STATISTICAL ANALYSIS ON ENVIRONMENTAL LIMITATIONS ON THRESHOLD-BASED IRRIGATION MANAGEMENT

by

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ABSTRACT

During the past four years (1988-1991), the United States Department of Agriculture (USDA) performed an experiment testing a theory known as the Thermal Kinetic Window (TKW) theory. This theory proposes that each species of crop can have an optimal yield if its canopy temperature can be kept within a window of temperatures. The main crop of study was cotton which has a TKW between 23° C and 32° C. An extensive amount of data was collected over the four years of study. The main purpose of this paper will be to present a method of extracting certain pieces of this data so that meaningful analyses can be performed to determine the permissiveness of the environment in allowing the canopy temperature to remain within the TKW. Some of these analyses will also be included in this paper.

CHAPTER I
INTRODUCTION: THE EXPERIMENT

The growth and maturity of cotton varies greatly throughout the season due to the many environmental characteristics acting upon the crop. Elements such as wind, radiation, humidity, and air temperature can, in excessive quantities, affect the growth and maturity of each plant. Due to the fact that these environmental elements are not controllable, theories have been developed which suggest that certain plant characteristics may be altered in order to aid the plant to adjust to the environmental factors. Two such characteristics, which have been a focus of the USDA, are water stress and canopy temperature.

Water stress is a condition in the plant which causes a deficiency of the requirements needed for proper transpiration in the plant. As the plant is exposed to both the soil and the atmospheric conditions, the soil moisture level determines the soil's ability to supply water to the plant depending on the atmospheric conditions at the time. For example, in areas where the relative humidity is high, the plant temperature will tend to remain constant with the air temperature, and in semi-arid areas, such as the Lubbock locale, where the humidity level is usually around 20-30%, the temperature of the air will usually be $2-4°$ higher than the temperature of the plant. One method that is generally used to determine whether or not the plant is suffering from water stress is to inspect the foliage to see if any wilting is present. Another more scientific method is to observe the canopy temperature (T_c) and the air temperature (T_a). This method is useful in determining the level of water stress through the derivation of the crop water stress index (CWSI) developed by Idso et al. (1981) [3]. The CWSI provides an upper and lower limit for $(T_c - T_a)$ at any deficit of vapor pressure.

Water stress has proven to be a major criterion in the development of the cotton during the flowering and boll development stages [1]. Through the observation of the canopy temperature, an irrigation schedule was developed that would adjust the water stress level of the plant. In addition, this irrigation schedule allowed the USDA to test the TKW theory developed by J.R. Mahan et al. (1987) [2]. This theory suggests that if the canopy temperature of the plant was maintained within the window set for its species, specifically 23° C and 32° C for cotton, then the overall yield would be increased with more efficient water usage. The USDA also theorized that within the TKW there exists an interval of normalized temperatures (T_n) which the plant tries to maintain when specific environmental conditions are satisfied. The T_n for cotton is between 26° C and 30° C, and these temperatures became the main focus of the USDA study. They found that the optimal yield, in relation to fiber length and strength, was obtained when the T_c was kept within these values.

The USDA was able to observe the T_c through the use of infra-red thermometers (IRT's). Two IRT's were placed on each of the plots of land, one on the north side and one on the south side. On each plot of land, there were eighteen 30.5 meter rows of cotton that were spaced 76 cm apart and ran from east to west. One of the advantages to using the IRT's, as opposed to other temperature reading devices, is that the IRT's do not touch the plant at any point which allows the plant to remain in a natural state. The IRT's read the temperature by inputting the amount of heat and radiation being reflected by the plant. Through the use of a computer system and the IRT's, the T_c's were measured every 15 seconds. Then an average of these readings was calculated every 15 minutes and recorded. These averages were performed twenty-four hours a day, seven days a week throughout the growing season. Therefore, based on the 15-minute average readings from the IRT's, the USDA developed the irrigation schedules that would decrease water stress and, hopefully, improve overall yield.

In order to perform a useful analysis, the USDA set up several plots of cotton, each receiving a different irrigation schedule. One plot of land was irrigated each week based on the standard method of observing the soil water profile. If the profile of the water in the soil was substantially decreased, water was applied in order to replenish the water level. This treatment will be referred to as the Soil Water Replacement Fixed (SWRF) treatment and will be used as the control plot. Another plot of land was designed to implement a watering schedule at variable times depending on when the soil water profile was substantially decreased; however, this method was more lenient than the SWRF treatment. Most times this plot of land was irrigated every two weeks. This treatment is called the Soil Water Replacement Variable (SWRV) treatment. Another plot was designed to receive only the initial preplant irrigation and the rainfall thereafter.

This treatment will be referred to as the dryland (DRY) treatment. Throughout the study, at most three plots of land were designed to monitor the periods of irrigation based on the T_c of the plant. The base temperature varied by 2° C between each plot of land. If after any 15 minute period, the T_c exceeded the threshold temperature set for that plot, the irrigation process would begin and remain on throughout the next 15 minute period. If after the end of that period the T_c was still above the threshold, irrigation would continue.

In 1988, the three temperature treatments that were studied were 28° C, 30° C, and 32° C as well as the SWRF, SWRV, and DRY treatments. The following Table 1.1 gives the final results of each of the six different treatments in terms of the total water applications and the overall lint yield.

Table 1.1: Six treatments with water use and lint yield for 1988.

Trt	H_2O applied	Lint Yield
28° C	70 cm	1431 $\frac{kg}{ha}$
30° C	46 cm	1073 $\frac{kg}{ha}$
32° C	36 cm	1073 $\frac{kg}{ha}$
SWRF	138 cm	1430 $\frac{kg}{ha}$
SWRV	75 cm	1147 $\frac{kg}{ha}$
DRY	0 cm	353 $\frac{kg}{ha}$

After observing the overall yield in comparison to the amount of water applied to each plot, the USDA came to the conclusion that the 28° C treatment had a sufficiently greater lint yield [1]. Over the next three years, they concentrated on temperatures close to 28° C. In 1989, they used 26° C, 28° C, and 30° C as the temperature treatments. In 1990, they studied only two plots with different base temperatures, 26° C and 28° C. Finally, in 1991, only the 28° C treatment was studied as a temperature controlled plot.

Over the four years, an immense amount of data was collected considering that the temperature readings were recorded every 15 minutes of every day for an average of 150 days each year. So that proper analyses could be performed on this data, a system was developed that would allow the analyst to extract certain pieces of the data depending on what types of tests were to be analyzed. The main purpose of this study was to develop such a system through the use of FORTRAN programs. In the following chapters, an explanation of the programs and some analyses performed through the use of these programs will be given.

In chapter 2, a user's manual for the main program that actually extracts the data for analysis is provided with an example, while in chapter 3 there will be a discussion of some of the analyses performed as well as a discussion of other programs used in each analysis. Finally, in chapter 4, results of the analyses and possible future analyses will be discussed.

CHAPTER II

USER'S MANUAL

2.1 Getting Started

Before the program can be run, the user must make sure that the data is properly set up and in the right directories. For some years, a drybulb and wetbulb temperature was recorded. However, even though the wetbulb data may not have been collected for a certain year, the data must appear as if it had been. During times when some piece of equipment may not have been operating properly, a missing value number was recorded in place of the bad data. This number is represented by -99.0 in this study. Therefore, if during some year the proper amount of data had not been collected, a column of missing values should be placed into the data set in the respective position. Each data file must be sixteen columns wide with the first column containing the day of the year. The second column represents the time of the day beginning with 0 and going through 2345 in 15 minute intervals. The other fourteen columns will contain the data with every odd column being the drybulb data, and every even column the wetbulb data. After each file has been properly formatted, the user must put the files into their respective directories. The data files should be placed in the subdirectory corresponding to its year and data type:

\USDA\‘year’\‘type’\

For example, the air temperature data from 1988 should be placed into the

\USDA\1988\AIR\

subdirectory.

Each file must also be properly named in order for the program to be able to locate it. Each file, which contains the data for a certain day, must have the following format:

'typeday'.DAT

For example, AIR163.DAT is the air temperature for day 163.

In each instance above, 'type' will be one of the following: AIR, IRT, RAD, WIN, or CONT. AIR is the air temperature data. IRT is the infra-red thermometer data. RAD is the radiation data. WIN is the wind data, and CONT is the control data which specifies when the system was actually irrigating. The 'year' will be either 1988, 1989, 1990, or 1991. The 'day' will correspond to the day that is recorded in that file. The range of days varies from year to year. The days range from 161-318 in 1988, 171-304 in 1989, 158-297 in 1990, and 155-307 in 1991. Once each of the above conditions has been met, the program will work properly.

2.2 Running the Program

The program is not required to be in any certain directory; however, it must be on the same drive as the data, preferably in the root directory. In order to begin the program, the following command must be entered.

$$\text{C:}\backslash > \text{USDA} < CR >$$

where USDA is the name of the program, and the $< CR >$ denotes a carriage return. After a few moments, the main menu will appear on the screen (Figure 2.1). By choosing each of the options available, the user will be able to extract any portion of data that is desired. Due to the fact that each year is different with respect to the days recorded and the treatments, Option 1 should always be selected first.

Throughout the rest of this chapter, the following example will be used in order to demonstrate the procedures of the program. The data to be extracted is found in Table 2.1.

2.2.1 Entering the years

At times the user may not want to analyze all of the years, so an option has been added which allows the operator to analyze either one year or any combination of years (Figure 2.2).

Table 2.1: Example of an application of program USDA

Years	1988,1989,1990,1991
Types	AIR,IRT
Days	195-250
Treatments	drybulb, 28° C
Times	700,1200,1600-1700

	MAIN MENU
CODE	FUNCTION
1	Enter the years for analysis
2	Enter the types for analysis
3	Enter the days for analysis
4	Enter the treatments for analysis
5	Enter the times for analysis
6	Get the data
7	Quit
Enter the desired code : _	

Figure 2.1: Main menu from program USDA.

If the user chooses to analyze the data within one year (Option 1), he will then be prompted to enter which year is to be analyzed:

Enter the year for analysis: _

However, if the operator chooses option 2, the program will prompt him to enter the number of years for analysis and the years. Thus, following the example, the user will select option 2 and answer the prompts accordingly.

YEAR MENU	
CODE	FUNCTION
1	Perform analysis within a year
2	Perform analysis among years

Enter the desired code: _

Figure 2.2: Year menu from program USDA.

Enter the number of years for analysis: 4
Enter the year 1 for analysis: 1988
Enter the year 2 for analysis: 1989
Enter the year 3 for analysis: 1990
Enter the year 4 for analysis: 1991

At this time, the program will return to the main menu (Figure 2.1).

2.2.2 Entering the types

The user should enter the types of data to be analyzed by selecting option 2. Upon selecting this option, the operator will receive the following prompt:

Enter the number of types for analysis (1-6): _

This prompt allows the user to extract anywhere from one to six types of data at a time. After entering the number of types to extract, the output that will appear on the screen can be found in Figure 2.3. This screen will be shown as many times as the number of types chosen above.

If for some reason the user enters the same type more than once, the program will give an error message stating that the type has already been selected and will ask the user to type a carriage return. The output appears in Figure 2.4.

Again, the program will now return to the main menu (Figure 2.1).

	TYPE MENU
CODE	TYPE
1	Air temperature
2	Infra-red thermometer
3	Radiation
4	Wind
5	Yield
6	Irrigation control
Enter the desired code: _	

Figure 2.3: Type menu from program USDA.

2.2.3 Entering the days

The next option to be chosen should be option 3, which allows the user to specify which days he wants to extract. Upon selecting this option, a new menu will appear on the screen giving the user a variety of ways to select the days for analysis (Figure 2.5, p.12). Again, this menu will appear on the screen as many times as the number of years chosen. This option has been added in case the user wants to select different days from each year. The operator can opt to analyze only one day of the year by selecting option 1, or he can select a number of days by selecting one of the options 2-4 depending on which suits his needs.

If option 1 is chosen, the following prompt will appear on the screen:

Enter the day for analysis (*beg-end*): _

where *beg* is the first day of the year, and *end* is the last day of the year. If the user wishes to extract one or more intervals of days, the best option to choose is option 2 which yields these prompts:

Enter the number of intervals (1-*num*): _

where *num* is the number of days in that year for which data was collected.

Enter the number of types for analysis (1-6): 2

	TYPE MENU
CODE	TYPE
1	Air temperature
2	Infra-red thermometer
3	Radiation
4	Wind
5	Yield
6	Irrigation control

Enter the desired code: 1

	TYPE MENU
CODE	TYPE
1	Air temperature
2	Infra-red thermometer
3	Radiation
4	Wind
5	Yield
6	Irrigation control

Enter the desired code: 2

Figure 2.4: Entering the types for example

Enter the beginning day of interval i for analysis (*beg- end*): _

where i is the i^{th} interval to be entered.

Enter the last day of interval i for analysis (*beg- end*): _

If for some reason the days entered are not within the specified interval or if the beginning and last days are not in the right order, an error message will be given, and the user will be prompted to start over.

If the user wants to select one day here and there, he should select option 3. In this instance, the program will first prompt for the number of days to be selected, and then will prompt for the specific days.

Enter the number of days for analysis (1-*num*): _

where *num* is the number of days within that year.

Enter the day i (*beg-end*): _

where i is the i^{th} day to be entered and *beg* and *end* are the first and last days of the year, respectively.

Finally, option 4 allows the user to select all of the days of the year without having to enter each day separately. If this option is chosen, the program will automatically enter the days for each year selected. After the days have been chosen, the main menu will appear on the screen (Figure 2.1).

Since the example extracts the data over all four years, the menu in Figure 2.5 will appear four times on the screen (Figure 2.6, Figure 2.7, Figure 2.8, and Figure 2.9).

2.2.4 Entering the treatments

In order to select the treatments for analysis, the user will select option 4 from the main menu (Figure 2.1). Since for some years drybulb and wetbulb data had been collected, the program will first prompt the user to select which type of data is to be extracted (Figure 2.10).

DAY MENU	
CODE	FUNCTION
1	Analyze one day
2	Analyze succesive days
3	Analyze intermittent days
4	Analyze entire year

Enter the desired code: _

Figure 2.5: Day menu for program USDA

DAY MENU	
CODE	FUNCTION
1	Analyze one day
2	Analyze succesive days
3	Analyze intermittent days
4	Analyze entire year

Enter the desired code: 2

Enter the number of intervals for analysis (1-160): 1
Enter the beginning day of interval 1 (161-318): 195
Enter the last day of interval 1 (161-318): 250

Figure 2.6: Entering the days for 1988

DAY MENU	
CODE	FUNCTION
1	Analyze one day
2	Analyze succesive days
3	Analyze intermittent days
4	Analyze entire year

Enter the desired code: 2

Enter the number of intervals for analysis (1-144): 1
Enter the beginning day of interval 1 (171-304): 195
Enter the last day of interval 1 (161-318): 250

Figure 2.7: Entering the days for 1989

DAY MENU	
CODE	FUNCTION
1	Analyze one day
2	Analyze succesive days
3	Analyze intermittent days
4	Analyze entire year

Enter the desired code: 2

Enter the number of intervals for analysis (1-139): 1
Enter the beginning day of interval 1 (158-297): 195
Enter the last day of interval 1 (161-318): 250

Figure 2.8: Entering the days for 1990

	DAY MENU
CODE	FUNCTION
1	Analyze one day
2	Analyze succesive days
3	Analyze intermittent days
4	Analyze entire year
Enter the desired code: 2	

Enter the number of intervals for analysis (1-152): 1
Enter the beginning day of interval 1 (155-307): 195
Enter the last day of interval 1 (161-318): 250

Figure 2.9: Entering the days for 1991

	TREATMENT MENU
CODE	FUNCTION
1	Analyze drybulb
2	Analyze wetbulb
3	Analyze both
Enter the desired code: _	

Figure 2.10: Treatment menu from program USDA

After the type of temperature readings have been selected, the program will prompt the user to enter the number of treatments for the year currently being considered.

Enter the number of treatments for ***year*** (1-***tot***): _

The treatment submenu for that year will then appear on the screen the same number of times as selected above. Each of the possible submenus will be demonstrated through the use of the example (Figure 2.11).

After the treatments have been entered, the program will return to the main menu (Figure 2.1)

2.2.5 Entering the times

The final criterion that the user needs to specify is the times of the day that he wants extracted. This is accomplished by selecting option 5 from the main menu (Figure 2.1). The operator will then have the option to either enter the times in intermittent intervals or enter the entire day (Figure 2.12).

If option 1 is chosen, the program will prompt for the number of intervals that will be included in the analysis.

Enter the number of intervals for analysis: _

The next two prompts will ask for the beginning and ending time for the i^{th} interval. These prompts will be repeated as many times as the time intervals chosen. If the beginning and ending times for any particular interval are not in the right order, a run time error will occur, the program will end, and the DOS prompt will appear. Notice that 1:00 pm is denoted as 1300 not as 100. It is very important that these numbers are input properly.

Enter the beginning time for interval ***i*** (0-2345, 15 min increments): _
Enter the ending time for interval ***i*** (0-2345, 15 min increments): _

The program will enter all of the times in between the beginning and ending times provided.

If option 2 is chosen, the program will automatically enter all times starting

	TREATMENT MENU
CODE	FUNCTION
1	Analyze drybulb
2	Analyze wetbulb
3	Analyze both

Enter the desired code: 1

Enter the number of treatments for 1988 (1-7): 1

	TREATMENT SUBMENU FOR 1988
CODE	FUNCTION
1	28° C
2	30° C
3	32° C
4	Fixed soil water replacement
5	Variable soil water replacement
6	Drybase
7	2 meters (air only)

Enter the desired code: 1

Figure 2.11: Treatment submenus from program USDA with examples

from 0 to 2345 without any prompting for the user. Once completed, the main menu will once again appear on the screen.

Since the example calls for only a few time points, option 2 will be selected. The user should notice that if only a single time is desired, he will enter the same time for both the beginning and ending time (Figure 2.13).

Enter the number of treatments for 1989 (1-8): 1

	TREATMENT SUBMENU FOR 1989
CODE	FUNCTION
1	Fixed soil water replacement
2	28° C treatment 1
3	28° C treatment 2
4	26° C
5	CTV
6	CTD
7	2 meters (air only)

Enter the desired code: 1

Enter the number of treatments for 1990 (1-6): 1

	TREATMENT SUBMENU FOR 1990
CODE	FUNCTION
1	Variable soil water replacement
2	26° C
3	30° C
4	28° C
5	Fixed soil water replacement
6	2 meters (air only)

Enter the desired code: 1

Figure 2.11: (cont.)

Enter the number of treatments for 1991 (1-6): 1

	TREATMENT SUBMENU FOR 1991
CODE	FUNCTION
1	7.0 HT
2	5.5 HT
3	4.0 HT
4	4.0 HT (dry furrow)
5	2.5 HT
6	28° C
7	2 meters (air only)
Enter the desired code: 1	

Figure 2.11: (cont.)

	TIME SUBMENU
CODE	FUNCTION
1	Analyze intermittent time intervals
2	Analyze entire day
Enter the desired code: _	

Figure 2.12: Time submenu from program USDA

2.2.6 Retrieving the data

After all of the specifications have been made as to exactly which pieces of the data are needed for the analyses, the user should select option 6. At this time the program will take over and extract exactly those pieces of data chosen.

TIME SUBMENU	
CODE	FUNCTION
1	Analyze intermittent time intervals
2	Analyze entire day
Enter the desired code: 1	

Enter the number of time intervals for analysis (1-96): 3
Enter the beginning time for interval 1 (0-2345, 15 min increments): 700
Enter the ending time for interval 1 (0-2345, 15 min increments): 700
Enter the beginning time for interval 1 (0-2345, 15 min increments): 1200
Enter the ending time for interval 1 (0-2345, 15 min increments): 1200
Enter the beginning time for interval 1 (0-2345, 15 min increments): 1600
Enter the ending time for interval 1 (0-2345, 15 min increments): 1700

Figure 2.13: Entering the times for the example

The data will be placed into separate files depending on the type and the year of the data. As each file for a chosen day is read, a message will appear on the screen stating that the program is currently working on that day. This will give the user some idea of the length of time that will be required for each file.

Once the program has completed the extraction, the main menu will appear on the screen, and the user may begin over and select other data for different analyses. However, if the user wishes to save the files created by the program, he must exit the program and rename the files that were created. If the user fails to rename the files, they will be deleted and rewritten with the new data.

2.2.7 Stopping the program

If at any time the user decides not to extract the data, or he finishes extracting data, he can select option 7 from the main menu. If this option is chosen, any options that were inputted without being extracted will be lost. For example, if the operator enters the years, types, and days, and then selects option 7 from the main menu, the DOS prompt will appear, and the years, types, and days that he entered will be lost. The data files will not be deleted, but the options will have to be re-entered. All files formed by this program will not be deleted unless the user chooses to do so at the DOS prompt, or if the program is run twice.

CHAPTER III
ANALYZING THE DATA

The USDA program has proven to be a major tool in the analysis of the data provided by the Department of Agriculture. However, this program is strictly used to extract data and does not have any analyzing capabilities. Other programs were implemented in order to put the data into a form so that software such as SAS and PEST could be used for the analyses.

3.1 Drybulb versus Wetbulb

One such program computed the averages of the air temperatures from 1988 and 1989 over a one-hour time period between 12:00 pm and 1:00 pm. These averages were then used to compute weekly averages, and a correlation analysis was performed on these averages using SAS to test if there was a significant difference between the drybulb and wetbulb data to justify using both types of information in each analysis. Table 3.1 shows the results of that study for 1988.

In each cell of Table 3.1, two pieces of information are given. The numbers on the top in each cell are the Pearson Correlation Coefficients which describe how closely each treatment is linearly related to each of the others. The correlation coefficient will always be a number between -1.0 and 1.0. If the coefficient is close to either of the endpoints, the treatments are said to be highly correlated. If the number is close to 0.0, the treatments are not linearly correlated. In each instance, the correlation coefficient is a value very close to a value of 1.0 which suggests that the two methods of measuring the temperature are strongly correlated.

The null hypothesis that is being tested with this procedure is $H_0 : \rho = 0$, where ρ is the correlation coefficient, against $H_A : \rho \neq 0$. The bottom number in each cell, called the p-value, is the smallest significance level at which the null hypothesis can be rejected. In general, as the p-value gets smaller, the null hypothesis is more likely to be rejected. Notice that with the exception of the cells along the main diagonal, each of the lower values are .0001 which also implies that the two methods of measuring the temperature are significantly correlated.

Table 3.1: Correlation analysis between drybulb and wetbulb for 1988

	D28	W28	D30	W30	D32	W32	DF
D28	1.00000 0.0	0.94159 0.0001	0.99731 0.0001	0.95766 0.0001	0.99880 0.0001	0.94683 0.0001	0.99608 0.0001
W28	0.94159 0.0001	1.00000 0.0	0.92459 0.0001	0.97449 0.0001	0.93140 0.0001	0.98921 0.0001	0.92511 0.0001
D30	0.99731 0.0001	0.92459 0.0001	1.00000 0.0	0.94380 0.0001	0.99867 0.0001	0.93152 0.0001	0.99733 0.0001
W30	0.95766 0.0001	0.97449 0.0001	0.94380 0.0001	1.00000 0.0	0.94812 0.0001	0.98575 0.0001	0.93984 0.0001
D32	0.99880 0.0001	0.93140 0.0001	0.99867 0.0001	0.94812 0.0001	1.00000 0.0	0.93522 0.0001	0.99545 0.0001
W32	0.94683 0.0001	0.98921 0.0001	0.93152 0.0001	0.98575 0.0001	0.93522 0.0001	1.00000 0.0	0.93150 0.0001
DF	0.99608 0.0001	0.92511 0.0001	0.99733 0.0001	0.93984 0.0001	0.99545 0.0001	0.93150 0.0001	1.00000 0.0
WF	0.95146 0.0001	0.97930 0.0001	0.93543 0.0001	0.98415 0.0001	0.93924 0.0001	0.98719 0.0001	0.93802 0.0001
DV	0.99591 0.0001	0.92193 0.0001	0.99579 0.0001	0.93830 0.0001	0.99603 0.0001	0.92621 0.0001	0.99724 0.0001
WV	0.95315 0.0001	0.98935 0.0001	0.94270 0.0001	0.97229 0.0001	0.94509 0.0001	0.98631 0.0001	0.94160 0.0001
DD	0.99774 0.0001	0.92779 0.0001	0.99790 0.0001	0.94629 0.0001	0.99888 0.0001	0.93209 0.0001	0.99586 0.0001
WD	0.95510 0.0001	0.99220 0.0001	0.94218 0.0001	0.98378 0.0001	0.94562 0.0001	0.99644 0.0001	0.94167 0.0001
D2	0.99870 0.0001	0.94171 0.0001	0.99598 0.0001	0.95608 0.0001	0.99880 0.0001	0.94466 0.0001	0.99234 0.0001
W2	0.96578 0.0001	0.99093 0.0001	0.94996 0.0001	0.98907 0.0001	0.95683 0.0001	0.98903 0.0001	0.94936 0.0001

Table 3.1: (cont.)

	WF	DV	WV	DD	WD	D2	W2
D28	0.95146 0.0001	0.99591 0.0001	0.95315 0.0001	0.99774 0.0001	0.95510 0.0001	0.99870 0.0001	0.96578 0.0001
W28	0.97930 0.0001	0.92193 0.0001	0.98935 0.0001	0.92779 0.0001	0.99220 0.0001	0.94171 0.0001	0.99093 0.0001
D30	0.93543 0.0001	0.99579 0.0001	0.94270 0.0001	0.99790 0.0001	0.94218 0.0001	0.99598 0.0001	0.94996 0.0001
W30	0.98415 0.0001	0.93830 0.0001	0.97229 0.0001	0.94629 0.0001	0.98378 0.0001	0.95608 0.0001	0.98907 0.0001
D32	0.93924 0.0001	0.99603 0.0001	0.94509 0.0001	0.99888 0.0001	0.94562 0.0001	0.99880 0.0001	0.95683 0.0001
W32	0.98719 0.0001	0.92621 0.0001	0.98631 0.0001	0.93209 0.0001	0.99644 0.0001	0.94466 0.0001	0.98903 0.0001
DF	0.93802 0.0001	0.99724 0.0001	0.94160 0.0001	0.99586 0.0001	0.94167 0.0001	0.99234 0.0001	0.94936 0.0001
WF	1.00000 0.0	0.93590 0.0001	0.97409 0.0001	0.93656 0.0001	0.98471 0.0001	0.94673 0.0001	0.98314 0.0001
DV	0.93590 0.0001	1.00000 0.0	0.93663 0.0001	0.99643 0.0001	0.93677 0.0001	0.99349 0.0001	0.94832 0.0001
WV	0.97409 0.0001	0.93663 0.0001	1.00000 0.0	0.94271 0.0001	0.99318 0.0001	0.95380 0.0001	0.98595 0.0001
DD	0.93656 0.0001	0.99643 0.0001	0.94271 0.0001	1.00000 0.0	0.94350 0.0001	0.99776 0.0001	0.95496 0.0001
WD	0.98471 0.0001	0.93677 0.0001	0.99318 0.0001	0.94350 0.0001	1.00000 0.0	0.95452 0.0001	0.99146 0.0001
D2	0.94673 0.0001	0.99349 0.0001	0.95380 0.0001	0.99776 0.0001	0.95452 0.0001	1.00000 0.0	0.96639 0.0001
W2	0.98314 0.0001	0.94832 0.0001	0.98595 0.0001	0.95496 0.0001	0.99146 0.0001	0.96639 0.0001	1.00000 0.0

Naturally, all the entries along the main diagonal are 0.0 due to the fact that each treatment is being compared to itself. Thus, the null hypothesis is rejected.

Similar results were found for the data from 1989 in Table 3.2.

With these results, it is reasonable to assume that the same conclusions can be obtained regardless of whether drybulb or wetbulb data was used in the analysis. Thus, the remaining analyses will be performed using only the drybulb data from each treatment.

3.2 Air versus Canopy

Another correlation analysis was performed between the air temperature and the canopy temperature. If there is a strong correlation between these two measurements, the difference between the the measurements should remain close to zero. Table 3.3 shows the results of this analysis.

This analysis is based on the same weekly averages as the previous correlation analysis between drybulb and wetbulb. One can see by comparing the air temperature averages with their respective IRT averages that they are highyly correlated with the exception of the 28° C and the 30° C treatments. The 28° C treatment claims that $\rho = .23096$ with a p- value $= .289$. This implies that the null hypothesis $H_0 : \rho = 0$ will be rejected only if a significance level of 28.9% or greater is chosen which is unrealistic. Therefore, H_0 will not be rejected. Comparing the D30 and S30 variables, the analyst finds that H_0 will be rejected as long as a significance level over 1.8% is used for the test. The remainder of the variables ensure that H_0 will be rejected for almost any significance level desired.

3.3 Analyzing the Data as a Time Series

Since the study performed by the USDA concluded that the 28° C treatment has the highest yield in relation to the amount of water used, the remainder of this chapter will concentrate on this treatment only. The next type of analysis that was performed was a time series analysis to see if a model can be determined by the data so that anyone will be able to predict future results. In each of the following subsections, a different aspect of the analysis will be addressed. The data used in each of the analyses is described in Table 3.4.

Table 3.2: Correlation analysis between drybulb and wetbulb for 1989

	D281	W281	D282	W282	D262	W262	DF
D281	1.00000 0.0	0.91108 0.0001	0.99740 0.0001	0.93153 0.0001	0.99764 0.0001	0.92807 0.0001	0.99811 0.0001
W281	0.91108 0.0001	1.00000 0.0	0.89992 0.0001	0.99151 0.0001	0.89902 0.0001	0.99685 0.0001	0.91888 0.0001
D282	0.99740 0.0001	0.89992 0.0001	1.00000 0.0	0.92665 0.0001	0.99639 0.0001	0.92103 0.0001	0.99570 0.0001
W282	0.93153 0.0001	0.99151 0.0001	0.92665 0.0001	1.00000 0.0	0.91958 0.0001	0.99707 0.0001	0.93666 0.0001
D262	0.99764 0.0001	0.89902 0.0001	0.99639 0.0001	0.91958 0.0001	1.00000 0.0	0.91732 0.0001	0.99504 0.0001
W262	0.92807 0.0001	0.99685 0.0001	0.92103 0.0001	0.99707 0.0001	0.91732 0.0001	1.00000 0.0	0.93350 0.0001
DF	0.99811 0.0001	0.91888 0.0001	0.99570 0.0001	0.93666 0.0001	0.99504 0.0001	0.93350 0.0001	1.00000 0.0
WF	0.91809 0.0001	0.99668 0.0001	0.90972 0.0001	0.99589 0.0001	0.90692 0.0001	0.99813 0.0001	0.92434 0.0001
DV	0.98608 0.0001	0.90074 0.0001	0.98346 0.0001	0.91457 0.0001	0.98442 0.0001	0.91213 0.0001	0.98953 0.0001
WV	0.91782 0.0001	0.99558 0.0001	0.90754 0.0001	0.99091 0.0001	0.90656 0.0001	0.99274 0.0001	0.92640 0.0001
DD	0.99776 0.0001	0.89930 0.0001	0.99722 0.0001	0.91973 0.0001	0.99771 0.0001	0.91726 0.0001	0.99642 0.0001
WD	0.95924 0.0001	0.98392 0.0001	0.95168 0.0001	0.98872 0.0001	0.95255 0.0001	0.99019 0.0001	0.96238 0.0001
D2	0.97605 0.0001	0.92095 0.0001	0.96684 0.0001	0.92354 0.0001	0.96942 0.0001	0.92457 0.0001	0.98316 0.0001
W2	0.92243 0.0001	0.99446 0.0001	0.91226 0.0001	0.99044 0.0001	0.91083 0.0001	0.99201 0.0001	0.93172 0.0001

Table 3.2: (cont.)

	WF	DV	WV	DD	WD	D2	W2
D281	0.91809 0.0001	0.98608 0.0001	0.91782 0.0001	0.99776 0.0001	0.95924 0.0001	0.97605 0.0001	0.92243 0.0001
W281	0.99668 0.0001	0.90074 0.0001	0.99558 0.0001	0.89930 0.0001	0.98392 0.0001	0.92095 0.0001	0.99446 0.0001
D282	0.90972 0.0001	0.98346 0.0001	0.90754 0.0001	0.99722 0.0001	0.95168 0.0001	0.96684 0.0001	0.91226 0.0001
W282	0.99589 0.0001	0.91457 0.0001	0.99091 0.0001	0.91973 0.0001	0.98872 0.0001	0.92354 0.0001	0.99044 0.0001
D262	0.90692 0.0001	0.98442 0.0001	0.90656 0.0001	0.99771 0.0001	0.95255 0.0001	0.96942 0.0001	0.91083 0.0001
W262	0.99813 0.0001	0.91213 0.0001	0.99274 0.0001	0.91726 0.0001	0.99019 0.0001	0.92457 0.0001	0.99201 0.0001
DF	0.92434 0.0001	0.98953 0.0001	0.92640 0.0001	0.99642 0.0001	0.96238 0.0001	0.98316 0.0001	0.93172 0.0001
WF	1.00000 0.0	0.90387 0.0001	0.99420 0.0001	0.90630 0.0001	0.98750 0.0001	0.91905 0.0001	0.99387 0.0001
DV	0.90387 0.0001	1.00000 0.0	0.91787 0.0001	0.98698 0.0001	0.94217 0.0001	0.99113 0.0001	0.92299 0.0001
WV	0.99420 0.0001	0.91787 0.0001	1.00000 0.0	0.90625 0.0001	0.98319 0.0001	0.93510 0.0001	0.99926 0.0001
DD	0.90630 0.0001	0.98698 0.0001	0.90625 0.0001	1.00000 0.0	0.95259 0.0001	0.97290 0.0001	0.91068 0.0001
WD	0.98750 0.0001	0.94217 0.0001	0.98319 0.0001	0.95259 0.0001	1.00000 0.0	0.94619 0.0001	0.98310 0.0001
D2	0.91905 0.0001	0.99113 0.0001	0.93510 0.0001	0.97290 0.0001	0.94619 0.0001	1.00000 0.0	0.94117 0.0001
W2	0.99387 0.0001	0.92299 0.0001	0.99926 0.0001	0.91068 0.0001	0.98310 0.0001	0.94117 0.0001	1.00000 0.0

Table 3.3: Correlation analysis between Air and IRT Temperatures

	D28	S28	D30	S30	D32	S32
D28	1 0	0.23096 0.289	0.99731 0.0001	0.47428 0.0222	0.9988 0.0001	0.95503 0.0001
S28	0.23096 0.289	1 0	0.1693 0.44	0.05589 0.8	0.20669 0.344	0.37419 0.0786
D30	0.99731 0.0001	0.1693 0.44	1 0	0.48763 0.0183	0.99867 0.0001	0.94332 0.0001
S30	0.47428 0.0222	0.05589 0.8	0.48763 0.0183	1 0	0.49181 0.0171	0.53492 0.0085
D32	0.9988 0.0001	0.20669 0.344	0.99867 0.0001	0.49181 0.0171	1 0	0.95063 0.0001
S32	0.95503 0.0001	0.37419 0.0786	0.94332 0.0001	0.53492 0.0085	0.95063 0.0001	1 0
DF	0.99608 0.0001	0.16188 0.4605	0.99733 0.0001	0.4582 0.0279	0.99545 0.0001	0.94579 0.0001
SF	0.90184 0.0001	0.09467 0.6674	0.90544 0.0001	0.42668 0.0423	0.89797 0.0001	0.91107 0.0001
DV	0.99591 0.0001	0.18267 0.4041	0.99579 0.0001	0.45615 0.0287	0.99603 0.0001	0.95106 0.0001
SV	0.93128 0.0001	0.09836 0.6552	0.93504 0.0001	0.44062 0.0353	0.92999 0.0001	0.94015 0.0001
DD	0.99774 0.0001	0.18837 0.3894	0.9979 0.0001	0.48044 0.0203	0.99888 0.0001	0.94893 0.0001
SD	0.91108 0.0001	0.20519 0.3476	0.91033 0.0001	0.47355 0.0225	0.90858 0.0001	0.93182 0.0001

Table 3.3: (cont.)

	DF	SF	DV	SV	DD	SD
D28	0.99608 0.0001	0.90184 0.0001	0.99591 0.0001	0.93128 0.0001	0.99774 0.0001	0.91108 0.0001
S28	0.16188 0.4605	0.09467 0.6674	0.18267 0.4041	0.09836 0.6552	0.18837 0.3894	0.20519 0.3476
D30	0.99733 0.0001	0.90544 0.0001	0.99579 0.0001	0.93504 0.0001	0.9979 0.0001	0.91033 0.0001
S30	0.4582 0.0279	0.42668 0.0423	0.45615 0.0287	0.44062 0.0353	0.48044 0.0203	0.47355 0.0225
D32	0.99545 0.0001	0.89797 0.0001	0.99603 0.0001	0.92999 0.0001	0.99888 0.0001	0.90858 0.0001
S32	0.94579 0.0001	0.91107 0.0001	0.95106 0.0001	0.94015 0.0001	0.94893 0.0001	0.93182 0.0001
DF	1 0	0.92405 0.0001	0.99724 0.0001	0.95064 0.0001	0.99586 0.0001	0.91628 0.0001
SF	0.92405 0.0001	1 0	0.91721 0.0001	0.96715 0.0001	0.90016 0.0001	0.91032 0.0001
DV	0.99724 0.0001	0.91721 0.0001	1 0	0.95161 0.0001	0.99643 0.0001	0.91563 0.0001
SV	0.95064 0.0001	0.96715 0.0001	0.95161 0.0001	1 0	0.93339 0.0001	0.91932 0.0001
DD	0.99586 0.0001	0.90016 0.0001	0.99643 0.0001	0.93339 0.0001	1 0	0.91172 0.0001
SD	0.91628 0.0001	0.91032 0.0001	0.91563 0.0001	0.91932 0.0001	0.91172 0.0001	1 0

Table 3.4: Data for time series analysis

YEARS	1988,1989,1990,1991
TYPES	AIR,IRT
DAYS	171-297
TREATMENTS	28° C
TIMES	700,1200,1600

The range of days was chosen from 171-297 due to the fact that an interval was needed that was contained within each year. The times where chosen such that one measurement was from the coldest part of the day (700), one from the midrange (1200), and one from the hottest (1600). Choosing the times in this manner allows the study of the temperature variations throughout the day.

3.3.1 Analyzing the Morning Data

The first step in the analysis is to plot the data in order to determine if any trends are apparent such as cyclic, upward, or downward trends. Each of the following analyses will use the difference between the air temperature and infrared thermometer temperature ($T_c - T_a$). The first four figures show the plots of the morning differences for each year (Figure 3.1, Figure 3.2, Figure 3.3, and Figure 3.4).

Notice in each figure that the values are, for the most part, close to a value of zero. By studying these plots, one can see that there is not any apparent upward or downward trend. This is marked by the fact that, as the days increase, the temperature differences do not continually decrease or increase. The plots do not show any obvious signs of repetition which implies the absence of a cyclic trend. Therefore, at first glance, one would expect that the data is stationary with no deterministic trends.

The next step is to try to model the data. This process was attempted with the aid of a program called PEST by Peter J. Brockwell and Richard A. Davis. In order to do any analyzing with PEST, a model must first be entered. Thus, after entering the morning data for 1988, the autocorrelation (ACF) and partial

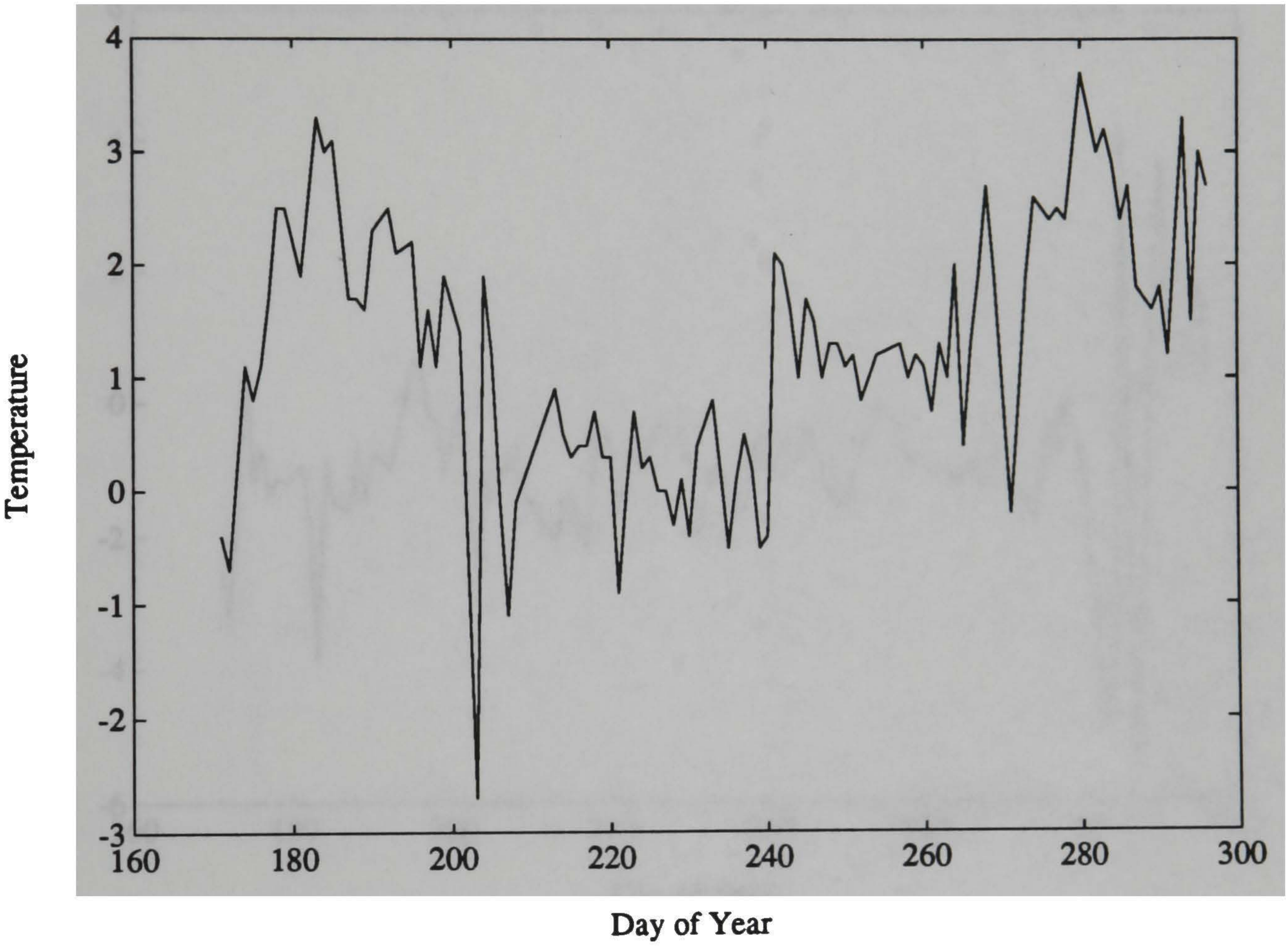

Figure 3.1: Plot of morning values for 1988

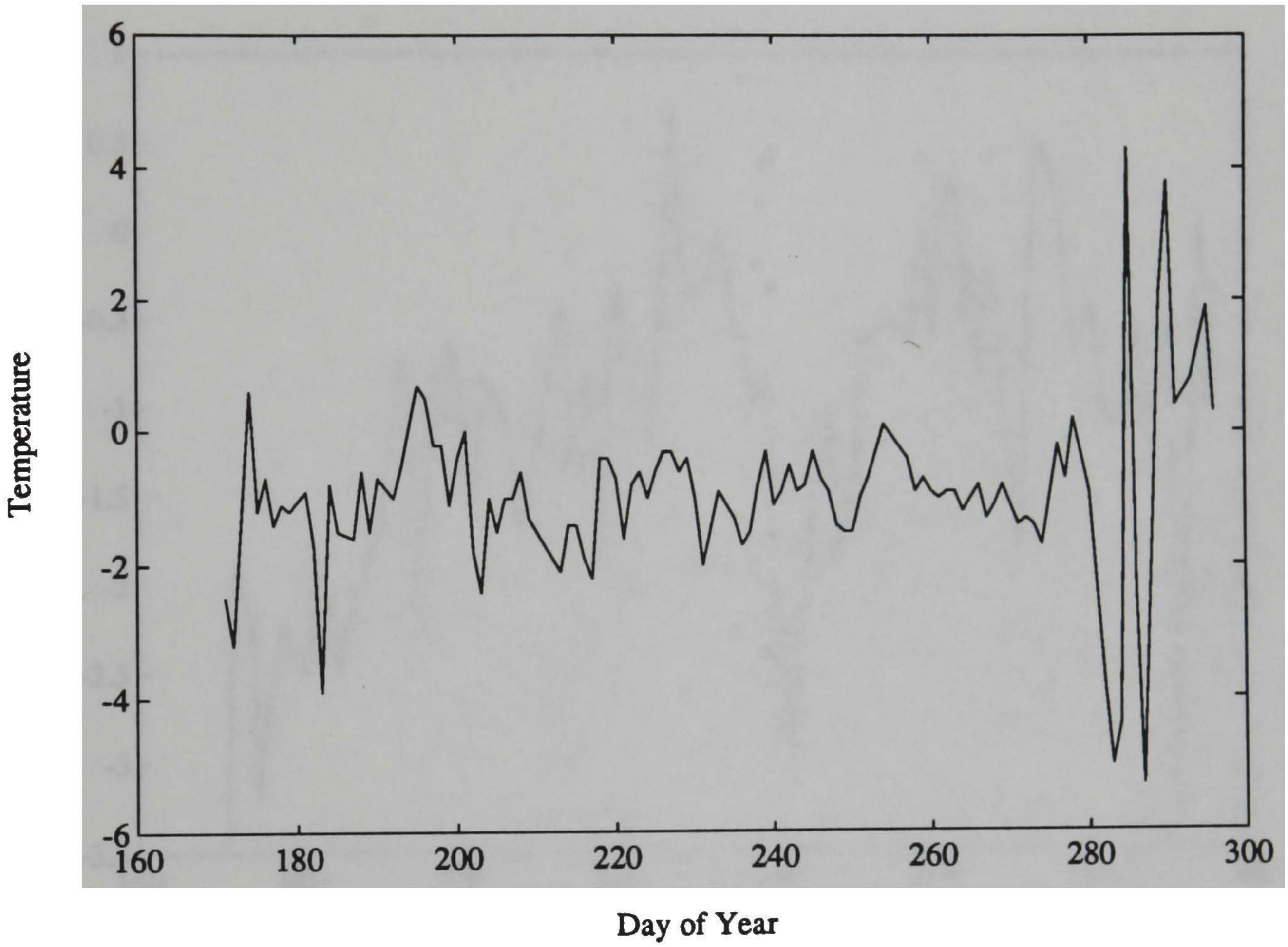

Figure 3.2: Plot of morning values for 1989

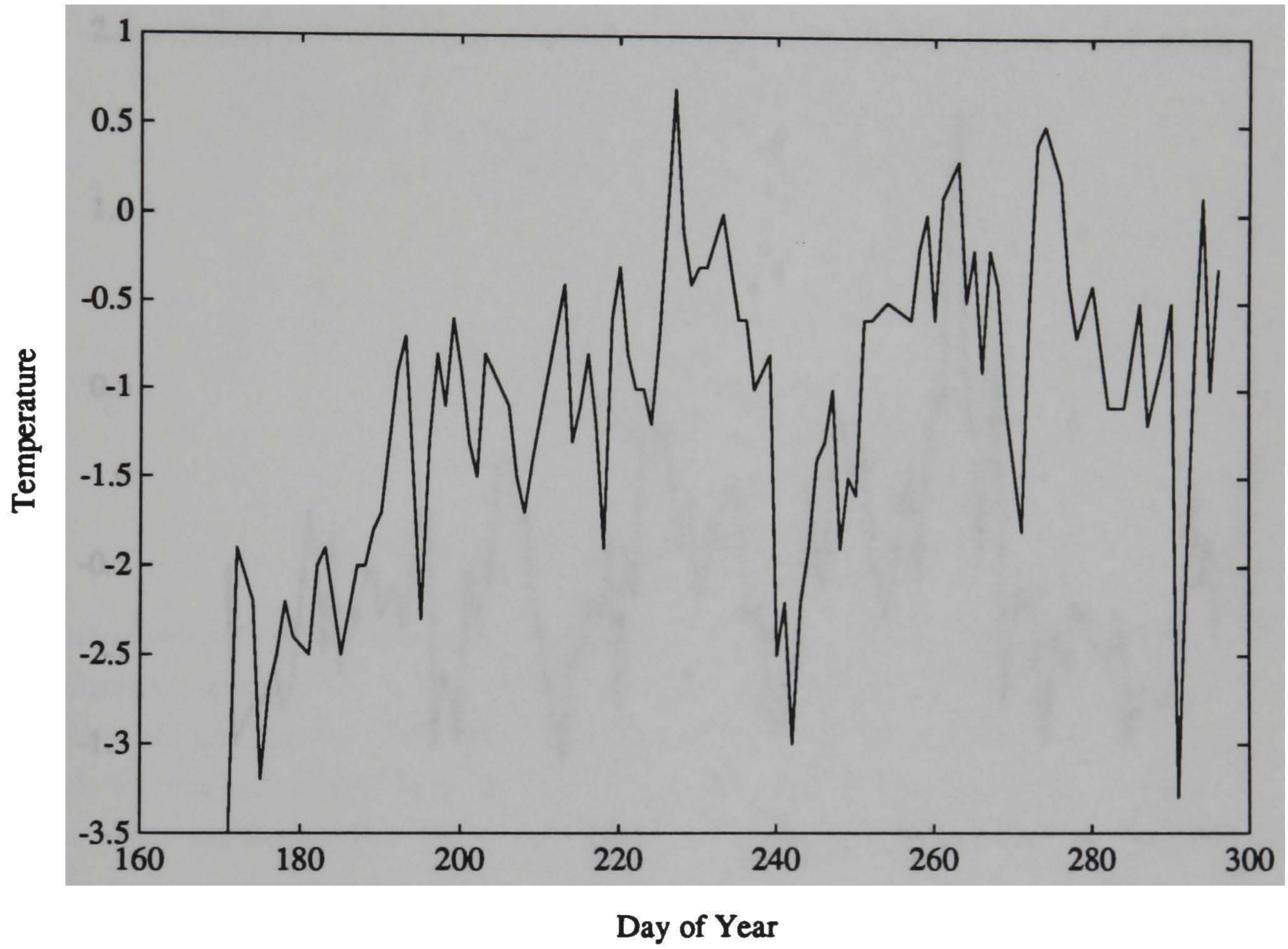

Figure 3.3: Plot of morning values for 1990

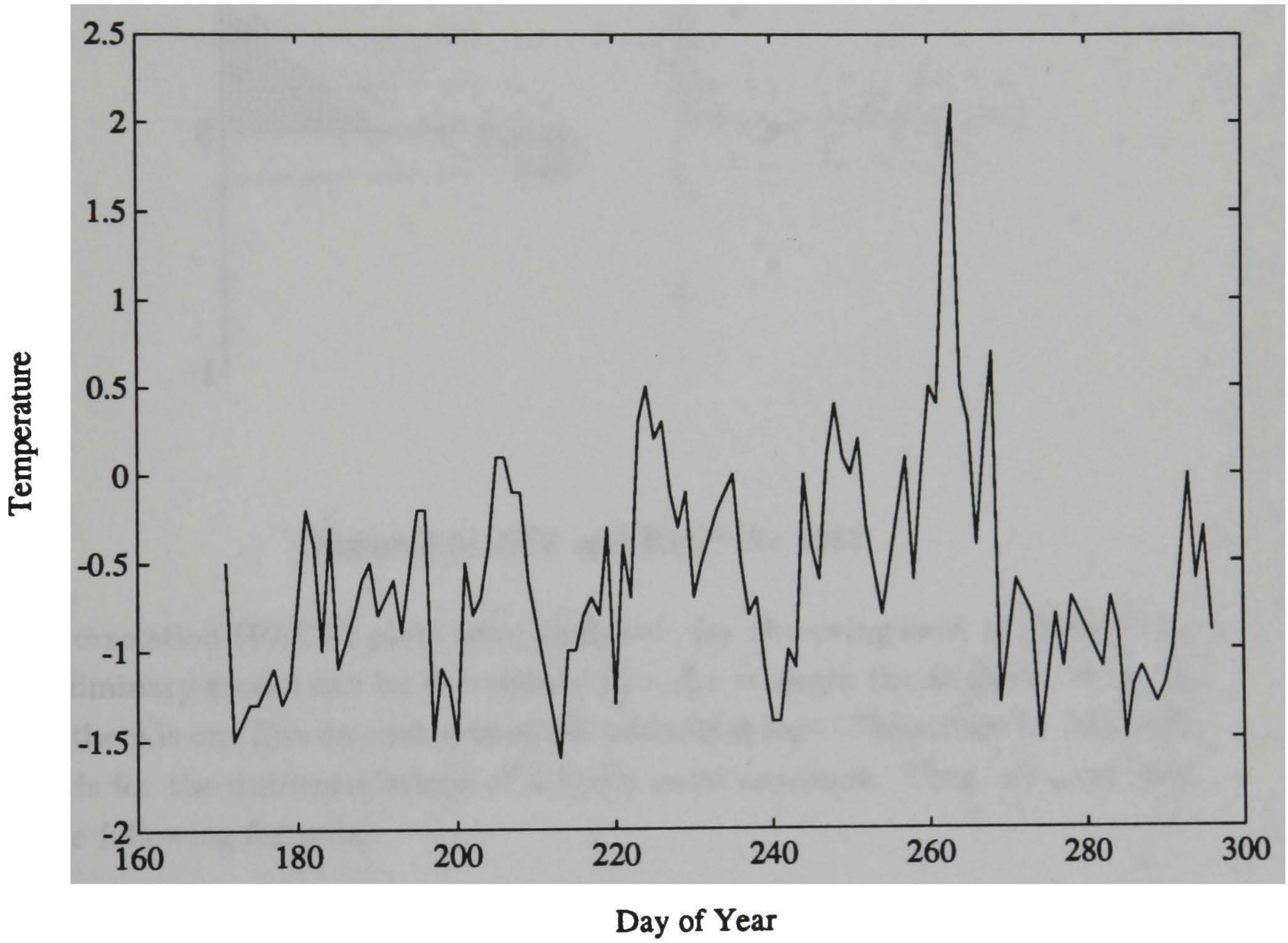

Figure 3.4: Plot of morning values for 1991

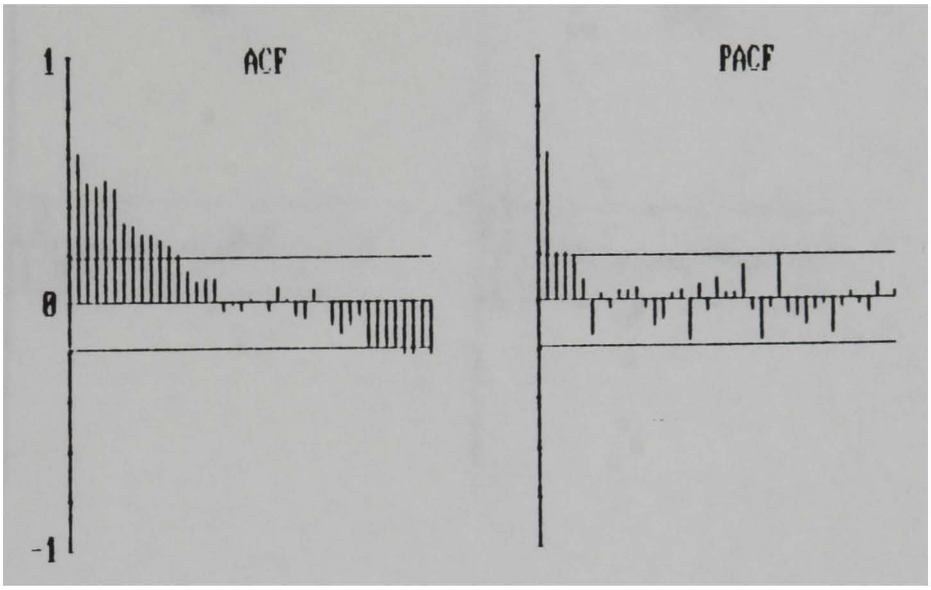

Figure 3.5: ACF and PACF for 1988

autocorrelation (PACF) plots were analyzed. By observing each of these plots, a preliminary model can be determined in order to begin the analysis. On each plot, there is one line on each side of the horizontal axis. These lines are the 95% bounds for the autocorrelations of a white noise sequence. They are computed by the following formula:

$$\pm 1.96/\sqrt{n}$$

If the data is a sample from an independent, identically distributed sequence, then approximately 95% of the autocorrelations should be within these bounds. Observing the ACF plot reveals the possible moving-average portion of the model by counting the number of lines between the beginning value and the last line that extends above the limits. The PACF plot reveals the possible auto-regressive portion of the model in the same manner. Thus, the model suggested by the ACF and PACF for the morning data from 1988 is an ARMA(1,11) (Figure 3.5).

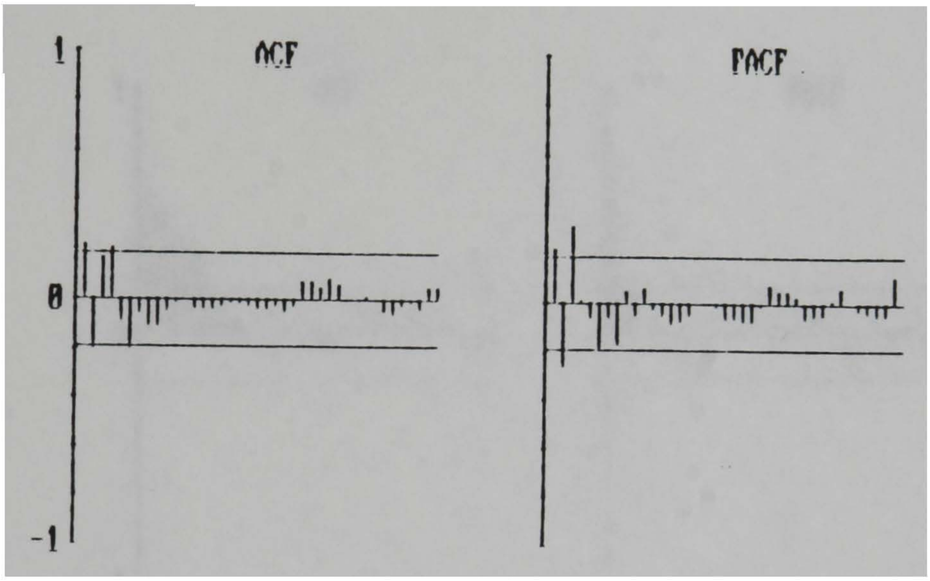

Figure 3.6: ACF and PACF for 1989

The next step is to estimate the parameters of this model. An option in PEST allows one to perform this estimation by entering the ARMA(p,q) model suggested by the plots. Upon entering the ARMA(1,11) model, the program returns with a message stating that the model chosen is not causal which implies that the autoregressive portion of the model has a zero within the unit circle. Therefore, since there is only one auto regressive coefficient, the next logical model to try is an ARMA(0,11) or MA(11) model. The program will list the coefficients of each of the terms followed by the ratio of each estimate to its standard error (S_e) times 1.96. The values of $|S_e * 1.96|$, which are less than 1.0, suggest that those coefficients could possibly be zero. After preliminary estimation of the parameters, PEST will optimize those estimates using one of two methods: maximum likelihood or least squares. The optimum model chosen by PEST for the ARMA(0,11) model is as follows:

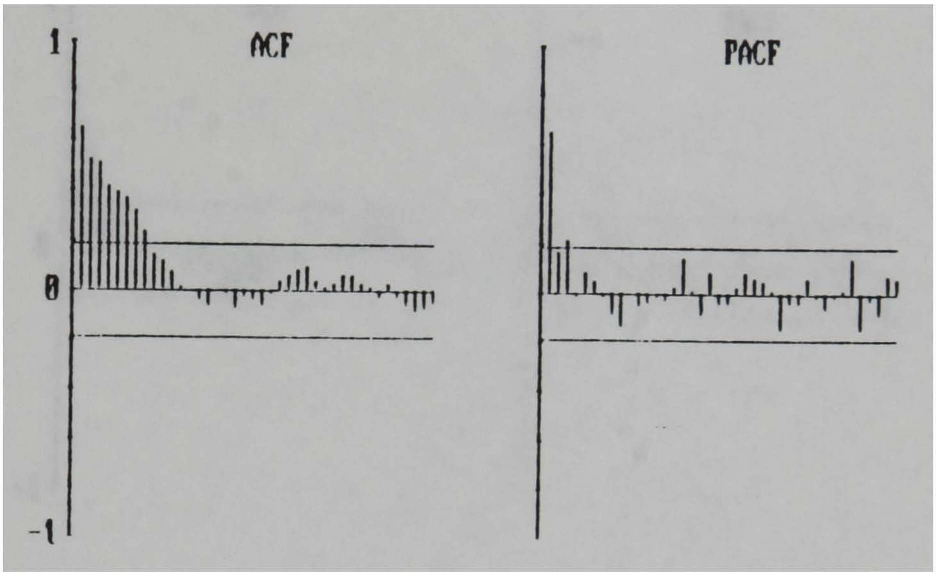

Figure 3.7: ACF and PACF for 1990

$$X(t) = Z(t) + .533Z(t-1) + .415Z(t-2) + .525Z(t-3) + .544Z(t-4)$$
$$+ .454Z(t-5) + .171Z(t-10).$$

Choosing several pieces of the data to test the model, the following results were obtained when trying to predict future values (Table 3.5).

Observing the error terms in the last column of each table, one can see that the model is not predicting the actual observed values very well. Thus, a natural assumption is that some type of trend exists which is not evident. This idea is justified by Brockwell and Davis [4]. They claim that if on the ACF plot the values decrease slowly, then some trend may be involved with the data. The same results are obtained for 1990 and 1991 (Figure 3.7 and Figure 3.8).

Due to the fact that the ACF and PACF plots for 1989 morning data do not resemble any of the plots for the other years, the different model chosen was an ARMA(0,6) (Figure 3.6). The same procedures were run for this data, and the model determined by these results was

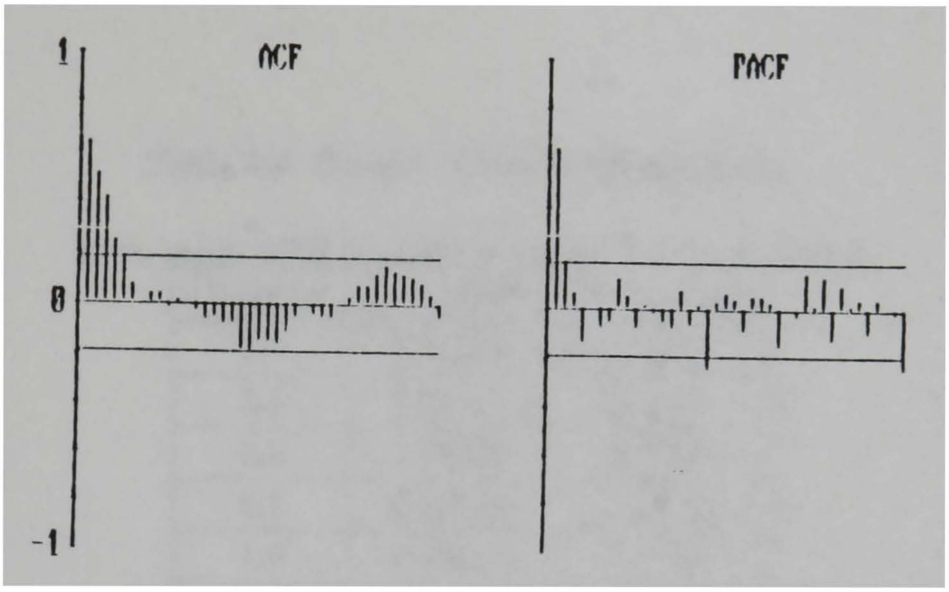

Figure 3.8: ACF and PACF for 1991

$$X(t) = Z(t) + .280Z(t-1) - .263Z(t-2) + .244Z(t-4) - .265Z(t-5) \\ -.275Z(t-6).$$

The final results are found in Table 3.6.

Thus, the results for this model reflect the same conclusion as the other years.

3.3.2 The Noon Data

The plots of the data collected at noon throughout the years reveal almost the same characteristics as the plots from the morning values (Figure 3.9-Figure 3.12). However, the spread of the data is larger than the spread found in the morning. More than likely, this is caused by the fact that the temperature of the plant does not increase quite as rapidly as the temperature of the air.

Table 3.5: Results of Model ARMA(0,11)

Data used: 1.7 2.5 2.5 1.9 3.3 3.0 3.1 1.7 1.7 1.6 2.3

Observed	Computed	Obs. - Com.
2.5	1.92668	0.5734
2.1	1.59615	0.5039
2.2	1.31676	0.8833
1.1	0.94214	0.1579
1.6	0.49526	1.1048

Data used: -0.9 0.0 0.7 0.2 0.3 0.0 0.0 -0.3 0.1 -0.4 0.4

Observed	Computed	Obs. - Com.
0.8	0.41517	0.3848
-0.5	0.44207	0.9421
0.1	0.72215	-0.6221
0.5	0.63743	-0.1374
0.2	0.49279	-0.2928

Data used: 0.8 1.9 2.6 2.4 2.5 2.4 3.7 3.0 3.2 2.9 2.4

Observed	Computed	Obs. - Com.
2.7	2.34275	0.3572
1.8	1.93128	-0.1313
1.6	1.75832	-0.1583
1.8	0.99661	0.8034
1.2	0.17222	1.0278

Table 3.6: Results of Model ARMA(0,6)

Data used: -3.2 0.6 -1.2 -0.7 -1.4 -1.1

Observed	Computed	Obs. - Com
-1.2	0.17937	-1.3793
-0.9	0.42608	-1.3261
-1.7	0.15304	-1.8530
-3.9	-0.42855	-2.47145
-0.8	0.45331	-1.2533

Data used: -0.6 -1.0 -0.6 -0.3 -0.3 -0.6

Observed	Computed	Obs. - Com
-0.4	0.17937	-0.5794
-1.0	0.42608	-1.4261
-2.0	0.15304	-2.1530
-0.9	-0.42855	-0.4715
-1.3	0.45331	-1.7533

Data used: -0.7 0.2 -0.9 -3.8 -5.0 -4.4

Observed	Computed	Obs. - Com
4.3	-0.03600	4.3360
-2.3	0.11190	-2.4119
-5.3	-0.64267	-4.6573
2.1	0.10867	1.9913
3.8	1.33973	2.4603

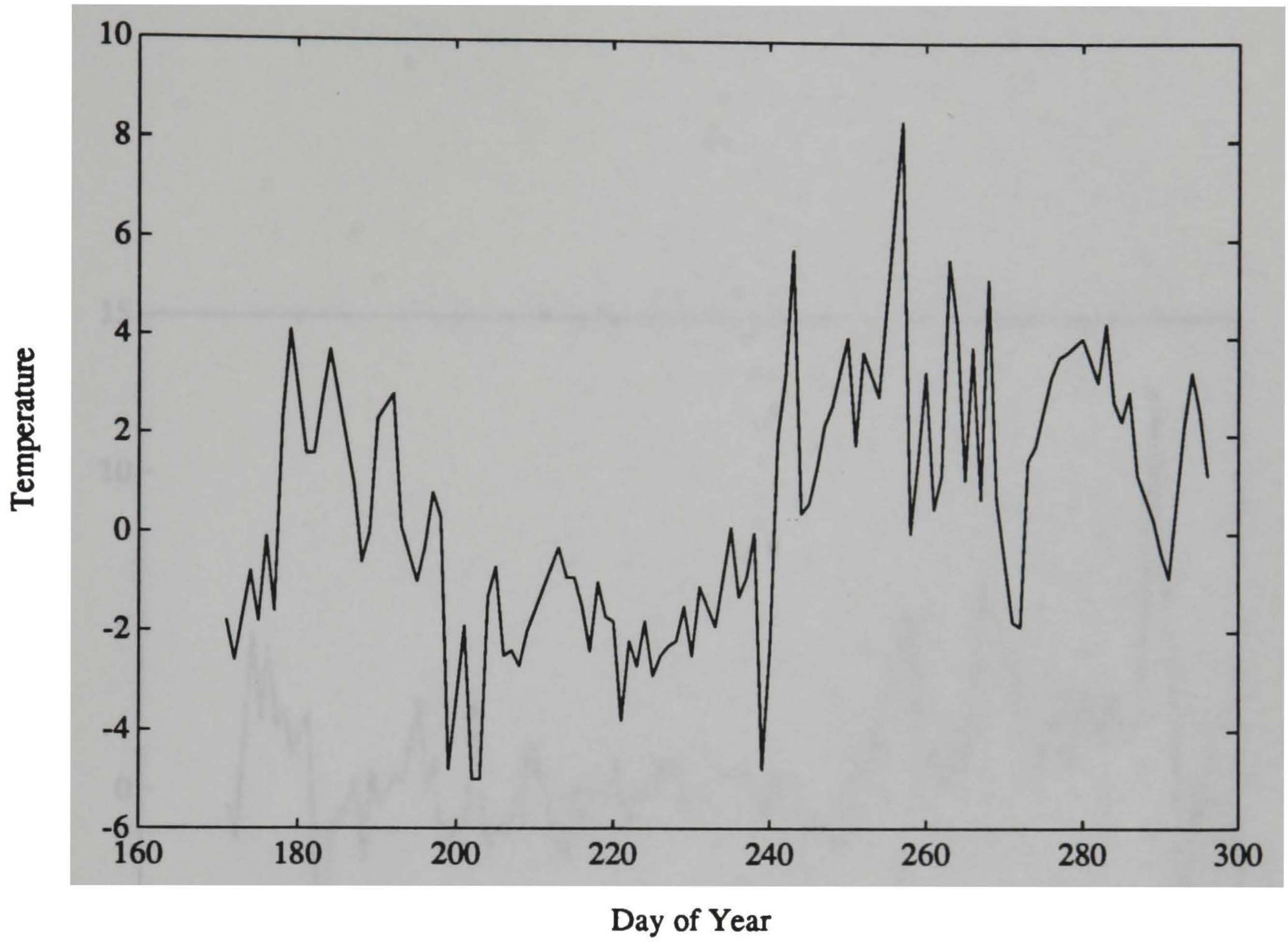

Figure 3.9: Plot of noon values for 1988

The time series analysis of this data has very similar results to those of the analysis of the morning temperatures. Therefore, those analyses will not be included in this work.

3.3.3 The Evening Data

Again, the plots of the evening data resemble those of the other two time periods (Figure 3.13-Figure 3.16). They follow the noon values more closely than the morning values due to the fact that a larger increase in temperature usually occurs between 7:00 am and 12:00 pm than between 12:00 pm and 4:00pm.

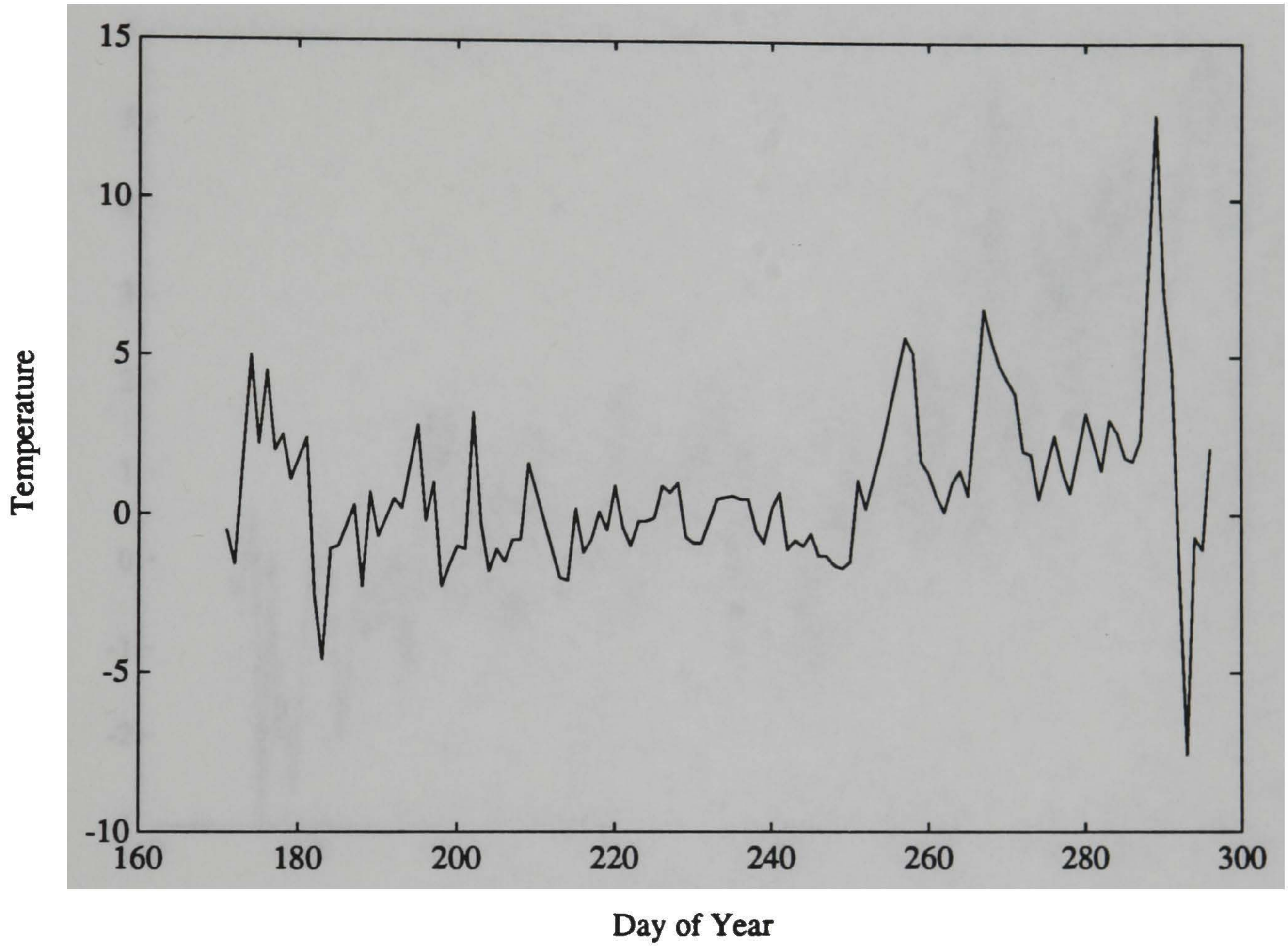

Figure 3.10: Plot of noon values for 1989

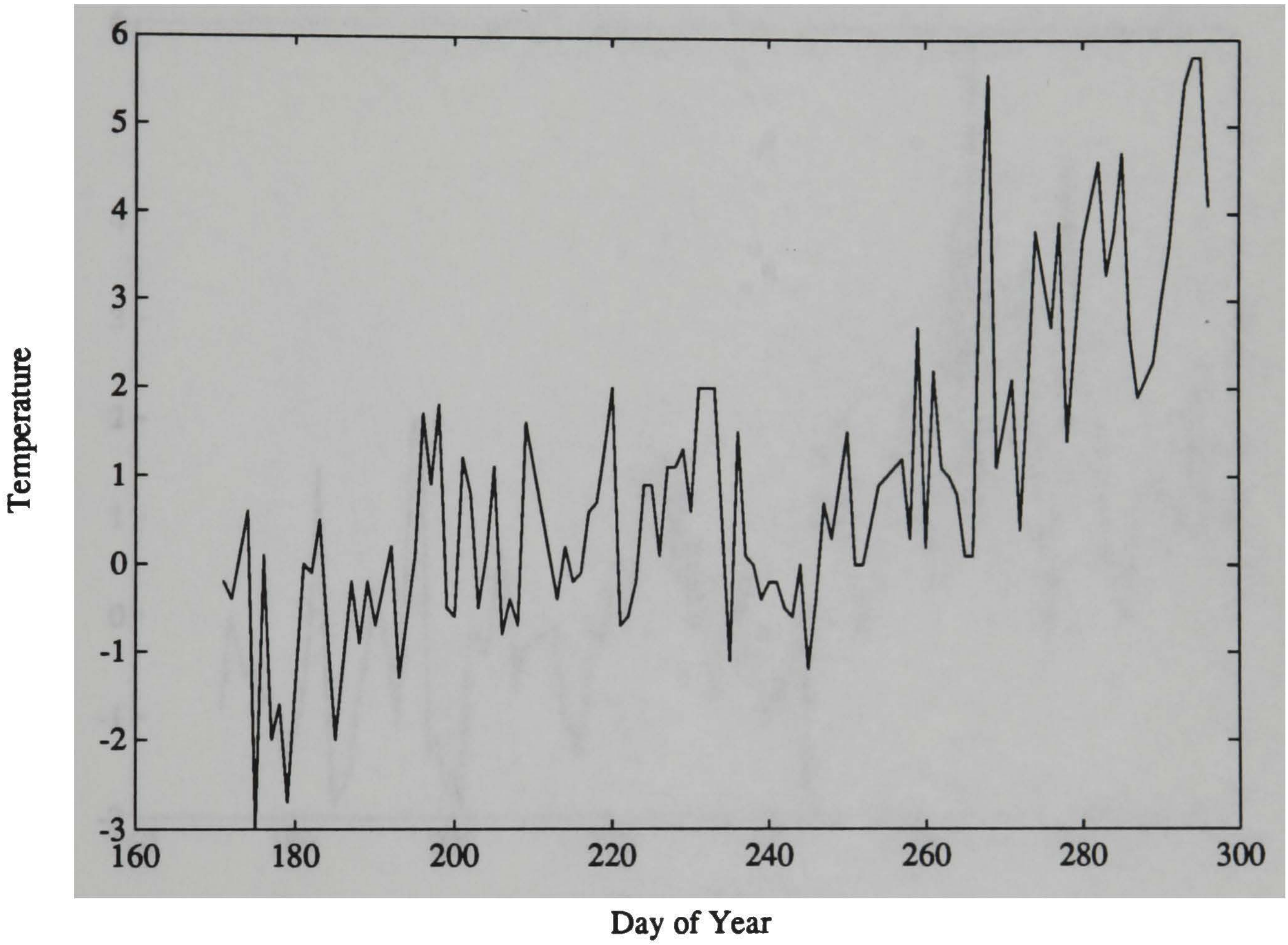

Figure 3.11: Plot of noon values for 1990

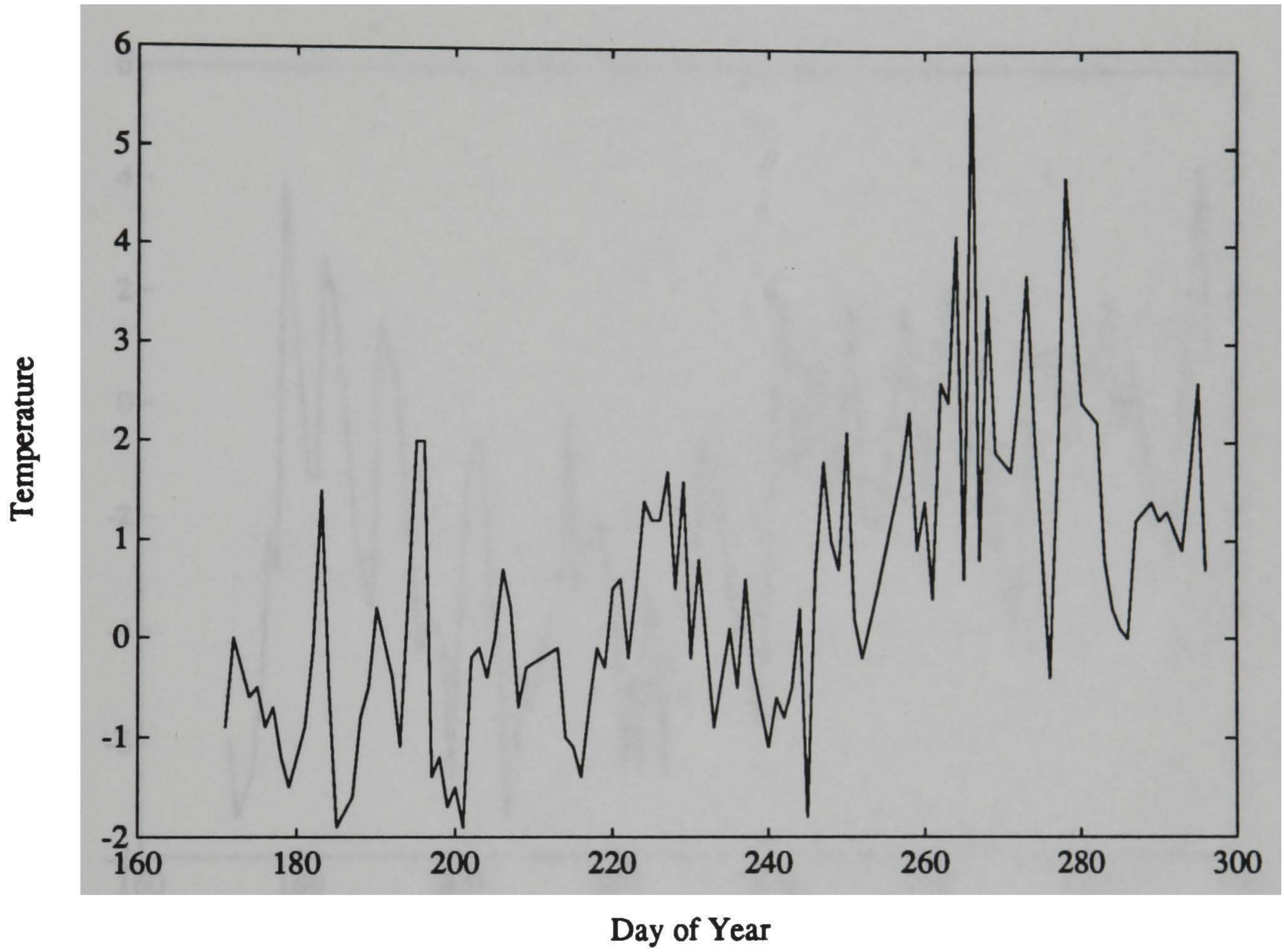

Figure 3.12: Plot of noon values for 1991

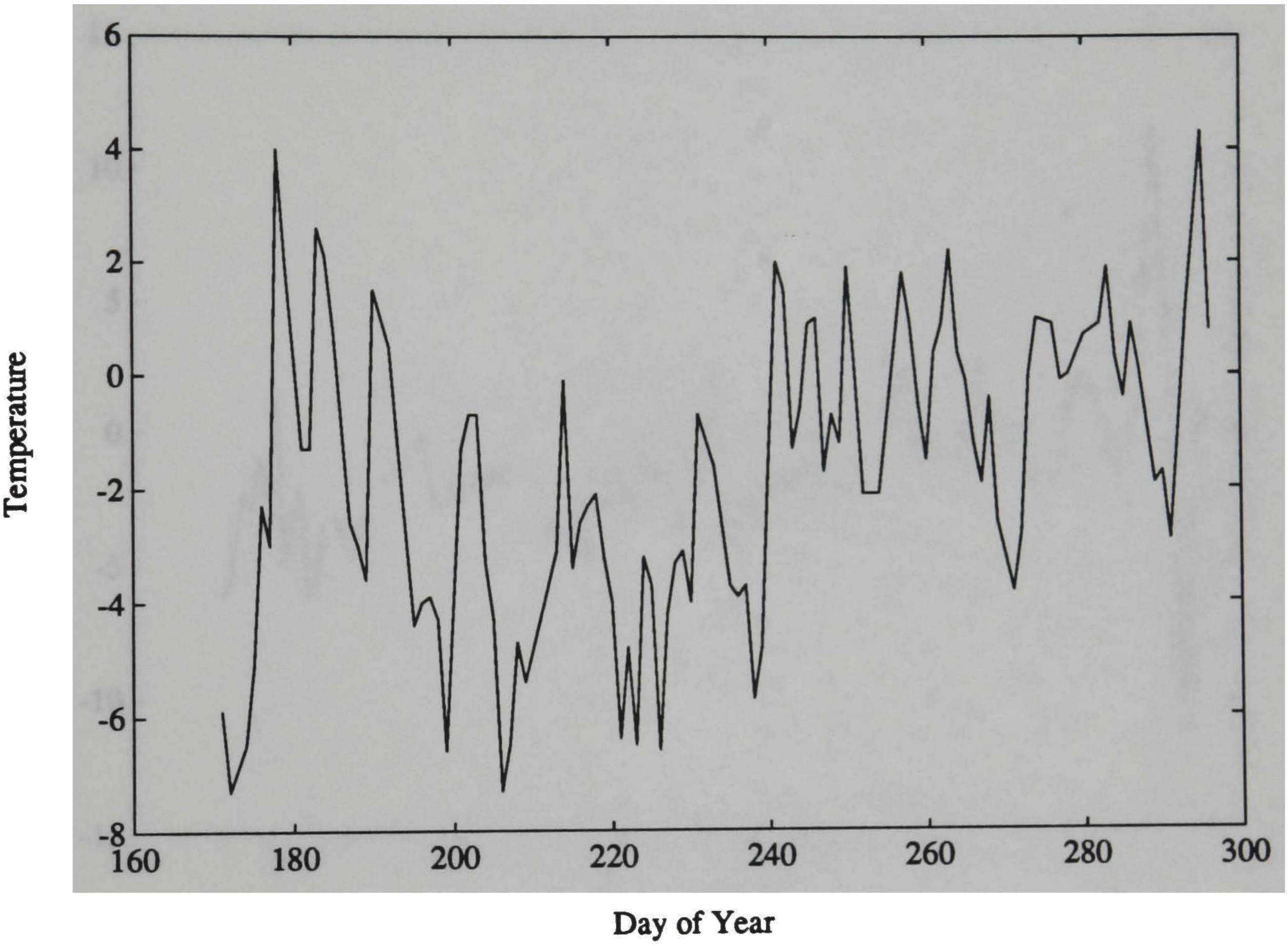

Figure 3.13: Plot of evening values for 1988

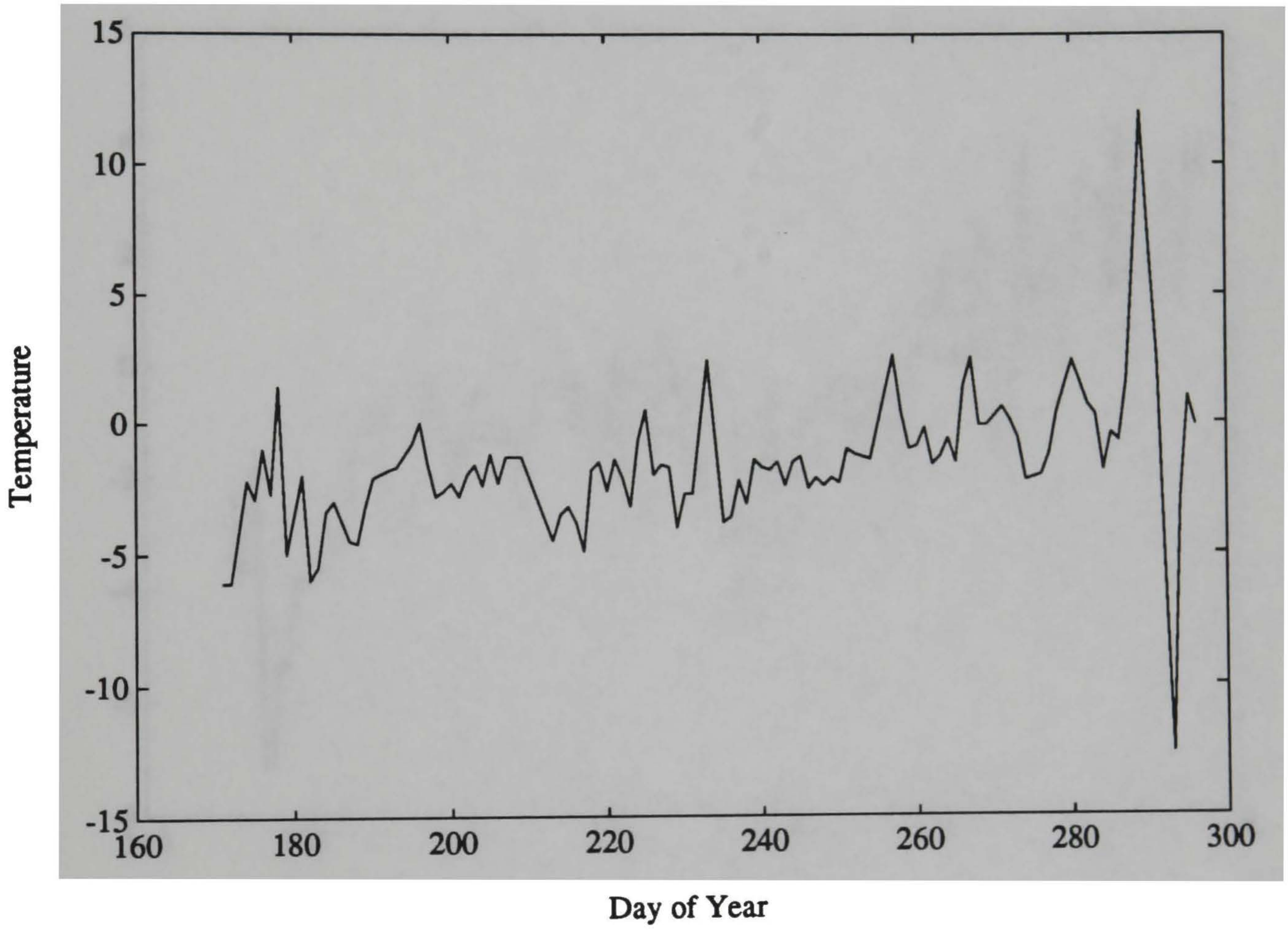

Figure 3.14: Plot of evening values for 1989

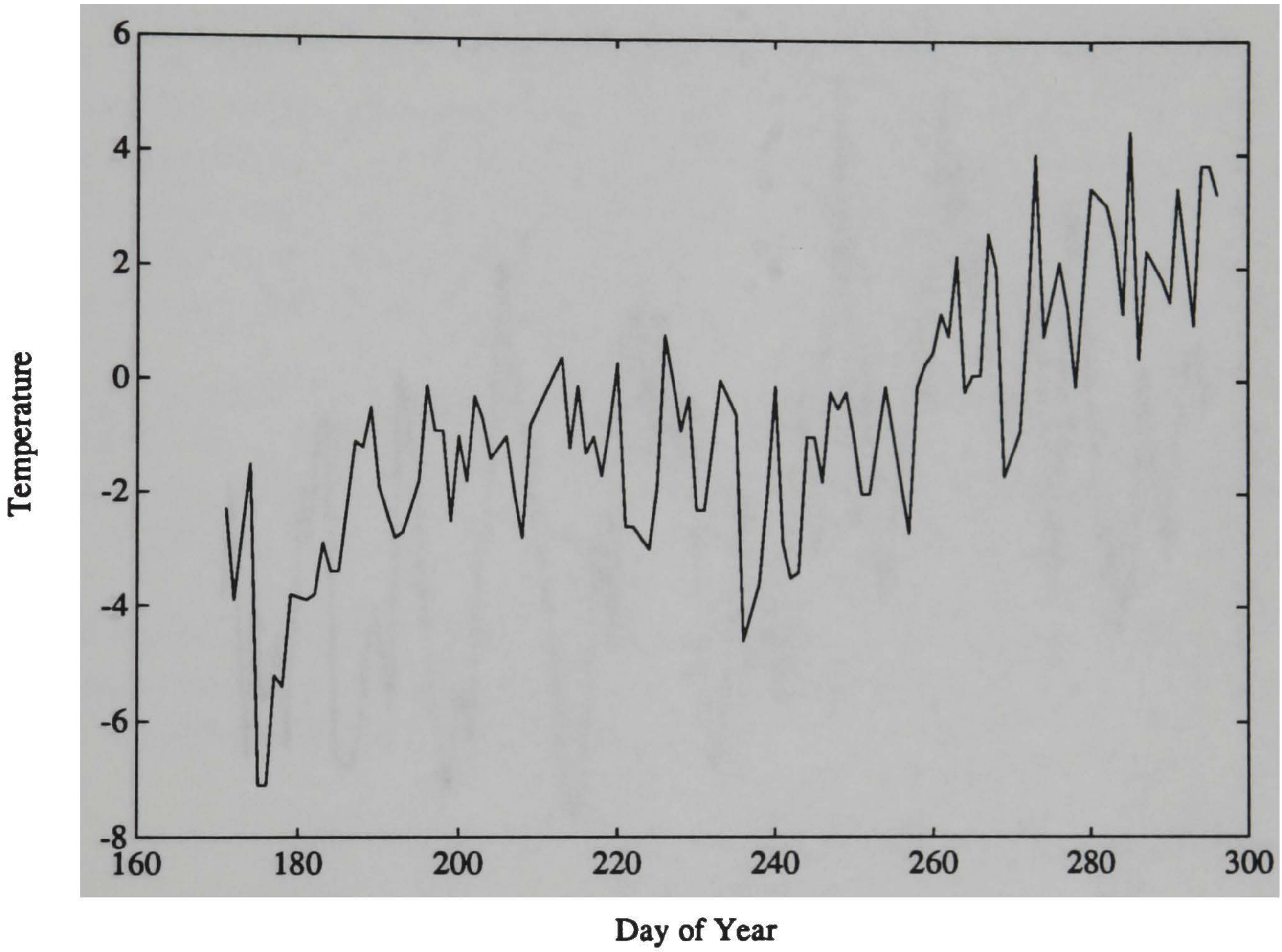

Figure 3.15: Plot of evening values for 1990

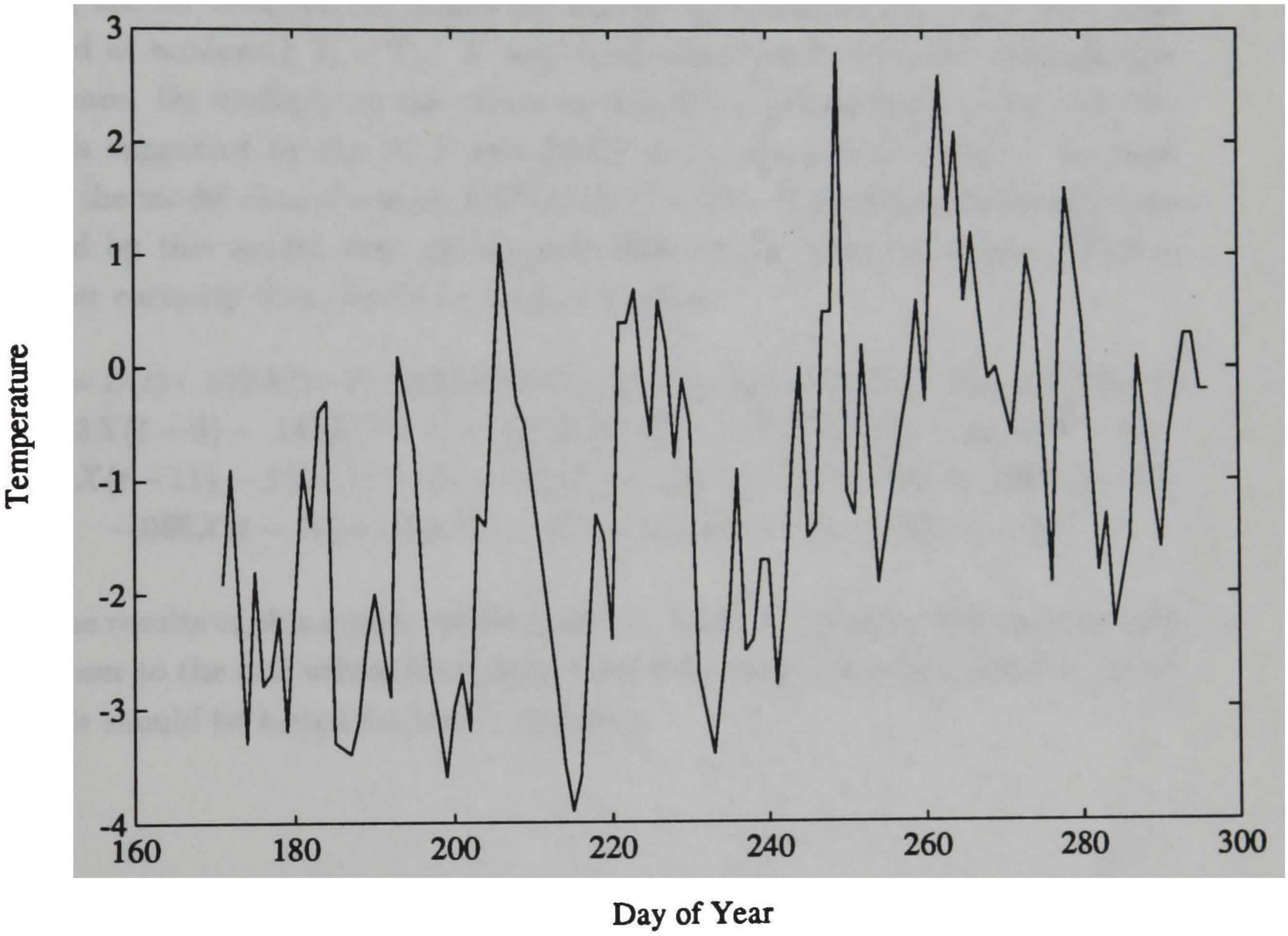

Figure 3.16: Plot of evening values for 1991

The time series analyses for this time period closely resembles that of the morning and noon temperatures, so again, the analyses will not be provided in this paper.

3.3.4 An Interesting Result

A question arose as to how the analyses would differ if the values formed by taking the air temperature minus the canopy temperature ($T_a - T_c$) were used instead of analyzing $T_c - T_a$. A very interesting result occurred through this difference. By multiplying the values used in the previous analyses by -1.0, the models suggested by the ACF and PACF plots changed drastically. In most cases, the model chosen was an ARMA(18,1) model. In addition, the predictions formed by this model were significantly close to the observed values. This is another curiosity that should be studied further.

$$\begin{gathered} X(t) = Z(t) + .922X(t-1) - .075X(t-2) - .108X(t-3) + .158X(t-4) - .035X(t-5) \\ + .213X(t-6) - .141X(t-7) + .095X(t-8) - .297X(t-9) - .312X(t-10) \\ - .016X(t-11) - .220X(t-12) + .059X(t-13) - .018X(t-14) + .109X(t-15) \\ - .086X(t-16) + .084X(t-17) + .033X(t-18) - .305Z(t-1) \end{gathered}$$

The results of this model can be found in Table 3.7. Notice that these results are closer to the real values than those from the previous models; however, other models should be tested for better accuracy.

Table 3.7: Results of Model ARMA(18,1)

Data used: 2.5 3.2 -0.6 1.2 0.7 1.4 1.1 1.2 0.9
1.7 3.9 0.8 1.5 1.6 0.6 1.5 0.7 0.7

Observed	Computed	Obs. - Com.
1.0	1.14991	-0.14991
0.5	0.51474	-0.01474
-0.6	0.13933	-0.73933
-0.7	1.08985	-1.78985
-0.5	0.37916	-0.87916

Data used: 1.5 1.0 0.7 -0.5 -0.1 -0.1 0.4 0.9 0.7
0.9 1.0 0.9 0.9 1.2 1.0 0.8 1.3 1.1

Observed	Computed	Obs. - Com.
0.8	1.07920	-0.27920
1.4	1.00079	0.39921
1.3	0.93071	0.36929
1.4	0.79010	0.60990
1.7	0.72413	0.97587

CHAPTER IV
CONCLUSIONS

In experiments such as the one performed by the USDA, it is common to obtain tremendous amounts of data. Due to the vastness of the data sets, any type of analysis becomes difficult and cumbersome. However, with the development of the USDA program, the data can be broken up into smaller pieces depending upon what type of analysis is to be performed. The program which allows the user to extract any piece of data from the large set provides a user-friendly atmosphere so that any person can use the program without difficulty.

At the current time, the program is set up to analyze only the data collected from 1988 to 1991. However, an upcoming revision will contain an option that will allow the user to input any year for which data has been collected. He will have to input the year, range of days, and treatments for each additional year. Once this option has been added, the program will be more versatile with the exception of the manner in which the data must be set up. The data will have to maintain the format specified in Section 2.1. The analyst will thus be able to use this program to perform any type of analysis on any data collected in the future as well as that which has already been obtained.

As a result of the time series analysis performed in this study, the analyst should consider the possibility that this data cannot be modelled using this type of analsis. However, one should try to determine if there exists any deterministic trend or random trend that is affecting this data. In addition, they should consider for other possible methods that would describe the characteristics of this data. The number of analyses that can be performed using the current data is endless. The analyses performed in this study dealt strictly with a very small portion of the air temperatures and canopy temperatures even though many other environmental elements exist that will affect the growth of the plants. In addition, the other environmental elements should be analyzed to see what substantial effect they might have on the growth and maturity of the cotton plant.

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