)*(TLEAFA   TEMPC);
*... TOTAL RADIATION ABSORBED BY LEAF=HALF AVAILABLE ;
*;
          SUBTOT = Q - R1 - C1 - L3;
          IF N = 1 THEN LEFT = SUBTOT;
          IF N = 2 THEN RIGHT = SUBTOT;
          IF N = 3 THEN DO;
             PROD = SUBTOT*RIGHT;
             IF PROD < 0.0 THEN DO;
                LEFTA = TLEAFAA;
                TLEAFAA = (LEFTA + RIGHTA)*0.5;
             END;
             IF PROD > 0.0 THEN DO;
                RIGHTA = TLEAFAA;
                TLEAFAA = (LEFTA + RIGHTA)*0.5;
             END;
*;
*            IF (LEFTA - RIGHTA) > 0.01 THEN GO TO CONTIN;
             IF (LEFTA - RIGHTA) > 1.0 THEN GO TO CONTIN;
*            IF (LEFTA - RIGHTA) > 0.5 THEN GO TO CONTIN;
*;
          END;
       END;   *END OF N LOOP;
*;
*... E) END/FINAL CALCULATION ;
* CONVERT TLEAF BACK TO CELCIUS AND LOAD INTO THE ARRAYS;
     TLEAFAA = TLEAFAA - 273;
*;
* USE MODIFIED TINGEY CURVES - PRESENTED HERE AS CORRECTION FACTORS;
* R FACTORS ARE TO CONVERT THE EMISSION FACTORS AT FULL SUNLIGHT TO A;
* LOWER LIGHT INTENSITY:  R400 = 1.95  R200 = 4.75  R100 = 10.72;
     MONO(CNTYPE*8+I) = EXP(0.0739 * (TLEAFAA-30));
     ALPH(CNTYPE*8+I) = EXP(0.067 * (TLEAFAA-30));
* PICK APPRO ISOP CURVE - INTERPOLATE IF BETWEEN CURVES;
 IF SOLAR >= 800 THEN
  ISOP(CNTYPE*8+I)=10**(1.200/(1+EXP(-0.400*(TLEAFAA-28.30)))-0.796);
 ELSE IF SOLAR < 800 AND SOLAR > 400 THEN DO;
     F800 = 10**(1.200/(1+EXP(-0.400*(TLEAFAA-28.30)))-0.796);
     F400 = 10**(0.916/(1+EXP(-0.239*(TLEAFAA-29.93)))-0.462);
     ISOP(CNTYPE*8+I) = F400/1.95 + (F800-F400/1.95) * (SOLAR-400)/400;
       END;
```

```
 ELSE IF SOLAR = 400 THEN DO;
        F400 = 10**(0.916/(1+EXP(-0.239*(TLEAFAA-29.93)))-0.462);
        ISOP(CNTYPE*8+I) = F400/1.95;
        END;
 ELSE IF SOLAR < 400 AND SOLAR > 200 THEN DO;
        F400 = 10**(0.916/(1+EXP(-0.239*(TLEAFAA-29.93)))-0.462);
        F200 = 10**(0.615/(1+EXP(-0.696*(TLEAFAA-32.79)))-0.077);
 ISOP(CNTYPE*8+I) = F200/4.75 + (F400/1.95-F200/4.75) * (SOLAR-200)/200;
        END;
 ELSE IF SOLAR = 200 THEN DO;
        F200 = 10**(0.615/(1+EXP(-0.696*(TLEAFAA-32.79)))-0.077);
        ISOP(CNTYPE*8+I) = F200/4.75;
        END;
 ELSE IF SOLAR < 200 AND SOLAR > 100 THEN DO;
        F200 = 10**(0.615/(1+EXP(-0.696*(TLEAFAA-32.79)))-0.077);
        F100 = 10**(0.437/(1+EXP(-0.312*(TLEAFAA-31.75)))-0.160);
ISOP(CNTYPE*8+I) = F100/10.73+(F200/4.75-F100/10.73) * (SOLAR-100)/100;
        END;
 ELSE IF SOLAR = 100 THEN DO;
        F100 = 10**(0.437/(1+EXP(-0.312*(TLEAFAA-31.75)))-0.160);
        ISOP(CNTYPE*8+I) = F100/10.73;
        END;
 ELSE IF SOLAR < 100 AND SOLAR > 0 THEN DO;
        F100 = 10**(0.437/(1+EXP(-0.312*(TLEAFAA-31.75)))-0.160);
        ISOP(CNTYPE*8+I) = (F100/10.73) * SOLAR/100;
        END;
 ELSE IF SOLAR <= 0 THEN
        ISOP(CNTYPE*8+I) = 0;
*;
      OUTLOOP2:
*;
   END;       *END OF I LOOP - CANOPY LAYERS 8 - 1;
*;
END;          *END OF TYPE LOOP;
*;
*-----------------------------------------------------------------*
|     CALCULATE NON-CANOPY EMISSION CORRECTION FACTORS USING TINGEY |
|      CURVES.                                                      |
| USE MODIFIED TINGEY CURVES - PRESENTED HERE AS CORRECTION FACTORS |
| R FACTORS ARE TO CONVERT THE EMISSION FACTORS AT FULL SUNLIGHT TO A |
| LOWER LIGHT INTENSITY:  R400 = 1.95  R200 = 4.75  R100 = 10.72    |
| USE AIR TEMPERATURE TO DETERMINE SOIL TEMPERATURE AND A NO EMISSION |
| FLUX FOR SOIL NO.                                                 |
*-----------------------------------------------------------------*;
DATA OUT2.NCEMFAC;
*MERGE IN1.BIOTEMP IN2.BIOSOLR;
 MERGE IN1.TEMP IN2.BIOSOLR;
 BY COL ROW HOUR;
   LENGTH DEFAULT=4;
* CALCULATE CORRECTION FACTORS FOR EACH SPECIE, EACH HOUR;
   MONO = EXP(0.0739 * (TEMP-30));
   ALPH = EXP(0.067 * (TEMP-30));
* PICK APPRO ISOP CURVE - INTERPOLATE IF BETWEEN CURVES;
 IF SOLARE >= 800 THEN
```

```
        ISOP = 10**(1.200/(1+EXP(-0.400*(TEMP-28.30)))-0.796);
  ELSE IF SOLARE < 800 AND SOLARE > 400 THEN DO;
        F800 = 10**(1.200/(1+EXP(-0.400*(TEMP-28.30)))-0.796);
        F400 = 10**(0.916/(1+EXP(-0.239*(TEMP-29.93)))-0.462);
        ISOP = F400/1.95 + (F800 - F400/1.95) * (SOLARE - 400) / 400;
        END;
  ELSE IF SOLARE = 400 THEN DO;
        F400 = 10**(0.916/(1+EXP(-0.239*(TEMP-29.93)))-0.462);
        ISOP = F400/1.95;
        END;
  ELSE IF SOLARE < 400 AND SOLARE > 200 THEN DO;
        F400 = 10**(0.916/(1+EXP(-0.239*(TEMP-29.93)))-0.462);
        F200 = 10**(0.615/(1+EXP(-0.696*(TEMP-32.79)))-0.077);
      ISOP = F200/4.75 + (F400/1.95 - F200/4.75) * (SOLARE - 200) / 200;
        END;
  ELSE IF SOLARE = 200 THEN DO;
        F200 = 10**(0.615/(1+EXP(-0.696*(TEMP-32.79)))-0.077);
        ISOP = F200/4.75;
        END;
  ELSE IF SOLARE < 200 AND SOLARE > 100 THEN DO;
 F200 = 10**(0.615/(1+EXP(-0.696*(TEMP-32.79)))-0.077);
 F100 = 10**(0.437/(1+EXP(-0.312*(TEMP-31.75)))-0.160);
 ISOP = F100/10.73 + (F200/4.75 - F100/10.73) * (SOLARE - 100) / 100;
        END;
  ELSE IF SOLARE = 100 THEN DO;
        F100 = 10**(0.437/(1+EXP(-0.312*(TEMP-31.75)))-0.160);
        ISOP = F100/10.73;
        END;
  ELSE IF SOLARE < 100 AND SOLARE > 0 THEN DO;
        F100 = 10**(0.437/(1+EXP(-0.312*(TEMP-31.75)))-0.160);
        ISOP = (F100/10.73) * SOLARE / 100;
        END;
  ELSE IF SOLARE <= 0 THEN
        ISOP = 0;
*;
***** NEW NO ALGORITHM ---- ADDED 6/89 ---- LGM ******************;
*;
* THE ORIGINAL NOX CALCULATIONS (BELOW) HAVE BEEN SUPERCEDED BY THE;
* FOLLOWING ALGORITHMS WHICH WERE TAKEN FROM A FAX SENT TO MARK;
* SAEGER FROM FRED FEHSENFELD (NOAA) ON MAR 21, 1989.;
* NOTE THE FOLLOWING UNITS: TEMPERATURE: DEGREES C;
*                           NO FLUX : NG NITROGEN/SQ M * SECONDS;
*;
    STEMP = (0.70*TEMP) + 3.6;
    QNO   = 0.74*EXP(0.079*STEMP);
*;
************** OLD NO ALGORTHM COMMENTED OUT 6/89----LGM ********;
*;
* CALCULATE HOURLY NOX FLUX FOR EACH GRID CELL;
* DETAILED EQUATION: STEMP KELVIN = (0.69 * TEMP CELSIUS + 2.1) + 273;
* DETAILRD EQUATION: QNO NG N/M2/SEC = 5.1E16 NG N/M2/SEC/PPM * 2 PPM
            * EXP(-97000 J MOLE /(8.314 J/MOLE/KELVIN * STEMP KELVIN));
 *STEMP = 0.69 * TEMP + 275.1;
 *QNO = 10.2E16 * EXP(-97000/(8.314 * STEMP));
```

```
 KEEP COL ROW HOUR ISOP MONO ALPH QNO;
* UNITS FOR QNO ARE NG N/M2/SEC;
*;
*PROC PRINT DATA=OUT1.CNPEMFAC(OBS=500);
*TITLE 'CANOPY EMISSION CORRECTION FACTORS - FIRST 500 OBS';
*PROC PRINT DATA=OUT2.NCEMFAC(OBS=500);
*TITLE 'NONCANOPY EMISSION CORRECTION FACTORS - FIRTST 500 OBS';
*;
```

RADMBIO.SAS

```
*********************************************************************
* RUNSTREAM TO EXECUTE PROGRAM BIO.RADMBIO.SAS
*
* RADMBIO.SAS CALCULATES STANDARD EMISSIONS AS A FUNCTION OF BIOMASS
* AND THEN APPLIES HOURLY TEMPERATURE AND SOLAR RADIATION CORRECTION
* FACTORS FROM CORRECT2.SAS.  THE INPUT/OUTPUT FILES ARE:
*
*     IN1:  GRIDDED NONCANOPY LAND COVERAGE (FROM BIOMASS.SAS)
*     IN2:  GRIDDED BIOMASS FOR URBAN TREES (FROM BIOMASS.SAS)
*     IN3:  NONCANOPY EMISSION CORRECTION FACTORS (FROM CORRECT2.SAS)
*     IN4:  GRIDDED CANOPY BIOMASS (FROM BIOMASS.SAS)
*     IN5:  CANOPY EMISSION CORRECTION FACTORS (FROM CORRECT2.SAS)
*
*  INTER1:  ADJUSTED GRIDDED HOURLY NONCANOPY EMISSIONS
*  INTER2:  ADJUSTED GRIDDED HOURLY CANOPY EMISSIONS
*
*    OUT1:  COMBINED CANOPY AND NONCANOPY BIOGENIC EMISSIONS FOR
*           RADM INPUT
********************************************************************
* RADMBIO.SAS;
*-------------------------------------------------------------------*
|     READS IN THE CANOPY AND NON-CANOPY BIOFACTORS AND THE GRIDDED |
|     BIOMASS AND CREATES THE DATASET FOR MERGING WITH THE OTHER    |
|    EMISSIONS SOURCES (MAJOR,MINOR,AREA)                           |
*-------------------------------------------------------------------*;
*;
* LGM 7/89 - IBM/TSO VERSION;
* BRG 6/89   CMS VERSION;
* BRG 5/89 - BIOGENIC EMISSIONS PROCESSING VERSION 2.1;
* REVISED CANOPY MODEL FOR RADM;
* BRG 3/89 - BIOGENIC EMISSIONS PROCESSING VERSION 2.0;
* IMPLEMENTATION OF THE CANOPY MODEL;
* BRG 2/89   BIOGENIC EMISSIONS PROCESSING VERSION 2.0;
* ADD SOIL NO AND NO2 - CONVERT FROM MOLE/SEC TO G/SEC;
* BRG 12/88 - BIOGENIC EMISSIONS PROCESSING VERSION 1.0;
*;
* ------- CALCULATE EMISSIONS FOR EACH GRID CELL & HOUR ------------*
|                        NON-CANOPY VERSION                         |
|  WATER DATA HAS BEEN DELETED FOR THE 2.1 BEIS.                    |
|  WAT_ER WAT1-WAT4  WAT_ER = 145.0 WAT1 = 0 WAT2 = 0 WAT3 = 0      |
|  WAT4 = 1.00 WAT_ER WAT1-WAT4 WATER                               |
|                                                                   |
*-------------------------------------------------------------------*;
*;
* SET UP EMISSION RATES & PERCENT COMPOSITIONS;
DATA EMISRATE;
  LENGTH DEFAULT=4;
  ARRAY EMISRTE(18) ALF_ER SOR_ER HAY_ER SOY_ER COR_ER POT_ER TOB_ER
             WHT_ER COT_ER RYE_ER RIC_ER PEA_ER BAR_ER OAT_ER RNG_ER
             GRS_ER UGR_ER CMS_ER;
  * COMPOSITION TYPES ARE ISOP, ALPHA, MONO, UNKNOW;
  ARRAY EMISCMP(72) ALF1-ALF4 SOR1-SOR4 HAY1-HAY4 SOY1-SOY4 COR1-COR4
        POT1-POT4 TOB1-TOB4 WHT1-WHT4 COT1-COT4 RYE1-RYE4 RIC1-RIC4
```

```
       PEA1-PEA4 BAR1-BAR4 OAT1-OAT4 RNG1-RNG4 GRS1-GRS4
       UGR1-UGR4 CMS1-CMS4;
   ALF_ER = 37.9;
   SOR_ER = 39.4;
   HAY_ER = 189.0;
   SOY_ER = 22.2;
   COR_ER = 3542.0;
   POT_ER = 48.1;
   TOB_ER = 294.0;
   WHT_ER = 30.0;
   COT_ER = 37.9;
   RYE_ER = 37.9;
   RIC_ER = 510.0;
   PEA_ER = 510.0;
   BAR_ER = 37.9;
   OAT_ER = 37.9;
   RNG_ER = 189.0;
   GRS_ER = 281.0;
   UGR_ER = 281.0;       * URBAN GRASS;
   CMS_ER = 37.9;        * CROPS MISC;
   ALF1 = .50; ALF2 = .10; ALF3 = .10; ALF4 = .30;
   SOR1 = .20; SOR2 = .25; SOR3 = .25; SOR4 = .30;
   HAY1 = .20; HAY2 = .25; HAY3 = .25; HAY4 = .30;
   SOY1 = 1.00; SOY2 = 0;  SOY3 = 0;   SOY4 = 0;
   COR1 = 0;   COR2 = .10; COR3 = .10; COR4 = .80;
   POT1 = 0;   POT2 = .25; POT3 = .25; POT4 = .50;
   TOB1 = 0;   TOB2 = .10; TOB3 = .10; TOB4 = .80;
   WHT1 = .50; WHT2 = .10; WHT3 = .10; WHT4 = .30;
   COT1 = .20; COT2 = .25; COT3 = .25; COT4 = .30;
   RYE1 = .20; RYE2 = .25; RYE3 = .25; RYE4 = .30;
   RIC1 = .20; RIC2 = .25; RIC3 = .25; RIC4 = .30;
   PEA1 = .20; PEA2 = .25; PEA3 = .25; PEA4 = .30;
   BAR1 = .20; BAR2 = .25; BAR3 = .25; BAR4 = .30;
   OAT1 = .20; OAT2 = .25; OAT3 = .25; OAT4 = .30;
   RNG1 = .20; RNG2 = .25; RNG3 = .25; RNG4 = .30;
   GRS1 = .20; GRS2 = .25; GRS3 = .25; GRS4 = .30;
   UGR1 = .20; UGR2 = .25; UGR3 = .25; UGR4 = .30;
   CMS1 = .20; CMS2 = .25; CMS3 = .25; CMS4 = .30;

DATA EMISA;
 SET IN1.GNCBIO;
  LENGTH DEFAULT=4;
 IF (_N_ = 1) THEN DO;
    SET EMISRATE;       *BRING IN EMISSION RATES & COMPOSITIONS;
    * CONVERT FACTOR TO GET EMISSIONS INTO G/HR (HA TO M2 AND UG TO G);
    CONVR = 1E-2;
 END;
 RETAIN CONVR;
 * EMISSION RATES BY VEG TYPE;
 ARRAY EMISRTE(18) ALF_ER SOR_ER HAY_ER SOY_ER COR_ER POT_ER TOB_ER
            WHT_ER COT_ER RYE_ER RIC_ER PEA_ER BAR_ER OAT_ER RNG_ER
            GRS_ER UGR_ER CMS_ER;
 * COMPOSITION TYPES ARE ISOP, ALPHA, MONO, UNKNOW;
 ARRAY EMISCMP(72) ALF1-ALF4 SOR1-SOR4 HAY1-HAY4 SOY1-SOY4 COR1-COR4
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       POT1-POT4 TOB1-TOB4 WHT1-WHT4 COT1-COT4 RYE1-RYE4 RIC1-RIC4
       PEA1-PEA4 BAR1-BAR4 OAT1-OAT4 RNG1-RNG4 GRS1-GRS4
       UGR1-UGR4 CMS1-CMS4;
 * BIOMASS TYPES;
 ARRAY VEG(18) ALFA SORG HAY SOYBN CORN POTAT TOBAC WHEAT COTT RYE RICE
                PEANUT BARL OATS SCRUB GRASS URB_GRSS CRP_MS;
 * EMISSION AMOUNTS  AISAMT AMOAMT AALAMT AUNAMT;
 AISAMT = 0;
 AMOAMT = 0;
 AALAMT = 0;
 AUNAMT = 0;
 DO I = 1 TO DIM(VEG);
   AMT = VEG(I) * EMISRTE(I) * CONVR;          * CALC EMISSION RATE;
   J = (I - 1) * 4;              * CALCULATE OFFSET;
   AISAMT + (EMISCMP(J+1) * AMT);
   AMOAMT + (EMISCMP(J+2) * AMT);
   AALAMT + (EMISCMP(J+3) * AMT);
   AUNAMT + (EMISCMP(J+4) * AMT);
 END;
 NOXGRS = SUM(URB_GRSS,GRASS) * 1E4;   *KEEP GRASS AREA IN M2 FOR NOX;
 KEEP COL ROW AISAMT AMOAMT AALAMT AUNAMT NOXGRS;
*-------------------------------------------------------------*
|              URBAN TREES                                    |
*-------------------------------------------------------------*;
DATA EMISRATE;
  LENGTH DEFAULT=4;
 ARRAY ISOPER(4) ISOPER1 - ISOPER4;
 ARRAY ALPHER(4) ALPHER1 - ALPHER4;
 ARRAY MONOER(4) MONOER1 - MONOER4;
 ARRAY UNKWER(4) UNKWER1 - UNKWER4;
 * EMISSION TYPES ARE HIGH ISOP, LOW ISOP, NON-IOSP, CONF;
  ISOPER1 = 14.69;
  ISOPER2 = 6.60;
  ISOPER3 = 0.0;
  ISOPER4 = 0.0;
  ALPHER1 = 0.13;
  ALPHER2 = 0.05;
  ALPHER3 = 0.07;
  ALPHER4 = 1.13;
  MONOER1 = 0.11;
  MONOER2 = 0.05;
  MONOER3 = 0.07;
  MONOER4 = 1.29;
  UNKWER1 = 3.24;
  UNKWER2 = 1.76;
  UNKWER3 = 1.91;
  UNKWER4 = 1.38;
DATA EMISB; * CALCULATE EFFECTIVE EMISSION RATE FOR EACH COMPOUND;
 SET IN2.GUTBIO;
  LENGTH DEFAULT=4;
 IF (_N_ = 1) THEN DO;
    SET EMISRATE;       *BRING IN EMISSION RATES;
 * CONVERT FACTOR TO GET EMISSIONS INTO G/HR = KG TO G AND UG TO G;
    CONVR = 10**-3;
```

```
 END;
 RETAIN CONVR;
 * EMISSION TYPES ARE HIGH ISOP, LOW ISOP, NON-IOSP, CONF;
 ARRAY ISOPER(4) ISOPER1 - ISOPER4;
 ARRAY ALPHER(4) ALPHER1 - ALPHER4;
 ARRAY MONOER(4) MONOER1 - MONOER4;
 ARRAY UNKWER(4) UNKWER1 - UNKWER4;
 * BIOMASS AMOUNTS TYPES ARE HIGH ISOP, LOW ISOP, NON-ISOP, CONF;
 ARRAY BIOMASS(4) BIOHI BIOLI BIONI BIOCF;
 BISAMT = 0;
 BMOAMT = 0;
 BALAMT = 0;
 BUNAMT = 0;
 DO I = 1 TO 4;
   BISAMT + (BIOMASS(I) * ISOPER(I) * CONVR);   *CALC EMISSION RATE;
   BMOAMT + (BIOMASS(I) * MONOER(I) * CONVR);
   BALAMT + (BIOMASS(I) * ALPHER(I) * CONVR);
   BUNAMT + (BIOMASS(I) * UNKWER(I) * CONVR);
 END;
 KEEP COL ROW BISAMT BMOAMT BALAMT BUNAMT;
*-------------------------------------------------------------------*
|       COMBINE URBAN TREES AND OTHER NON-CANOPY VEGATION          |
*-------------------------------------------------------------------*;
DATA INTER1.GNCEM;
 MERGE EMISA IN3.NCEMFAC EMISB;
 BY COL ROW;
  LENGTH DEFAULT=4;
* HYDROCARBON UNITS ARE G/SEC -  ADJUST HOURLY;
 NCISOP = ISOP * SUM(AISAMT, BISAMT);
 NCMONO = MONO * SUM(AMOAMT, BMOAMT);
 NCALPH = ALPH * SUM(AALAMT, BALAMT);
 NCUNKW = MONO * SUM(AUNAMT, BUNAMT);
* GET HOURLY SOIL NO AND NO2 IN MOLE/SEC;
* DETAILED EQUATIONS: NO NG N/SEC = GNO NG N/M2/SEC * NOXGRS M2;
*          NCNO MOLE/SEC = NO NG N/SEC * 1G/1E9NG * 1MOLE/14.0067G;
*          NCNO2 MOLE/SEC = NCNO MOLE/SEC * 0.06; *NO2 IS 6% OF NO;
 NCNO = (QNO * NOXGRS) * 7.13944E-11;
 IF NCNO = . THEN NCNO = 0.0;
 NCNO2 = NCNO * 0.06;
 KEEP COL ROW HOUR NCISOP NCMONO NCALPH NCUNKW NCNO NCNO2;
*;
* ------- CALCULATE EMISSIONS FOR EACH GRID CELL & HOUR ------------*
|                         CANOPY VERSION                            |
*  -----------------------------------------------------------------*;
DATA EMISRATE;
  LENGTH DEFAULT=4;
 ARRAY ISOPER(4) ISOPER1 - ISOPER4;
 ARRAY ALPHER(4) ALPHER1 - ALPHER4;
 ARRAY MONOER(4) MONOER1 - MONOER4;
 ARRAY UNKWER(4) UNKWER1 - UNKWER4;
 * EMISSION TYPES ARE HIGH ISOP, LOW ISOP, NON-IOSP, CONF;
  ISOPER1 = 14.69;
  ISOPER2 = 6.60;
  ISOPER3 = 0.0;
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  ISOPER4 = 0.0;
  ALPHER1 = 0.13;
  ALPHER2 = 0.05;
  ALPHER3 = 0.07;
  ALPHER4 = 1.13;
  MONOER1 = 0.11;
  MONOER2 = 0.05;
  MONOER3 = 0.07;
  MONOER4 = 1.29;
  UNKWER1 = 3.24;
  UNKWER2 = 1.76;
  UNKWER3 = 1.91;
  UNKWER4 = 1.38;
DATA CNPEMIS; * CALCULATE EFFECTIVE EMISSION RATE FOR EACH COMPOUND;
 SET IN4.GCPBIO;
  LENGTH DEFAULT=4;
 IF (_N_ = 1) THEN DO;
    SET EMISRATE;       *BRING IN EMISSION RATES;
 * CONVERT FACTOR TO GET EMISSIONS INTO G/HR = KG TO G AND UG TO G;
    CONVR = 10**-3;
 END;
 RETAIN CONVR;
 * EMISSION TYPES ARE HIGH ISOP, LOW ISOP, NON-IOSP, CONF;
 ARRAY ISOPER(4) ISOPER1   ISOPER4;
 ARRAY ALPHER(4) ALPHER1 - ALPHER4;
 ARRAY MONOER(4) MONOER1 - MONOER4;
 ARRAY UNKWER(4) UNKWER1 - UNKWER4;
*BIOMASS CATEGORIES HIGH ISOP,LOW ISOP,NO ISOP,CONF- 8 CANOPY LAYERS;
 ARRAY BIOMASS1(8) BIOHI1-BIOHI8;
 ARRAY BIOMASS2(8) BIOLI1-BIOLI8;
 ARRAY BIOMASS3(8) BIONI1-BIONI8;
 ARRAY BIOMASS4(8) BIOCF1-BIOCF8;
* EMISSIONS FOR JANID, CONF - 8 CANOPY LAYERS;
 ARRAY ISAMT1(8) ISDE1-ISDE8;
 ARRAY MOAMT1(8) MODE1-MODE8;
 ARRAY ALAMT1(8) ALDE1-ALDE8;
 ARRAY UNAMT1(8) UNDE1-UNDE8;
 ARRAY ISAMT2(8) ISCF1-ISCF8;
 ARRAY MOAMT2(8) MOCF1-MOCF8;
 ARRAY ALAMT2(8) ALCF1-ALCF8;
 ARRAY UNAMT2(8) UNCF1-UNCF8;

* CALC EMISSION RATE;
 DO J = 1 TO 8;
     ISAMT1(J) = (BIOMASS1(J) * ISOPER(1) +
                  BIOMASS2(J) * ISOPER(2) +
                  BIOMASS3(J) * ISOPER(3)) * CONVR;
     MOAMT1(J) = (BIOMASS1(J) * MONOER(1) +
                  BIOMASS2(J) * MONOER(2) +
                  BIOMASS3(J) * MONOER(3)) * CONVR;
     ALAMT1(J) = (BIOMASS1(J) * ALPHER(1) +
                  BIOMASS2(J) * ALPHER(2) +
                  BIOMASS3(J) * ALPHER(3)) * CONVR;
     UNAMT1(J) = (BIOMASS1(J) * UNKWER(1) +
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                  BIOMASS2(J) * UNKWER(2) +
                  BIOMASS3(J) * UNKWER(3)) * CONVR;
      ISAMT2(J) = BIOMASS4(J) * ISOPER(4) * CONVR;
      MOAMT2(J) = BIOMASS4(J) * MONOER(4) * CONVR;
      ALAMT2(J) = BIOMASS4(J) * ALPHER(4) * CONVR;
      UNAMT2(J) = BIOMASS4(J) * UNKWER(4) * CONVR;
 END;
 KEEP COL ROW ISDE1-ISDE8 ISCF1-ISCF8 MODE1-MODE8 MOCF1-MOCF8
        ALDE1-ALDE8 ALCF1-ALCF8 UNDE1-UNDE8 UNCF1-UNCF8;
DATA INTER2.GCNPEM; *ADJUST BY HRLY CORRECTION FACTOR TO GET HRLY RATE;
 MERGE CNPEMIS IN5.CNPEMFAC;
 BY COL ROW;
  LENGTH DEFAULT=4;
* HOURLY EMISSION CORRECTION FACTORS - FOR BIOMASS TYPE - 8 LAYERS;
 ARRAY MONO1(8) MONODE1-MONODE8;
 ARRAY ALPH1(8) ALPHDE1-ALPHDE8;
 ARRAY ISOP1(8) ISOPDE1-ISOPDE8;
 ARRAY MONO2(8) MONOCF1-MONOCF8;
 ARRAY ALPH2(8) ALPHCF1-ALPHCF8;
 ARRAY ISOP2(8) ISOPCF1-ISOPCF8;
* EMISSIONS HIGH ISOP, LOW ISOP, NO ISOP, CONF - 8 CANOPY LAYERS;
 ARRAY ISAMT1(8) ISDE1-ISDE8;
 ARRAY MOAMT1(8) MODE1-MODE8;
 ARRAY ALAMT1(8) ALDE1-ALDE8;
 ARRAY UNAMT1(8) UNDE1-UNDE8;
 ARRAY ISAMT2(8) ISCF1-ISCF8;
 ARRAY MOAMT2(8) MOCF1-MOCF8;
 ARRAY ALAMT2(8) ALCF1-ALCF8;
 ARRAY UNAMT2(8) UNCF1-UNCF8;

 CPISOP = 0;
 CPMONO= 0;
 CPALPH = 0;
 CPUNKW = 0;
* ADJUST HOURLY;
 DO J = 1 TO 8;
     CPISOP + SUM(ISOP1(J) * ISAMT1(J), ISOP2(J) * ISAMT2(J));
     CPMONO + SUM(MONO1(J) * MOAMT1(J), MONO2(J) * MOAMT2(J));
     CPALPH + SUM(ALPH1(J) * ALAMT1(J), ALPH2(J) * ALAMT2(J));
     CPUNKW + SUM(MONO1(J) * UNAMT1(J), MONO2(J) * UNAMT2(J));
 END;
 KEEP COL ROW HOUR CPISOP CPMONO CPALPH CPUNKW;
* ------------ COMBINE & READY BIOGENICS FOR RADM ---------------*
|      COMBINE CANOPY AND NON-CANOPY EMISSIONS IN G/HR           |
|         MERGE THE CANOPY AND THE NON-CANOPY DATA               |
*-----------------------------------------------------------------*;
DATA TEMP.DATA;
 MERGE INTER2.GCNPEM INTER1.GNCEM;
 LENGTH DEFAULT=4;
 BY COL ROW;
* COMBINE & CONVERT FROM G/HR TO G/SEC;
 ISOP = SUM(CPISOP, NCISOP)/3600;
 MONO = SUM(CPMONO, NCMONO)/3600;
 ALPHA = SUM(CPALPH, NCALPH)/3600;
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 UNKW = SUM(CPUNKW, NCUNKW)/3600;
* CONVERT NO AND NO2 FROM MOLES/SEC TO G/SEC;
 BIONO = NCNO * 30.0061;         * MW OF N 14.0067 + MW OF O 15.9994;
 BIONO2 = NCNO2 * 46.0055;       * MW OF N 14.0067 + MW OF 2 O 31.9988;
 KLEVEL = 1;                             * ALL ON LAYER 1;
 RENAME COL=RAD_COL ROW=RAD_ROW;
 KEEP COL ROW HOUR KLEVEL ISOP MONO ALPHA UNKW BIONO BIONO2;
* SORT FOR MERGE WITH POINTS & AREAS;
PROC SORT DATA=TEMP.DATA OUT=OUT1.RADMBIO;
 BY HOUR RAD_COL RAD_ROW KLEVEL;
 PROC PRINT DATA=OUT1.RADMBIO(OBS=500);
 TITLE1 'COMBINED CANOPY AND NONCANOPY BIOGENIC EMISSIONS';
 TITLE2 '               FOR RADM INPUT ';
 PROC PRINT DATA=INTER1.GNCEM(OBS=300);
 TITLE 'ADJUSTED GRIDDED HOURLY NONCANOPY EMISSIONS';
 PROC PRINT DATA=INTER2.GCNPEM(OBS=300);
 TITLE 'ADJUSTED GRIDDED HOURLY CANOPY EMISSIONS';
 *;
```

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/7-91-006	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Development of Seasonal and Annual Biogenic Emissions Inventories for the U.S. and Canada		5. REPORT DATE November 1991
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Lysa G. Modica and John R. McCutcheon		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Alliance Technologies Corporation Foot of John Street Lowell, Massachusetts 01852		10. PROGRAM ELEMENT NO.
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12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Air and Energy Engineering Research Laboratory Research Triangle Park, North Carolina 27711		13. TYPE OF REPORT AND PERIOD COVERED Task final; 9/89 - 5/91
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15. SUPPLEMENTARY NOTES AEERL project officer is Christopher D. Geron, Mail Drop 63, 919/541-4639.

16. ABSTRACT The report describes the development of a biogenic emissions inventory for the U.S. and Canada, to assess the role of biogenic emissions in ozone formation. Emission inventories were developed at hourly and grid (1/4 x 1/6 degree) levels from input data at the same scales. Emissions were calculated as a function of biomass density and meteorological parameters (solar radiation, cloud cover, temperature, windspeed, and relative humidity). These factors were applied to a forest canopy algorithm that simulated processes generating biogenic emissions from foliage. Resultant emissions were aggregated to monthly, seasonal, and annual levels, and spatially to counties and states. (NOTE: Historically, ozone control programs based on reductions of known anthropogenic volatile organic compound (VOC) emissions have had limited success in obtaining the National Ambient Air Quality Standard. Researchers have, therefore, been actively evaluating VOC emission sources not routinely considered in ozone control strategies. One potentially large source of reactive VOCs is thought to be emissions from crop and forest foliage.) Approximately 50% of the biogenic hydrocarbon emissions occur in the summer, approximately equal amounts (20%) in the spring and fall, and much lower amounts in the winter.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Meteorology	Pollution Control	13B	04B
Ozone	Organic Compounds	Stationary Sources	07B	07C
Emission	Volatility	Biogenesis	14G	20M
Bioengineering	Vegetation	Volatile Organic Compounds (VOCs)	06B	08F
Inventories	Hydrocarbons		15E	
Biomass	Isoprene	Monoterpenes	08A, 06C	

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 144
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