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# A COMPUTER PROGRAM to Map Tree Crown Shadows in the Urban Forest

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## Abstract

A FORTRAN IV computer program maps the shadows cast by urban tree crowns at selected intervals during the day. The program is convenient to use, requiring only site and tree data. Latitude, date, and time of day are compensated for internally. Each tree on or adjacent to the site is described by height and crown dimensions. A maximum of nine trees is allowed, but a sequential series of computations will produce overlays mapping the shadows cast by additional trees. A test of the program shows that it produces maps within acceptable limits if the tree measurements are accurate.

# CROWN SHADOWS FROM THE URBAN FOREST

URBAN FORESTS and the shade cast by trees have been recognized as desirable esthetic features of metropolitan areas (Andresen 1978). Crown shadows also affect physical properties of the urban environment. For example, tree shadows modify the local energy balance. Consequently, environmental extremes can be reduced by shadows that may moderate tree water stress. Water stress is now recognized as the major factor limiting urban tree growth (Potts and Herrington 1979). Also, tree shadows can affect residential fuel requirements (Heisler and Herrington 1976): shading a building in the summer can lower fuel needs for air conditioning, but winter shade can increase fuel consumption for heating. Knowledge of shadow distribution could be used in urban planning and may even have legal implications. Reitze and Reitze (1976) discussed responsibilities associated with changing solar exposure. Although workers in these disciplines, and probably other fields, have an interest in shadow patterns, there is no coordinated system to predict shadow coverage at a site.

Shadow distribution and orientation vary with time of day and season of year. Before we can assess the impact of shadows, we must determine that distribution of shade on the site during the course of a day and at different times during the year. Shadow computations and mapping can be done manually, but the task would be lengthy. In contrast, computer systems can make laborious computations swiftly and produce maps at comparatively low cost. The objective of this study was to develop a computer mapping system that would delineate crown shade on a site at specified times and dates.

Previous work in shadow mapping has been largely confined to rural forests. Shadow source management has been proposed for silvicultural purposes (Marquis 1965) and to control snowmelt (Halverson and Smith 1974, 1979). Shadow mapping techniques have been developed to accomplish these forest management objectives (Brown and Merritt 1970, Halverson and Smith 1974, Satterlund 1977). Although these techniques vary in complexity and completeness, none is appropriate for urban forests because they concentrate on shadow length cast into an opening by boundary trees rather than shadow shape. The urban forest, which we define as the forest vegetation complex in and adjacent to populated areas, differs from the rural forest in both use and structure.

Uses of the urban forest are largely for amenity values and benefits and not for wood products. The structure of the urban forest is usually more open, with fewer stems per unit area. Species distribution may not reflect the composition of the native forest in the area. Soil and other site conditions may be altered by surrounding urban development. These kinds of differences between urban and rural forests led us to make some assumptions about urban forests and to define some requirements of a shadow mapping program.

Our assumptions and requirements were:

1. Because the density of urban forests tends to be low, the shadow cast by each crown must be described.
2. Because urban trees are open grown, tree crowns tend to be more spherical or elliptical than crowns developing in a dense forest (Mawson et al. 1976).
3. Urban sites of interest tend to be smaller so shadow mapping can be more detailed than in rural areas.
4. Many urban sites have altered topography, with a tendency to be leveled.
5. Because of the relatively small area mapped, the program must accommodate trees not on the site that may cast a shadow into the mapped area.
6. Because shadows vary drastically with time and date, the program should produce a series of maps based on specification of these variables.
7. The program will be designed for temperate northern latitudes, spanning the distribution of the Nation's urban regions.

## Map format

To meet the assumptions and requirements for shadow mapping, we followed certain conventions. We used the normal coordinate system with the origin (0,0) as an arbitrary point on the ground surface selected by the operator. The area covered by the map would be in the quadrant where both X and Y are positive. The length of the map in the X direction (east) would be 10 inches and the Y dimension (north) would be 8.33 inches. These dimensions occupy 100 spaces (X) and 50 lines (Y) on a computer line printer. Actual ground coverage will vary depending on the map scale chosen by the operator.

These conventional techniques mean we can locate a tree base on or off the map in the usual coordinate system. The X coordinate may exceed 100 spaces for a tree east of the mapped area, a negative X would place the tree west of the site. If the Y coordinate is negative, the tree is located southeast or southwest of the map area. By manipulating the coordinates of the tree base, we can map the tree shadow during the hours when the shadow falls in our area of interest.

# HARDWARE AND SOFTWARE

The shadow mapping program[1] was developed on an IBM 370 computer[2] in FORTRAN IV language. Recognizing that there are differences and some incompatibilities among computer systems, we tried to use program language that would be acceptable on any system. However, use of our program on another system may require modification of some statements.

We accepted some program inefficiency to make modification less troublesome. The program statements have not been packed, i.e., there are no multiple statements per card image, multiple equalities have not been used, and some computations are repeated so a minor program change will not affect a subsequent calculation. The output device is a standard line printer. We chose the printer because it is the most common output device and no special subroutines are required. Plotters or other display devices may require software or routines unique to a given computer installation and would lessen the utility of the mapping program.

# TIME CONVERSION

The expression of time during the day is a variable for which there are several options. In this program, we chose to use true solar time because it gives the most accurate calculation of solar location in the sky.

True solar time is based on true solar noon, the time when the center of the sun crosses the longitude of the observer. Local times are based on 15° time zones, with noon in local standard time occurring approximately when the sun crosses the time zone meridian. Standard time zone meridians for the 48 contiguous States are:

| | |
|---|---|
| Eastern | 75° W |
| Central | 90° W |
| Mountain | 105° W |
| Pacific | 120° W |

Daylight time and a realignment of time zone boundaries tend to make clock times unsuitable for solar calculations, so tree solar time is the best for solar calculating and was adapted for program development. However, true solar time can be converted manually to local standard (LST) by a two-step process.

When converting LST to true solar time, the first step is to compute a value known as mean solar time. This step requires knowledge of the longitude of the site. The mean solar time for a site is earlier or later than local

[1] The computer program described in this publication is available on request with the understanding that the U.S. Department of Agriculture cannot assure its accuracy, completeness, reliability, or suitability for any other purpose than that reported. The recipient may not assert any proprietary rights thereto nor represent it to anyone as other than a Government-produced computer program. For cost information write: Northeastern Forest Experiment Station, 370 Reed Road, Broomall, PA 19008.

[2] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

standard time by 4 minutes (0.0667 hour) for each degree of longitude the site is displaced from the time zone meridian. Mean solar time is earlier if the site is east and later if the site is west of the time zone meridian. Thus, for a site at 78° W longitude, mean solar noon occurs at 12:12 LST, or when expressed in decimal time, 12.2 hours.

Mean solar time is not equivalent to true solar time because of variations in the orbital path of the earth. The range of variation is approximately -14 to +16 minutes during the year and can be determined from an expression known as the equation of time. Solutions for equation of time have the form (List 1958):

| Date Calendar | Julian[a] | Minutes | Hours |
|---|---|---|---|
| Jan. 10 | 10 | - 7.2 | -0.12 |
| 24 | 24 | -12.0 | - .20 |
| Feb. 7 | 38 | -14.2 | - .24 |
| 20 | 51 | -13.9 | - .23 |
| Mar. 7 | 66 | -11.3 | - .19 |
| 21 | 80 | - 7.5 | .13 |
| Apr. 4 | 94 | - 3.3 | - .05 |
| 19 | 109 | + 0.5 | + .01 |
| May 3 | 123 | + 3.1 | + .05 |
| 18 | 138 | + 3.7 | + .06 |
| June 1 | 152 | + 2.4 | + .04 |
| 22 | 173 | - 1.6 | - .03 |
| July 12 | 193 | - 5.4 | - .09 |
| 27 | 208 | - 6.4 | .11 |
| Aug. 10 | 222 | - 5.4 | - .09 |
| 25 | 237 | - 2.3 | - .04 |
| Sept. 9 | 252 | + 2.4 | + .04 |
| 23 | 266 | + 7.3 | + .12 |
| Oct. 8 | 281 | +12.1 | + .20 |
| 22 | 295 | +15.3 | + .26 |
| Nov. 5 | 309 | +16.4 | + .27 |
| 19 | 323 | +14.7 | + .25 |
| Dec. 3 | 337 | +10.5 | + .18 |
| 22 | 356 | + 1.8 | + .03 |

[a] In a leap year, add 1 to each value after Feb. 28.

Mean solar time is converted to true solar time by adding the solution for the equation of time for the date. For our example at 78° W and a date of August 3, the value from the equation of time is about -6 minutes (-.10 hour); thus, true solar time is 12:06 (12.10 hours).

Converting true solar time to local standard time is accomplished by a reverse of the technique. First, the table value is algebraically subtracted if the site is west. In our example, true solar time at noon LST was 12:06 (12.10 hours). Subtracting the -6 minutes (-0.10 hour) yields 12:06-(-6) or 12:12 (12.2 hours). Since the site of interest is 3° west of the time zone meridian, we now subtract 12 minutes to yield 12:00. Thus, when true solar time is 12:06 (or 12.10 hours), it is noon in LST.

One additional compensation may be necessary. If daylight time is in effect, clock times must be adjusted. Since the imposition of daylight time is not universal, this correction must also be made manually.

## PROGRAM DESCRIPTION

The program is divided into one main program (CROWN) and three subroutines (SPHELP, LOCATE, and PMAP) (Appendix). Each routine does some computations and stores some variables in blank common. Variables stored in common are available to any of the routines and this technique is used to pass computed values from one routine to another. Several unused variables are also dimensioned in common to facilitate program modification or expansion.

### Data input

Two types of data are required. Data type I describes the site, the date of interest, and the map parameters. The second data type describes the trees on or near the site. CROWN reads the variables and stores them in arrays.

Program CROWN data cards supply information for computations. The first data card describes the site:

| | | | |
|---|---|---|---|
| Card Column | 4,5 | 9,10 | 12,13 |
| Variable | ID | MO | YR |
| Card Column | 17,18,19,20 | | 22-25 |
| Variable | ALAT | | ST |
| Card Column | 27,28,29,30 | | 32-35 |
| Variable | ET | | TI |
| Card Column | 40 | 42,43 | 48 |
| Variable | NT | SC | F |

Where: ID = Day number of the month, 01 to 31
MO = Month of the year, 01 to 12
YR = Last two digits of the year; for example, 79
ALAT = Latitude of the site, degrees north. Columns 19 and 20 can be used for decimal parts of a degree.

ST = The starting time of the mapping sequence, true solar. For example 6 a.m. would be entered at 0600 in columns 22 through 25. This value defaults to 0300 if unspecified. If the time specified or the default value is before sunrise, ST is increased to sunrise. Collumns 24 and 25 are used for decimal parts of an hour.

ET = Ending time of the mapping sequence, true solar. For example, 5:30 p.m. would be entered as 1750. This value defaults to 2100 if unspecified. If the time specified is after sunset, ET is decreased to sunset.

TI = Time interval between maps on the day specified, hours. If the value is less than .05 hours (3 minutes), this value defaults to 1 hour. Columns 34 and 35 are used for decimal parts of an hour.

NT = Number of trees on the site, maximum of 9, entered in column 40.

SC = Map scale, the number of feet, or meters, per inch on the final printed map, entered in column 42 and 43. Column 41 is used if a map scale greater than 99 is needed. The maximum value for SC is therefore 999 feet (or meters) per inch.

F = Scale factor entered in column 48.

1 = feet

2 = meters

The format of this card is 2I5, 5F5.2, I5, 2F5.2

The second type of data card describes a tree. As many as 9 cards may be entered, but the number of cards must be equal to the value NT on the first data card.

| Card Column | 8 | 18 | 28 | 38 | 48 | 58 | 68 | 78 |
|---|---|---|---|---|---|---|---|---|
| Variable | N | TH | CH | 1 | V | H | XT | YT |

In which:

N = Sequential tree number, 1 through 9, punched in column 8.

TH = Total tree height in feet or meters. The value is entered so that column 18 has the unit value; for example, a tree 30.25 feet tall would be described as 3025 in columns 17 through 20.

CH = Height to the base of the live crown in selected units. The value must be entered so that column 28 has the unit value; for example, a tree with a clear bole for 35 feet would be described as 3500 in columns 27 through 30.

1 = The numeral 1 in column 38. This field is reserved to define other crown shapes; the value 1 refers to a spherical or elliptical crown.

V = The vertical radius of the crown in feet or meters entered so the unit's value is in column 48; for example, a radius of 15.5 feet would be entered as 1550 in columns 47 through 50.

H = The horizontal radius of the crown in feet or meters. The unit values are in column 58; for example, a radius of 10 would be entered in columns 47 through 50 as 1000.

XT = The X coordinate of the tree base in feet or meters. The unit value is entered in column 68; for example, an X coordinate of 50 would be entered as 5000 in columns 67 through 70.

YT = The Y coordinate of the tree base in feet or meters. The unit value is entered in column 78; for example, a

Y coordinate of 25 would be entered as 2500 in columns 77 through 80.

The format of this card is 8F10.2.

Default data are provided for the time values. This was done to preclude attempting to map shadows before sunrise or after sunset and to prevent a series of maps produced without incrementing time through the day. Other data input errors will cause the program to abort or give incorrect results. Date, latitude, and map scales must be specified on the first data card. The number of trees specified must equal the number of tree description cards which follow.

The tree data requirements are stricter. The sequence numbers must be a single digit (1 through 9) and the cards should be in order. An error in tree dimensions or location will give an incorrect map. Total tree height (TH) minus the height to the base of the live crown (CH) should equal twice the vertical radius (2V). There is no default for errors in height or vertical radius because only field inspection can determine which value is in error. Vertical and horizontal radius should be equal if the crown is spherical. If the crown profile is elliptical, the horizontal radius will usually be less than the vertical radius, but this is not a program requirement.

The number of trees was limited to nine for two reasons. First, only a single character can be printed in a location. There are, of course, many other characters we could use. However, the second reason for the limit was that the shadow pattern from a large number of trees becomes too complex to interpret. If the shadows from many trees must be plotted, additional maps can be produced and overlaid to obtain the total pattern.

## Program CROWN, the main program

CROWN coordinates data input, checks for unrealistic values and assigns default values in some cases, computes solar location, and coordinates the flow of information to the subroutines. Additionally, it controls the format of the final array in which the map is stored.

Computations accomplished in CROWN are based on the equations needed to locate the sun in the sky. Four equations are used for solar computations:

$$SD = 23.45 \cos (DJ + C)\, 360/365.25 \quad (1)$$

$$ST = 12 - T \quad (2)$$

$$A = \sin^{-1} [\sin(L) \sin (SD) + \cos(L) \cos (SD) \cos (ST)] \quad (3)$$

$$AZ = \sin^{-1} [\cos(SD) \sin(ST)/\cos(A)] \quad (4)$$

The variables are

- SD = Solar declination, ranging from -23.45° to 23.45° depending on date and computed internally.
- T = True solar time, 0 to 24 hours decimal scale.
- ST = True solar time, before or after true solar noon.
- A = Solar elevation, radians above horizon.
- AZ = Solar azimuth, radians from south.
- DJ = Julian date, sequential number of the day during the year.
- C = Constant internally assigned to 10.5 or 7.5 depending on the value of DJ.

CROWN uses these equations for the data checking task. The operator selected starting time is checked with equation (3); if the operator's specified starting time is before sunrise, the value ST is adjusted forward to the time of sunrise. Similarly, if ending time is after sunset, the value of ET is incremented back to the time of sunset. Equation (4) is used to determine the due east and west crossing times of the sun and to determine in which of the four quadrants of the sky the sun is located at mapping time. These steps are necessary because azimuths used by the computer are altered to meet machine requirements for angular expressions. Consequently, we must define the solar location by quadrants to correctly map shadows.

CROWN, as a computational task, creates an array of blanks in memory that is used to store the final shadow map. Although any character could be used to create the array, the final output is more understandable with the background blanked. CROWN then calls the computational and mapping subroutines as they are needed.

## Subroutine SPHELP, defining the shadow perimeter

In SPHELP (from SPHere and ELliPse), the coordinates of the perimeter of the shadow, in map units of feet or meters, are computed. In an X-Y coordinate system where the X-axis is east and the Y-axis north, the equations are:

$$X = \frac{-CTC(Sin(AZ\ )Cos(A))}{Sin(A)} + \frac{V(Cos(W+AZ\ )Cos(AZ))}{Sin(A)} + H(Sin(W+AZ\ )\ Sin\ (AZ\ ) + XT \qquad (5)$$

$$Y = \frac{CTC(Cos(AZ)Cos(A))}{Sin\ (A)} + \frac{V(Cos(W+AZ)\ Sin\ (AZ\ ))}{Sin(A)} + H(Sin(W+AZ\ )\ Cos\ (AZ\ )) + YT \qquad (6)$$

The undefined terms have the values:

CTC = Height above the ground to the center of the tree crown, map units of feet or meters.

W = An internal variable set at 10°. Thus, the program calculates 36 points from 0 to 360° to define the perimeter of a crown shadow.

The computed coordinates for the crown are stored in an array to remain accessible to other subroutines. This subroutine is called for each crown.

## Subroutine LOCATE, screening the data

Within the limitations of the printer, subroutine LOCATE sequentially scales and examines each X and Y printer coordinate of the shadow perimeter. If the X coordinate is in the range $0 < X < 101$ and the Y coordinate is in the range $0 < Y < 51$, the point can be mapped and the sequential tree number is stored in the output map array in the location specified by the XY values. Points with an X or Y coordinate outside the map area are ignored.

The location of the tree base is examined in the same way. If the tree is located on the map, the base is also mapped, and the sequential tree number is stored in the proper location.

The character used to define the shadow perimeter and the tree base is the tree number. Because we use the number technique, each shadow on the map is identified with the source tree. However, because we examine shadows sequentially, points with identical coordinates will be identified by the larger number.

## Subroutine PMAP, control of printing

Subroutine PMAP (from Print MAP) serves only to control the printing after all the trees on the site have been examined for a particular time of day. It prints a two-line statement above the map that always begins with the phrase "block 1" and then identifies the scale, date, latitude, and true solar time of the map.

After printing the title, PMAP then prints the map and the X and Y axis. Along the axis, each inch is indexed by the letter "I". The distance value associated with each inch is identified in the lead statement and is not reproduced along the axis.

## Options under user control

Two options within the program provide a greater degree of user control. Additional sites, or maps of a given site on a different date, may be mapped by inserting additional sets of site and tree data cards in the data file. The mapping sequence will continue until all data have been processed. This option was included to reduce cost by eliminating the machine time needed to resubmit the program for each site or date.

The second option can be used to map a composite of the daily shadow pattern. The output array is blanked twice in the program. The first such clearing occurs after the input data are stored in an array (see statement 110 in CROWN). The second clearing occurs when all the shadows for a specific true solar time have been plotted on an output map (see statement 899 in CROWN). The time is then incremented forward by the specified time interval and data for a new map are generated. If the second clearing sequence is removed, each map will show the current and all previous shadow locations for the day. The last map will show an envelope, or composite, of the shadow pattern for the entire day. This option was included for those who need to see the progression of the shadow during the day.

## OUTPUT AND VERIFICATION

The model was tested by comparing a tree shadow on a level site with program output based on data taken from the same tree.

The test tree was an open-grown red maple (*Acer rubrum* L.). The tree was 34 feet tall with an elliptical crown that had a vertical radius of 14 feet and a horizontal radius of 9.4 feet. It was 6 feet from the ground to the base of the crown. Tree dbh was 8.5 inches. The tree was located at 40° N Latitude and 78° W Longitude. These site and tree data, the date August 3, 1979, and specified true solar times of 8.8 and 10.8 hours were mapped with the program.

On August 3, 1979, we measured the shadow cast by the tree at the specified true solar times. The shadow perimeter was identified by 17 points spaced along the boundary. Each point was then assigned X and Y coordinates corrected to the tree base location. The tree base was assigned coordinates 50, 25 to ensure that the entire shadow appeared on the map.

The computer maps for 8.8 true solar time (Fig. 1) and 10.8 solar time (Fig. 2) show good agreement between the computed and measured shadow. There were minor deviations because of printer limitations and irregularities in crown shape. The printer cannot fraction space either vertically or horizontally, so the coordinates are plotted at the

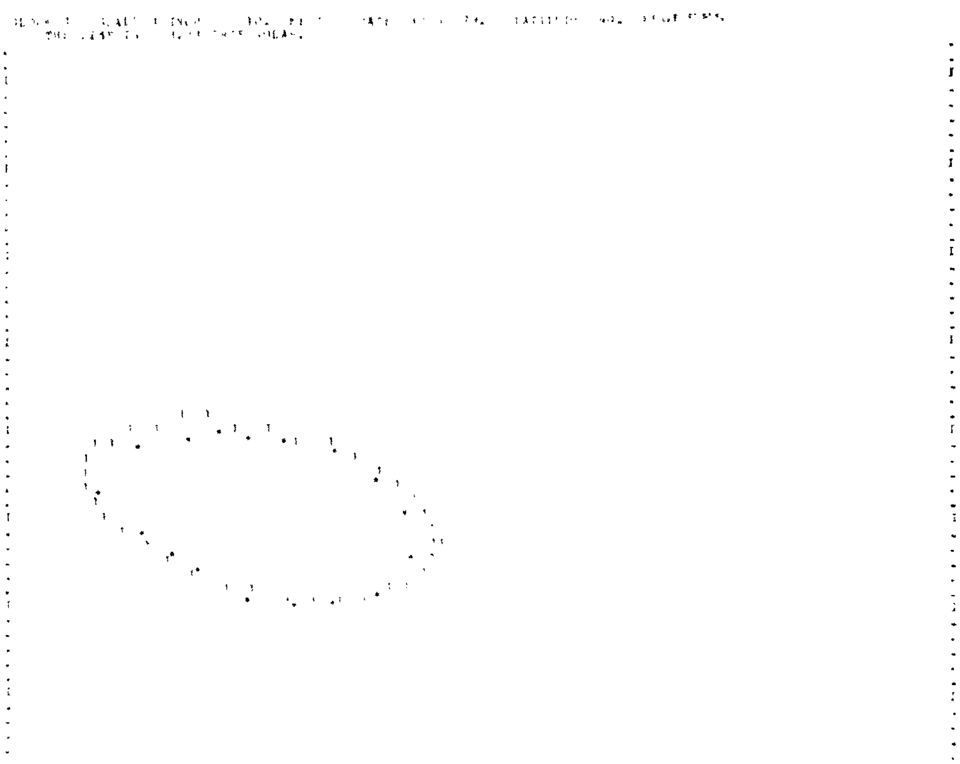

**Figure 1.—Computed and measured tree shadow and base for the test tree at 8.8 hours true solar time. The computer representation is the numeral 1; dots identify the measured shadow. The tree base is on the shadow perimeter. (The figure has been reduced by 50 percent.)**

**Figure 2.—Computed and measured tree shadow and base for the test tree at 10.8 hours true solar time. The computer map uses the numeral 1; dots identify the measured shadow. The tree base is inside the shadow perimeter. (The figure has been reduced by 50 percent).**

nearest location. Irregularities in the crown profile also cause small deviations. However, if the tree is measured carefully, and if the crown profile is nearly spherical or elliptical, the program plots an accurate representation of the shadow.

## SUMMARY

Shadow patterns affect local energy balances in urban and rural forest sites. This shadow mapping program was developed to meet application needs which have become apparent in urban forestry. Tree water stress, residential fuel requirements, and urban planning objectives can be affected by shadow patterns. Although not of primary interest in this work, shadow distribution may affect human thermal comfort and the urban energy balance. On rural forest sites, shadow patterns can influence the results of silvicultural treatments and snowmelt. Therefore, the shadow mapping program should be useful to foresters managing either urban or rural forests.

Although this shadow mapping program will be useful in many aspects of forestry, the routines used may have some limitations for specific applications. For example, tree crowns of interest may not be spherical or elliptical. The program was written to accommodate expansion to remove the shape limitation. A subroutine for another shape could be added to the program and the variable in column 38 of the tree description card changed and used to call the new subroutine. For other modifications, the variables XX, YY, ZZ, RSE, RSM, NPTS, and NPLPT are dimensioned in common but are available for use in program modification. We deliberately dimensioned these extra variables for future program changes to meet the needs of other users. In each application, the user is most able to decide program requirements, use the mapping program in modified or unmodified form, and implement the results.

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## APPENDIX

```
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION MT(12)
      COMMON/C8/ P(9,36),Q(9,36),TD(9,8),XX(36),
     1YY(36),ZZ(36),AL,ALAT,AR1,AZ,CO,D,DJ,ET,F,H,R,
     2RP,RSE,RSM,SA,SCALE,SIG,SLD,SOD,SOTC,SP,SS,S1,TI,
     3YR,XS,YS,XT,YT,CDR,PI
      COMMON/C4/ IPCK(9),MC(3,3),MN(9),I,ID,IQ,IR1,ITN,IZ,
     1KJ,K,J,M3,MO,MS,ND,NPIS,NT,NPLPT
      LOGICAL*1 IP(1,100,50)
      COMMON/C1/IP
C ==================================================================
C     THIS IS THE CONTROL ROUTINE FOR PROGRAM CROWN.
C     IT ALSO PERFORMS SOME COMMON CALCULATIONS.  THE
C     LABELED COMMON C8 RESERVES SPACE FOR DOUBLE
C     PRECISION VARIABLES.  COMMON C4 RESERVES SPACE
C     FOR INTEGER VARIABLES.  COMMON C1 AND THE
C     LOGICAL STATEMENT RESERVE A SINGLE SPACE FOR
C     EACH CHARACTER IN THE FINAL OUTPUT ARRAY FOR
C     THE MAP.  SOME REAL AND INTEGER VARIABLES ARE
C     RESERVED FOR FUTURE USE.
C ==================================================================
C
C
C ==================================================================
C     THE FOLLOWING ARITHMETIC STATEMENT FUNCTIONS
C     CAUSE TRIGNOMETRIC COMPUTATIONS TO USE DOUBLE
C     PRECISION ARITHMETIC.
C ==================================================================
      SIN(X)=DSIN(X)
      COS(X)=DCOS(X)
      TAN(X)=DTAN(X)
      ASIN(X)=DARSIN(X)
      ACOS(X)=DARCOS(X)
      DATA MT/0,31,59,90,120,151,181,212,243,273,304,334/
   10 READ(5,1000,END=999)ID,MO,YR,ALAT,ST,ET,TI,NT,SCALE,F
C ==================================================================
C     THE REQUIRED INPUT INFORMATION DESCRIBES THE
C     SITE.  VARIABLES ARE:
C          ID         DAY OF THE MONTH
C          MO         MONTH OF THE YEAR, NUMBER
C          YR         LAST TWO DIGITS OF THE YEAR
C        ALAT         LATITUDE OF THE SITE, DEGREES
C          ST         STARTING TIME OF THE MAP SEQUENCE,
C                        DECIMAL HOURS
C          ET         ENDING TIME OF THE MAP SEQUENCE,
C                        DECIMAL HOURS
C          TI         TIME INTERVAL BETWEEN MAPS ON THE
C                        SELECTED DAY, DECIMAL HOURS
C          NT         NUMBER OF TREES, MAXIMUM OF 9
C       SCALE         NUMBER OF FEET OR METERS PER INCH
```

```
C                         ON THE COMPUTER MAP
C              F        SELECT SCALE UNITS;
C                         1 = FEET
C                         2 = METERS
C==================================================
      PI=DATAN(1.D0)*4.
C==================================================
C     COMPUTE A FACTOR WHICH WILL BE USED TO CONVERT

C     DEGREES TO RADIANS (CDR)
C==================================================
      CDR=PI/180.
      ALAT=ALAT*CDR
      DO 20 IL=1,NT
   20 READ 1001,(TD(IL,K),K=1,8)
C==================================================
C     THE REQUIRED INPUT INFORMATION DESCRIBES THE
C     TREES ON THE SITE.  THE SUBSCRIPT IL REACHES A
C     MAXIMUM OF NT SET ON THE SITE DESCRIPTION CARD.
C     THE EIGHT TREE VARIABLES SUBSCRIPTED BY K ARE:
C             1       SEQUENTIAL TREE NUMBER, 1 THROUGH 9
C             2       TREE HEIGHT IN THE UNITS SELECTED
C             3       HEIGHT FROM THE GROUND TO THE BASE
C                         OF THE CROWN
C             4       THE SIDE SHAPE OF THE CROWN WHERE:
C                 1 = SPHERE OR ELLIPSE
C             5       VERTICAL RADIUS OF THE CROWN IN
C                         SELECTED UNITS
C             6       HORIZONTAL RADIUS OF THE CROWN IN
C                         SELECTED UNITS
C             7       X COORDINATE OF THE TREE BASE IN
C                         THE SELECTED UNITS
C             8       Y COORDINATE OF THE TREE BASE IN
C                         THE SELECTED UNITS
C==================================================
      XS=SCALE/10.
      YS=SCALE/6.
      KJ=0
      I=0
      J=0
   80 CONTINUE
      II=1
      IF(TI.LT.0.05) TI=1.
      IF(ST.LE.1.) ST=3.
      IF(ET.LE.1.) ET=21.
      DO 110 JJ=1,100
      DO 110 KK=1,50
  110 CALL CHMOVE(' ',IP(II,JJ,KK),1)
      DJ=MT(MO)+ID
      YR1=YR/4.
      IR1=YR1
```

```
      AR1=IR1
      D=YR1-AR1
      IF(D.EQ.0) GO TO 120
      GO TO 125
120   IF(MO.GE.2) DJ=DJ+1
125   IF(DJ.GE.335) GO TO 126
      IF(DJ.LE.213) GO TO 126
      CO=7.5
      GO TO 127
126   CO=10.5
127   CONTINUE
      SRD=(DJ+CO)*CDR
      DMM=(-23.45*CDR)
      SOD=DMM*COS(SRD)*360./365.25
      DO 128 IST=1,900
      G=(12.-ST)*15.*CDR
      A=ASIN(SIN(ALAT)*SIN(SOD)+COS(ALAT)*COS(SOD)*COS(G))
      IF(A.GE.0.) GO TO 129



      ST=ST+.01
128   CONTINUE
129   CONTINUE
      DO 130 IET=1,900
      G=(12.-ET)*15.*CDR
      A=ASIN(SIN(ALAT)*SIN(SOD)+COS(ALAT)*COS(SOD)*COS(G))
      IF(A.GE.0.) GO TO 131
      ET=ET-.01
130   CONTINUE
131   CONTINUE
      DE=0.
      T=3.
      DO 132 IE=1,900
      E=(12.-T)*15.*CDR
      B=ASIN(SIN(ALAT)*SIN(SOD)+COS(ALAT)*COS(SOD)*COS(E))
      BP=COS(SOD)*SIN(E)/COS(B)
      IF(DE.GE.BP) GO TO 133
      DE=BP
      T=T+.01
132   CONTINUE
133   T=T-.01
      TDW=24.-T
      TDE=T
      N=(ET-ST)/TI+1
      ST=ST-TI
134   CONTINUE
      ST=ST+TI
      H=(12.-ST)*15.*CDR
135   I=I+1
```

```
C================================================================
C     IF THESE CARDS ARE DELETED THE FINAL MAPS WILL
C     SHOW CURRENT AND ALL PREVIOUS SHADOW LOCATIONS
C     FOR THE DAY.
      II=1
      DO 899 JJ=1,100
      DO 899 KK=1,50
  899 CALL CHMOVE(' ',IP(II,JJ,KK),1)
C================================================================
      IF(I-N)401,401,10
  401 AL=ASIN(SIN(ALAT)*SIN(SOD)+COS(ALAT)*COS(SOD)*C
      AZ=ASIN(COS(SOD)*SIN(H)/CCS(AL))
      IF(ST.LE.TDE) AZ=PI-AZ
      IF(ST.GE.TDW) AZ=0.-PI-AZ
      ITN=0
  500 CONTINUE
      DO 700 J=1,NT
      ITN=ITN+1
  501 XT=TD(J,7)
      YT=TD(J,8)
      R=TD(J,5)
      MS=TD(J,4)
      MB=TD(J,5)
      TH=TD(J,2)
      CONTINUE
 6000 CALL SPHELP
      GO TO 99
   99 CALL LOCATE
  700 CONTINUE
      CALL PMAP
      GO TO 134




 1000 FORMAT(2I5,5F5.2,I5,2F5.2)
 1001 FORMAT(8F10.2)
  999 CONTINUE
      STOP
      END
```

```
      SUBROUTINE SPHELP
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/C8/ P(9,36),Q(9,36),TD(9,8),XX(36),
     1YY(36),ZZ(36),AL, ALAT,AR1,AZ,CO,D,DJ,ET,F,H,R,
     2RP,RSE,RSM,SA,SCALE,SIG,SID,SCD,SCTC,SP,SS,ST,TI,
     3YR,XS,YS,XT,YT,CDF,PI
      COMMON/C4/ IPCK(9),MC(3,3),MN(9),I,ID,IQ,IR1,ITN,IZ,
     1KJ,K,J,MB,MC,MS,ND,NPTS,NT,NPLPT
      LOGICAL*1 IP(1,100,50)
      COS(X)=DCOS(X)
      SIN(X)=DSIN(X)
      ASIN(X)=DARSIN(X)
      SIG=AZ-PI/2.
      THA=AL
      SW=10.*CDR
      W=0.-SW
      CTC=TD(J,2)-R
      A=TD(J,6)
      B=TD(J,5)
      DO 49 K=1,36
      W=W+SW
      P(J,K)=(0.-CTC*SIN(AZ)*COS(THA)/SIN(THA))+((B/SIN(THA))*
     1COS(W+SIG)*COS(SIG))+(A*SIN(W+SIG)*SIN(SIG))+XT
      Q(J,K)=(CTC*COS(AZ)*COS(THA)/SIN(THA))+((B/SIN(THA))*
     1COS(W+SIG)*SIN(SIG))-(A*SIN(W+SIG)*COS(SIG))+YT
   49 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE LOCATE
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION IBX(9),IBY(9)
      COMMON/C8/ P(9,36),Q(9,36),TD(9,8),XX(36),
     1YY(36),ZZ(36),AL, ALAT,AR1,AZ,CC,D,DJ,ET,F,H,R,
     2RP,RSE,RSM,SA,SCALE,SIG,SID,SCD,SCTC,SP,SS,ST,TI,
     3YR,XS,YS,XT,YT,CDR,PI
      COMMON/C4/ IPCK(9),MC(3,3),MN(9),I,ID,IQ,IR1,ITN,IZ,
     1KJ,K,J,MB,MC,MS,ND,NPTS,NT,NPLPT
      COMMON/C1/IP
      LOGICAL*1 IP(1,100,50),IDIGIT(9)
      DATA IBX/0,100,200,0,100,200,0,100,200/
      DATA IBY/0,0,0,100,100,100,200,200,200/
      DO 200 K=1,36
      XP=P(J,K)/XS+.5
      YQ= Q(J,K)/YS+.5
      IX=XP
      IY=YQ
      IB=1
      IF(IX.LE.0) GO TO 200
      IF(IX.GE.101) GO TO 200
   14 CONTINUE
      IF(IY.LE.0) GO TO 200
      IF(IY.GE.51) GO TO 200
   24 CONTINUE
   25 CONTINUE
      JX=IX-(IBX(IB))
      IF(JX.LT.1) JX=1
      JY=51-(IY-IBY(IB))
      IF(JY.LT.1) JY=1
      DATA IDIGIT/'1','2','3','4','5','6','7','8','9'/
      IP(IB,JX,JY)=IDIGIT(ITN)
  200 CONTINUE
      KX=XT/XS-(IBX(IB))
      IF(KX.LT.1) GO TO 201
      IF(KX.GE.100) GO TO 201
      KY=51-(YT/YS-IBY(IB))
      IF(KY.LT.1) GO TO 201
      IF(KY.GT.50) GO TO 201
      IP(IB,KX,KY)=IDIGIT(ITN)
  201 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE PMAP
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/C8/ P(9,36),Q(9,36),TD(9,8),XX(36),
     1YY(36),ZZ(36),AL, ALAT,AR1,AZ,CO,D,DJ,E1,F,H,R,
     2RP,RSE,RSM,SA,SCALE,SIG,SID,SCD,SOTC,SP,SS,ST,TI,
     3YR,XS,YS,XT,YT,CDR,PI
      COMMON/C4/ IPCK(9),MC(3,3),MN(9),I,ID,IC,IR1,ITN,IZ,
     1KJ,K,J,MB,MC,MS,ND,NPTS,NT,NPLPT
      LOGICAL*1 IP(1,100,50),UNITS(6)
      COMMON/C1/IP
      DO 5 II=1,9
    5 MN(II)=0
      NM=0
      II=1
   35 NM=NM+1
      MN(NM)=I
   40 CONTINUE
      DO 45 II=1,NM
      K=MN(II)
      K=1
      CALL CHMOVE('FEET  ' ,UNITS,6)
      IF(F.GE.1.5) CALL CHMOVE('METERS',UNITS,6)
      XLAT=ALAT/CDR
      PRINT 300,K,SCALE,UNITS,ID
     1,MO,YR,XLAT,ST
   42 CONTINUE
      DO 45 M=1,50
      IF(M.EQ.3) GO TO 43
      IF(M.EQ.9) GO TO 43
      IF(M.EQ.15) GO TO 43
      IF(M.EQ.21) GO TO 43
      IF(M.EQ.27) GO TO 43
      IF(M.EQ.33) GO TO 43
      IF(M.EQ.39) GO TO 43
      IF(M.EQ.45) GO TO 43
      PRINT 302,(IP(K,N,M),N=1,100)
      GO TO 45
   43 PRINT 303,(IP(K,N,M),N=1,100)
   45 CONTINUE
      PRINT 301
  300 FORMAT('1',9X,'BLOCK ',I1,2X,' SCALE 1 INCH = ',2X
     1 ,F3.0,2X,6A1,'  DATE ',I2,'/',I2,'/',F4.0,
     23X,'LATITUDE  ',F3.0,' DEGREES',/,12X,
     32X,'THE TIME IS  ',
     4 F5.2,' TRUE SOLAR.')
  301 FORMAT(9X,'I',10('---------I'),'.')
  302 FORMAT(9X,'.',100A1,'.')
  303 FORMAT(9X,'I',100A1,'I')
      RETURN
      END
```

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