NASA

Technical Memorandum 86163

SOIL TEMPERATURE EXTREMA RECOVERY RATES AFTER PRECIPITATION COOLING

J. E. Welker

OCTOBER 1984

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

TM 86163

SOIL TEMPERATURE EXTREMA RECOVERY RATES AFTER PRECIPITATION COOLING

Jean E Welker
Geodynamics Branch
Goddard Space Flight Center
Greenbelt, Maryland 20771

October 1984

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

SOIL TEMPERATURE EXTREMA RECOVERY RATES AFTER PRECIPITATION COOLING

Jean E. Welker

ABSTRACT

From a one dimensional view of temperature alone variations at the earth's surface manifest themselves in two cyclic patterns of diurnal and annual periods, due principally to the effects of diurnal and seasonal changes in solar heating as well as gains and losses of available moisture Beside these two well known cyclic patterns, a third cycle has been identified which occurs in values of diurnal maxima and minima soil temperature extrema at 10 cm depth usually over a mesoscale period of roughly 3 to 14 days. This mesoscale period cycle starts with precipitation cooling of soil and is followed by a power curve temperature recovery The temperature recovery clearly depends on solar heating of the soil with an increased soil moisture content from precipitation combined with evaporation cooling at soil temperatures lowered by precipitation cooling, but is quite regular and universal for vastly different geographical locations, and soil types and structures. The regularity of the power curve recovery allows a predictive model approach over the recovery period. Multivariable linear regression models allow predictions of both the power of the temperature recovery curve as well as the total temperature recovery amplitude of the mesoscale temperature recovery, from data available one day after the temperature recovery begins The principal data used were those from stations in the State of Georgia in the late 1970's and early 1980's, which were chosen because of the large fluctuations in precipitation and drought conditions in this period These results were compared to data from Iowa stations in the late 1970's as examples of different soil types and structures.

SOIL TEMPERATURE EXTREMA RECOVERY RATES AFTER PRECIPITATION COOLING

The study and interpretation of this temperature drop and recovery for diurnal maxima and minima values of soil temperature was originally undertaken in order to interpret older meteorological data sets where only air temperature and precipitation values had been recorded on a regular basis. The goal of the research was to relate the variations in diurnal air temperature and precipitation to soil temperature and soil moisture conditions for known situations, so that soil temperatures and soil moisture could be inferred for situations where only data for diurnal air temperatures and precipitation values were available. There was no problem skipping over the detailed variations of the diurnal temperature cycle itself, and representing each day with a single maximum and minimum temperature value, because the soil moisture variations sought were slower moving trends toward either sufficient soil moisture or toward drought conditions The scale of these events are more conveniently sought over time increments of weeks, rather than days or months, especially for an application such as the prediction of agricultural yield.

By adopting a single maximum and minimum temperature value to represent each 24 hour period the normal diurnal temperature cycle was filtered out of the data As previously mentioned, this elongated time scaling allows trends over mesoscale or weekly periods to be determined In addition to the time scaling adjustment, geographical scaling was another consideration The objective was to adopt a useful scale with available data to test for a condition of sufficient soil moisture versus a drought or near drought condition. Both time and geometrical scalings were considered with cognizance of the current and future availability of satellite remote sensing data (Reference 1) The first area selected for testing was the state of Georgia, which is conveniently sized into nine roughly equal Crop Reporting Districts, with crop yield data available at the county level Each Crop Reporting District contained roughly twenty counties, and the crop yield data, combined with crop calen-

dar information, established at least one criteria for assessing a sufficient or insufficient soil moisture condition. Subsequently, wet and dry years in the late 1970's and early 1980's were used to establish a comparative data base for soil temperature and soil moisture variations.

A number of data sets were plotted and statistically analyzed in order to accentuate the existence and the characteristics of this mesoscale soil temperature extrema variations at a soil depth of 10 cm and its relations to other parameters. The mesoscale cycle is initiated usually by a precipitation event, which bathes the soil and causes an immediate drop in the temperature extrema. This is followed by a temperature recovery period of roughly 3 to 14 days in the absence of any more precipitation. The increased soil moisture introduced by the precipitation changes the soil albedo and increases the heat capacity of the soil which allows larger temperature increases in soil temperature due to solar heating as the temperature recovery commences. Because of the reduced soil temperature alone, initially the role of evaporative cooling is also reduced during the soil temperature recovery phase. These reduced evaporation rates have been observed in the recorded data for pan evaporation rates for a given station. In a 5-month, March through July, period in northern mid-latitudes with no elongated periods of drought, the cycle can be expected to occur approximately one to four times a month. This temperature loss and recovery can be seen in Figure 1, in which drops in maximum soil temperatures at depths of 5, 10 and 20 cm for the Tifton Meteorological Station in the State of Georgia for the period of March through July 1979 are plotted (Reference 4). Although the diurnal minimum temperatures also go through a drop and recovery phase, they are not as sensitive to this cycle as the maximum temperatures.

This study was initiated using data from the State of Georgia, because of the contrasting severe drought and non-drought years which occurred in the late seventies-early eighties in that region (Reference 3) In contrast to the non-drought data, shown in Figure 1, Figure 2 contains 1980 data which is characterized by a severe 27-day dry period in May and June with only a trace of rainfall on 1 day in this period

For the Tifton Experimental Station in southern Georgia, four periods of dry or drought conditions were identified in the late 1970's and 1980 time span for the years 1976, 1977, 1978 and 1980 shown in Table 1. A fifth period, in 1983, was recently added as the data became available. These dry conditions were reflected also in data from selected Georgian meteorological stations in close proximity to the Tifton Experimental Station. For the soil of Tifton Experimental Station, listed as Tifton loamy sand, available water in soil, without refurbishment, can drop an order of magnitude in 30 to 40 days. The data came from experiments in which soil, to a 60cm depth, was wetted to field capacity, when three varieties of peanut plants reached the wetting stage and did not recover overnight These peanut irrigation experiments were conducted out of doors with rainfall controlled shelter covers (Reference 5).

From this study of hundreds of soil temperature drops and recoveries, one overriding characteristic emerged, the power curve behavior of the temperature recovery A schematic diagram of the temperature drop and recovery are shown in Figure 3 The power recovery curve, designated as (2) in the diagram, is the curve that begins at the minimum temperature value, a, and monotonically increases until it reaches the full recovery temperature, $a + \Delta T_R$ This temperature recovery curve can be represented as

$$\Delta T_R = a\, t^b \qquad (1)$$

where ΔT_R — magnitude of the temperature recovery

a — turning point/minimum temperature for the temperature drop and recovery curve

t — recovery period in days

b — power of the power curve recovery

The basic data set that was used to develop a predictive model approach to the power curve of temperature recovery, shown in equations 2 and 3, was the 28 soil temperature maxima drops and recoveries for the Tifton Meteorological Station data in 1979 (Figure 1) at a soil depth of 10cm Only one power curve fit for the 28 recoveries which occurred from March through July of that year had a coefficient of determination out of the $0\ 85 \leq R^2 \leq 1\ 00$ range, and that value was $R^2 = 0\ 76$

This 1979 Tifton, Georgia maximum soil temperature data set was used as the basic input data in a multi-variable linear regression model of the form

$$b = C_1 + C_2 \Delta T'_D + C_3 a + C_4 \Delta T_R \qquad (2)$$

where b — power of the temperature recovery curve

$\Delta T'_D$ — single day temperature drop to the temperature minimum, a.

a — temperature minimum and turning point

$\Delta T'_R$ — temperature recovery for the first day after the temperature minimum and turning point have been passed.

C_1, C_2, C_3, C_4 — constants

The following results, shown in Figures 4-8, were obtained.

The values for $b_{computed}$, shown in Figures 4-8, were obtained from fitting a power curve to the actual raw temperature recovery data. For the 1979 Tifton, Georgia data, all these fits but one had an R^2 in the range of $0.85 \leq R^2 \leq 1.00$ as previously stated. Curve fits for station data for other years had been fitted with comparable values of R^2 The $b_{projected}$ values were obtained using a multivariate linear regression model for b (Equation 2) as a function of three variables. These variables were the temperature drop, $\Delta T'_D$, which occurred on the single day prior to the minimum and turning point temperature value, a, the turning point temperature value, a, itself, and finally, the value of the temperature rise, $\Delta T'_R$, for the single day following the turning point temperature value, a In an alternate procedure, the entire monotonically decreasing temperature drop, ΔT_D, was used rather than the single day temperature drop, $\Delta T'_D$ In either case, the power of the temperature recovery curve, $b_{projected}$, can be predicted from data taken a single day after the minimum turning point temperature, a, has been reached

For the first three figures, Figures 4, 5, and 6, the 1979 Tifton, Georgia data set was used to predict the power of the temperature recovery curve for stations in Georgia i e the 1980 conditions at Tifton and the 1979 and 1980 conditions at Experiment, Georgia The best fits are shown in

figures 4 and 5, which are projections from one year to the next for the same station, Tifton, and projections from one station, Tifton, to another at Experiment, Ga within the same year, 1979, respectively

For the last two figures, 7 and 8, the 1977 Ames and Shenandoah, Iowa data were used as the basis of projecting values for b for Ames and Shenandoah, Iowa, stations in 1978, respectively. Initially, 1979 Tifton, Ga. data was used to predict 1978 values for b for both the Iowa stations. In spite of the fact that the Tifton, Ga. station had drastically different soil and geographic characteristics, the 1979 Tifton data set produced good projected values for b for Ames and Shenandoah, Iowa in 1978, but the 1978 values projected from 1977 Iowa data, as shown in Figures 7 and 8, were more accurate than those predicted from the 1979 Tifton, Ga. data. The Shenandoah, Iowa station does not publish maximum soil temperature data as other stations do but only soil temperature data at 5 p m. local time, thus reducing the maximum temperature value which would be directly comparable with the data from the other stations.

Although the power of the curve, b, can be anticipated quite well, the total rise of the temperature recovery, ΔT_R, must still be predicted. The results for one method of estimating ΔT_R are plotted in Figure 9, when a multivariable linear regression model is again used, but in the form

$$\Delta T_R = C_1 + C_2\, a + C_3\, b + C_4\, \Delta T_D' \qquad (3)$$

The coefficient of determination, R^2, is 0 85 for the basic input data, the 1979 Tifton, Ga. data set A number of alternative methods are being tested such as substitution of ΔT_D for $\Delta T_D'$, direct calculation of ΔT_R from a power curve and most probable estimate of the recovery period, estimates which include dryness of the soil measured by number of days without precipitation, amount of precipitation, etc Estimates made using meteorological parameters still present a major obstacle to the predictive process The convention used to define the meteorological parameter introduces an inherent uncertainty, e g , should the precipitation which occurs on the same day or the day before the temperature drop be considered as the cause of the drop or should precipitation lasting three or four

consecutive days due to a frontal movement passing through the area be listed as the cause. An alternative approach can be taken by dividing different types of precipitation events into two or more classes. In any case, the time of day in which the precipitation falls, the temperature of the precipitation, the efficiency of precipitation cooling, changes in the soil's heat capacity and albedo, the duration and magnitude of the precipitation event, the rate of evaporation, etc., are all factors which can affect the temperature drop and recovery despite the characteristic power curve recovery of temperature. Individual precipitation events for the basic 1979 Tifton, Ga. data set are carefully being inspected in an attempt to model and evaluate the effects of these factors.

Classification of different types of precipitation events as to magnitude and duration raises questions about the magnitude and duration of the temperature drop itself, especially with regard to the subsequent recovery For example, a temperature drop and recovery which closely follows a previous event may appear to have a small temperature drop and a relatively large temperature recovery This could be caused by the second temperature drop occurring before the soil temperature had fully recovered from the first temperature drop and recovery As a general assumption, it can be postulated that magnitude of the temperature rise for any event is valid only if the soil temperature had fully recovered to normal conditions from the previous event

In summary, a procedure has been outlined which can be used to predict soil temperature maxima in the roughly three to fourteen day period following an identified temperature drop and recovery, as described above The key to the predictive process is the characteristic power curve temperature recovery which occurs for soils of vastly different types, structures, and geographical locations This temperature power curve recovery is accompanied by increases in the evaporation rate as measured by pan evaporation data These changes in evaporation rates and other factors are currently being investigated in an attempt to understand the basic mechanism of the temperature power curve recovery These soil temperature drop and recovery events occur frequently enough to allow the characterization of soil temperatures over a seasonal period as a sequence of these mesoperiod-

scale events. The data sets from which this methodization has been derived are sufficiently incomplete as to prevent a definitive analysis of the competing heating/cooling and evaporative processes which result in the power curve temperature recovery after the initial temperature drop from cooling process, such as a precipitation event. The fact that this power curve recovery also occurs in temperature measurements of colocated — layers of air and evaporation pan water above the soil surface opens both additional problems in interpretation as well as additional data from which a proper physical interpretation can be concluded.

ACKNOWLEDGMENT

Without the patience, insights, advice, and encouragement of Professor Helmut Landsburg of the University of Maryland, this paper would not have been written. I acknowledge his help with gratitude, and assume sole responsibility for any speculations, errors, or mistakes contained within the body of this paper.

REFERENCES

1 Schmugge, T J , T J Jackson and H.L. Kim, "Survey of In-Situ and Remote Sensing Methods for Soil Moisture Determinations," in Deutsch, M., Wiesnet, D R., and Rango, A., eds. *Satellite Hydrology* American Water Resources Association, June 1979

2 Susskind, J., Rosenfield, J., Reuter, D and Chahine, M.T , "Remote Sensing of Weather and Climate Parameters from HIRS2/MSU on TIROS-N," *J Geophys. Res.*, 89, No C6 , 4677-4697 June 20, 1984

3 Welker, Jean E., "Soil Moisture from Temperature Measurements at the Earth's Surface," in Kahn, W D and Cohn, S.C , eds. *Geodynamics Branch Research Report — 1982.* NASA Technical Memorandum 85078 Greenbelt, Md.. NASA/GSFC, September 1983 5-17 — 5-21

_____ "Soil Moisture From Temperature Measurements at the Earth's Surface, Update," in Kahn, W D and Cohen, S.C., eds. *Geodynamics Branch Research Report — 1983* NASA Technical Memorandum 86123 Greenbelt, Md. NASA/GSFC June 1984, 5-8 — 5-11

4 All data for the State of Georgia from 1975 through 1983 was obtained from Environmental Data and Information Service, NOAA, *Climatological Data*, 79-87, Asheville, N C National Climatic Center, 1975-1983

5 Stansell, J R., Shepard, J L , Pallas, J E., Bruce, R R., Minton, N A , Bell, D K , and Morgan, L W , "Peanut Responses to Soil Water Variables in the Southeast," *Peanut Science* 3, No 1, Figure 7, 47, Spring, 1976

Table 1
Tifton Experimental Station Dry/Drought Periods

Year	Duration	Total Precipitation	Precipitation Occurrences
1975			
1976	28 days, Apr 2-29	< 0.35"	0.3 " April 7
			trace April 14
			trace April 22
			trace April 23
			trace April 26
1977	50 days, Apr 1-May 19	< 1.1"	0.45" April 5
			0.1 " April 23
			0.45" April 24
			trace May 5
			0.1 " May 9
1978	26 days, Mar 16-Apr 11	<0.1"	trace March 17
			trace March 25
1979			
1980	25 days, May 25-June 18	trace	trace June 9

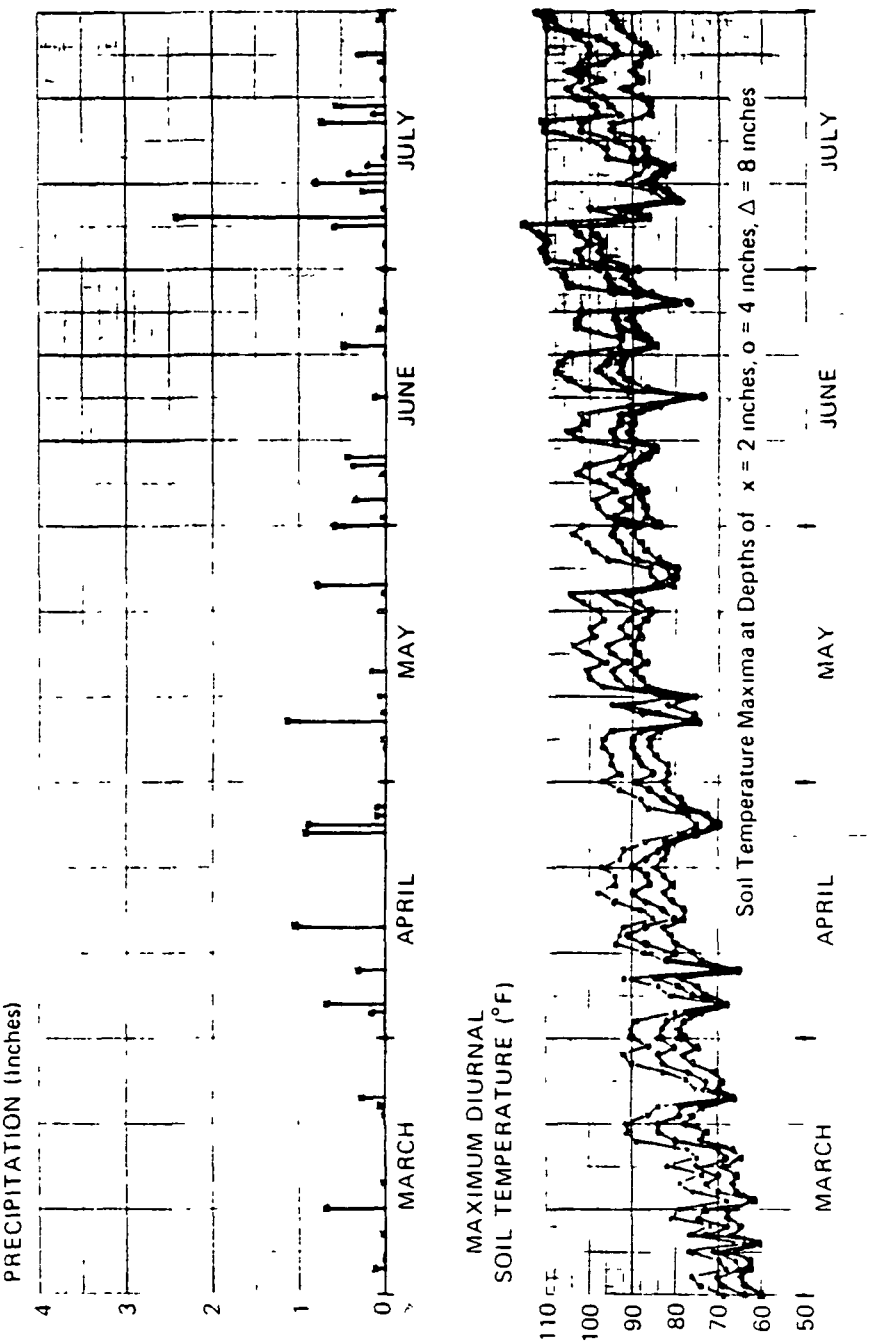

Figure 1

ORIGINAL PAGE IS
OF POOR QUALITY

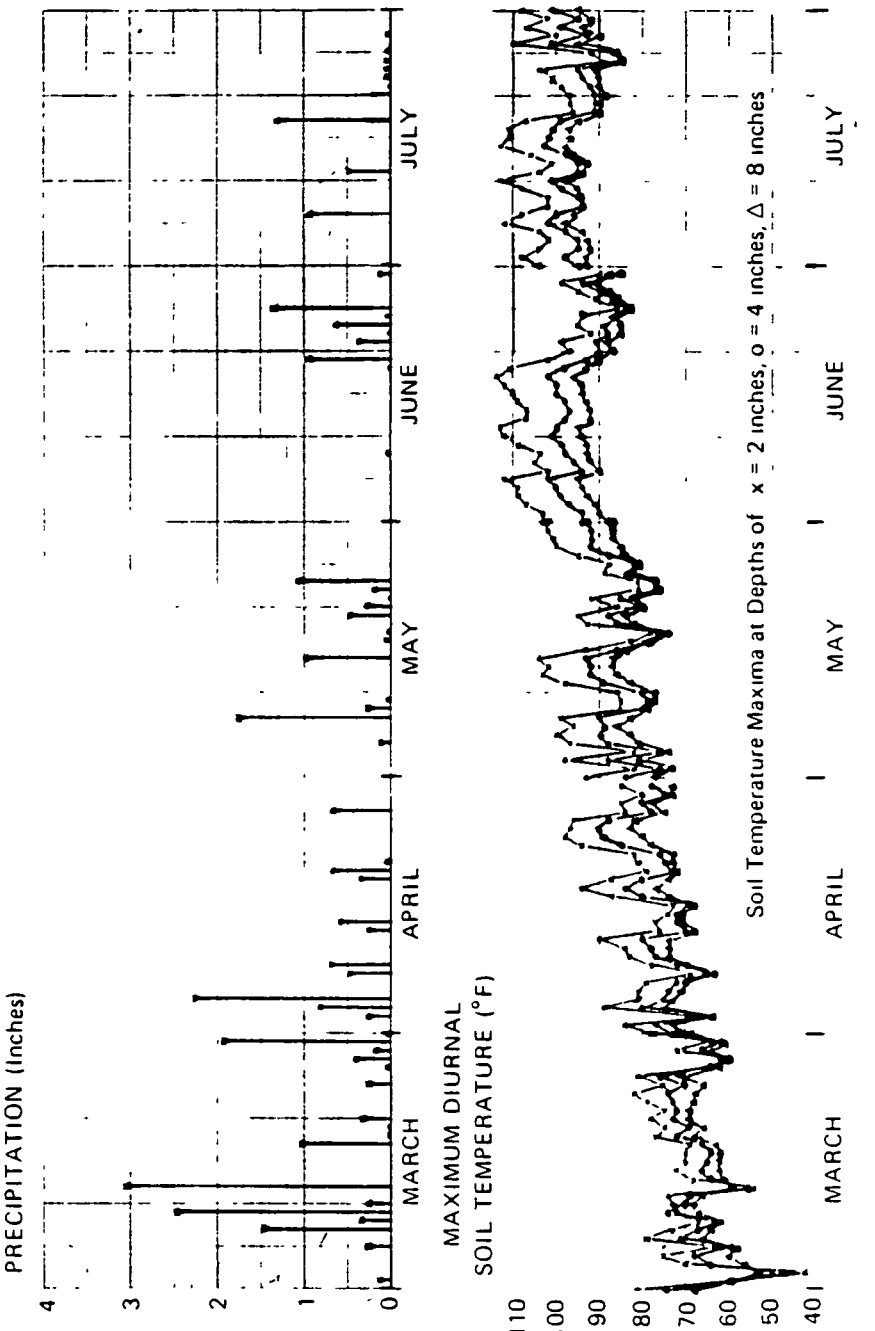

Figure 2

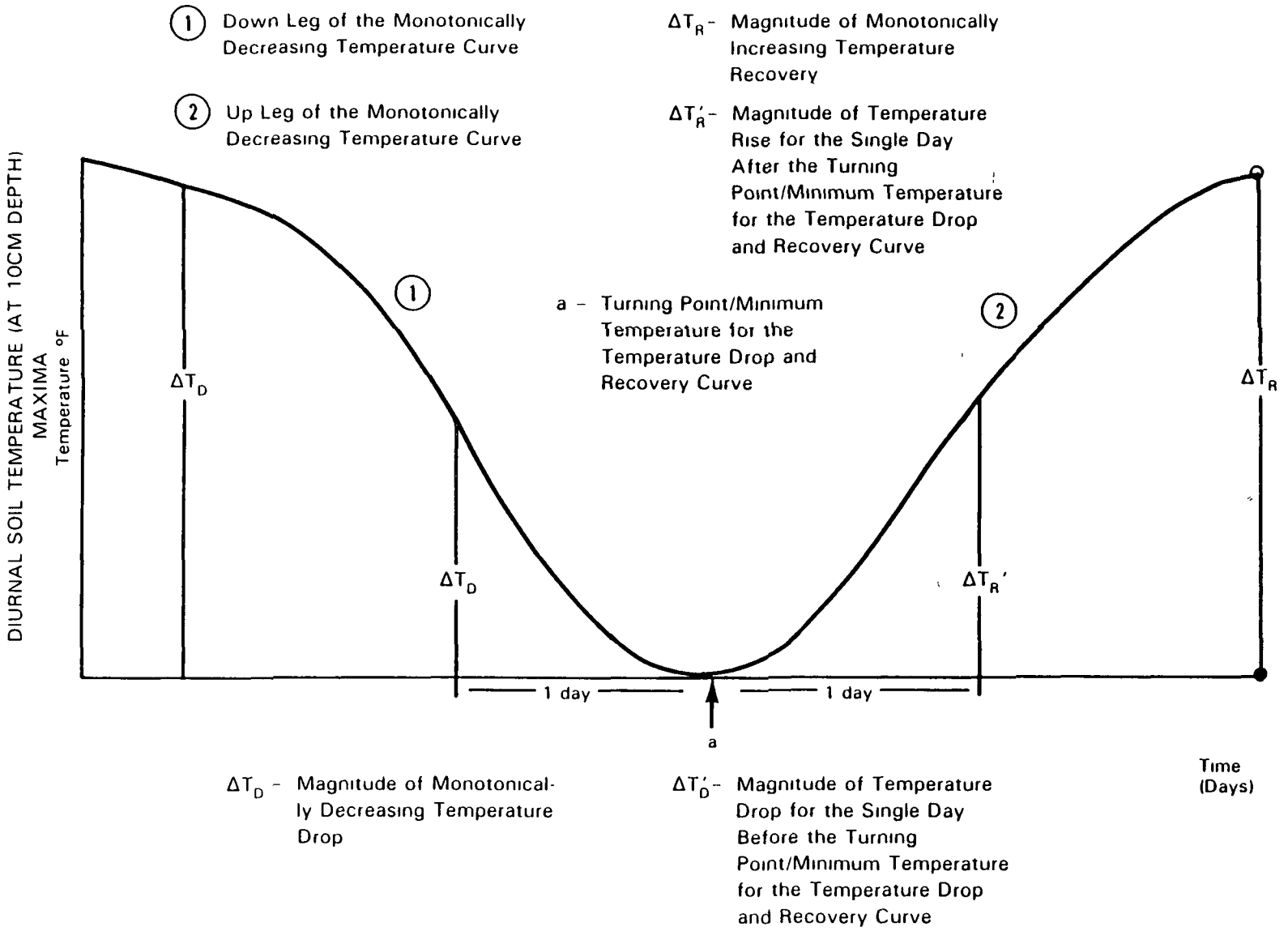

Figure 3 Schematic of Diurnal Soil Temperature Maximum Drop and Recovery

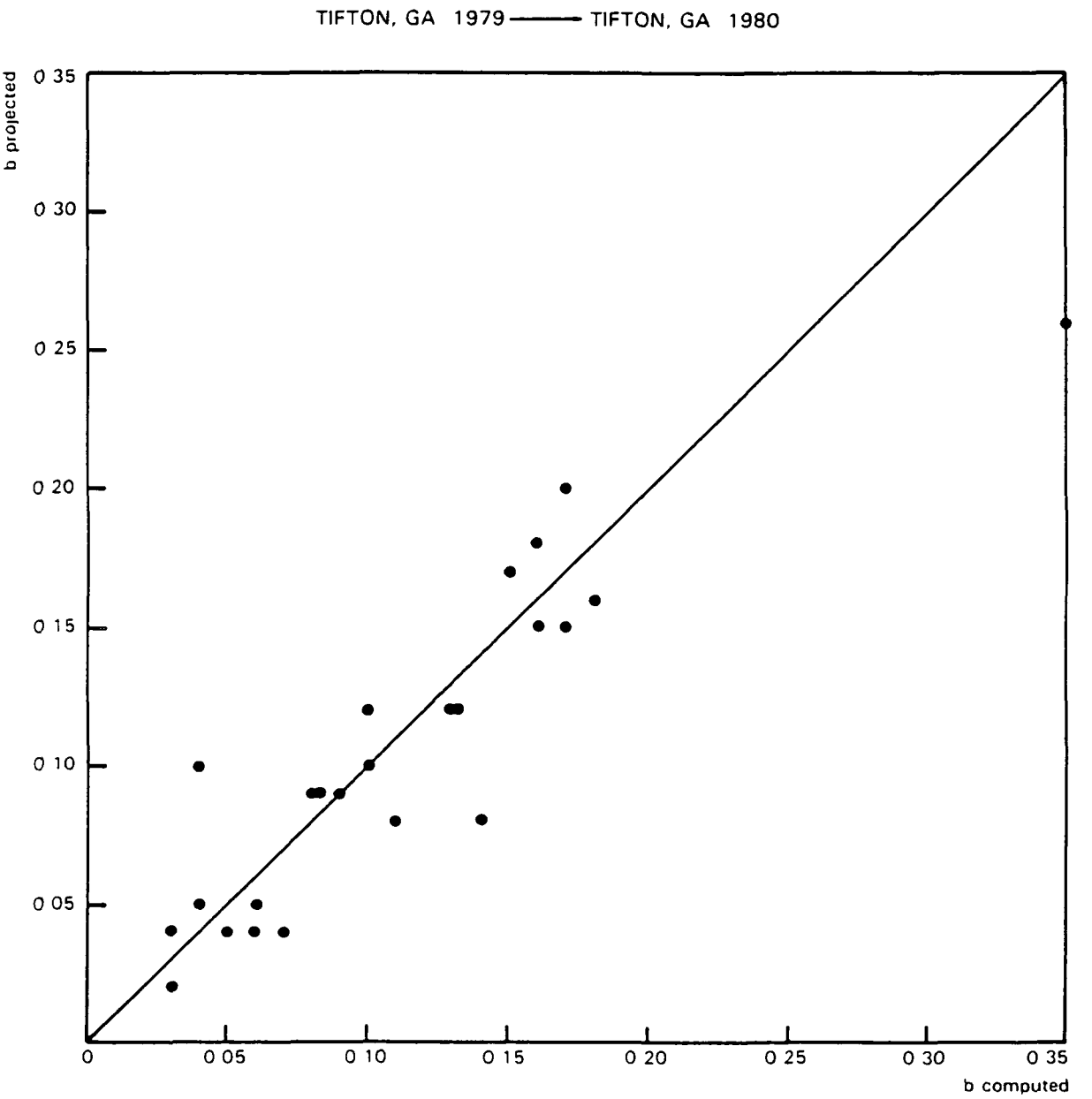

Figure 4 The projected power, $b_{projected}$, of the soil temperature recovery curve for Tifton, Ga in 1980 using the 1979 Tifton, Ga. data set line of slope 1 indicates $b_{computed} = b_{projected}$ The $b_{projected}$ values were obtained from a multivariate linear regression model of three variables, $\Delta T'_D$, a, and $\Delta T'_R$ which was established using the 1979 Tifton, Ga data set from March through July

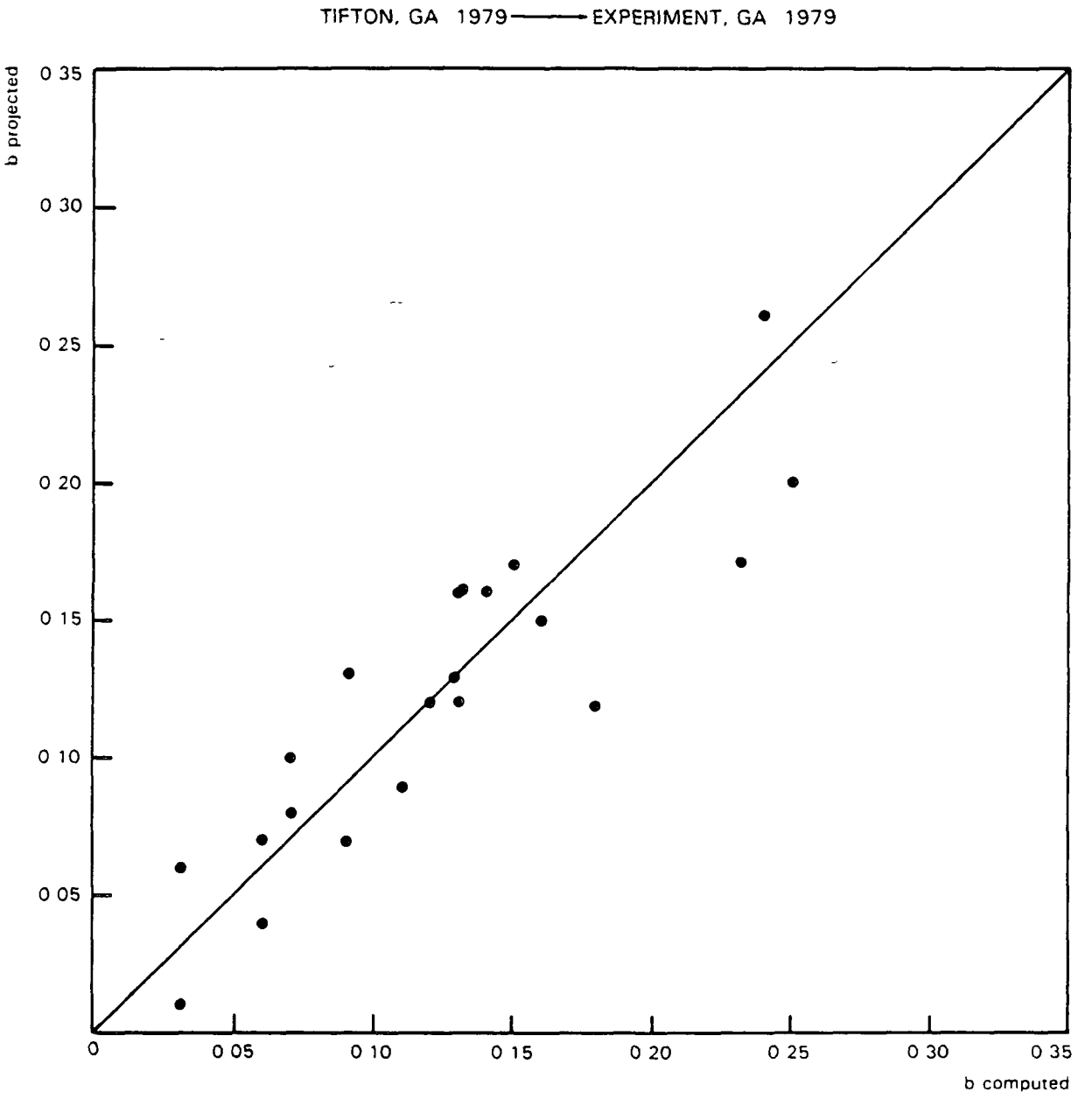

Figure 5 The projected power, $b_{projected}$, of the soil temperature recovery curve for Experiment, Ga in 1979 using the 1979 Tifton, Ga. data set Line of slope 1 indicates $b_{computed} = b_{projected}$ The $b_{projected}$ values were obtained from a multivariate linear regression model of three variables, $\Delta T_D'$, a, and $\Delta T_R'$ which was established using the 1979 Tifton, Ga data set from March through July

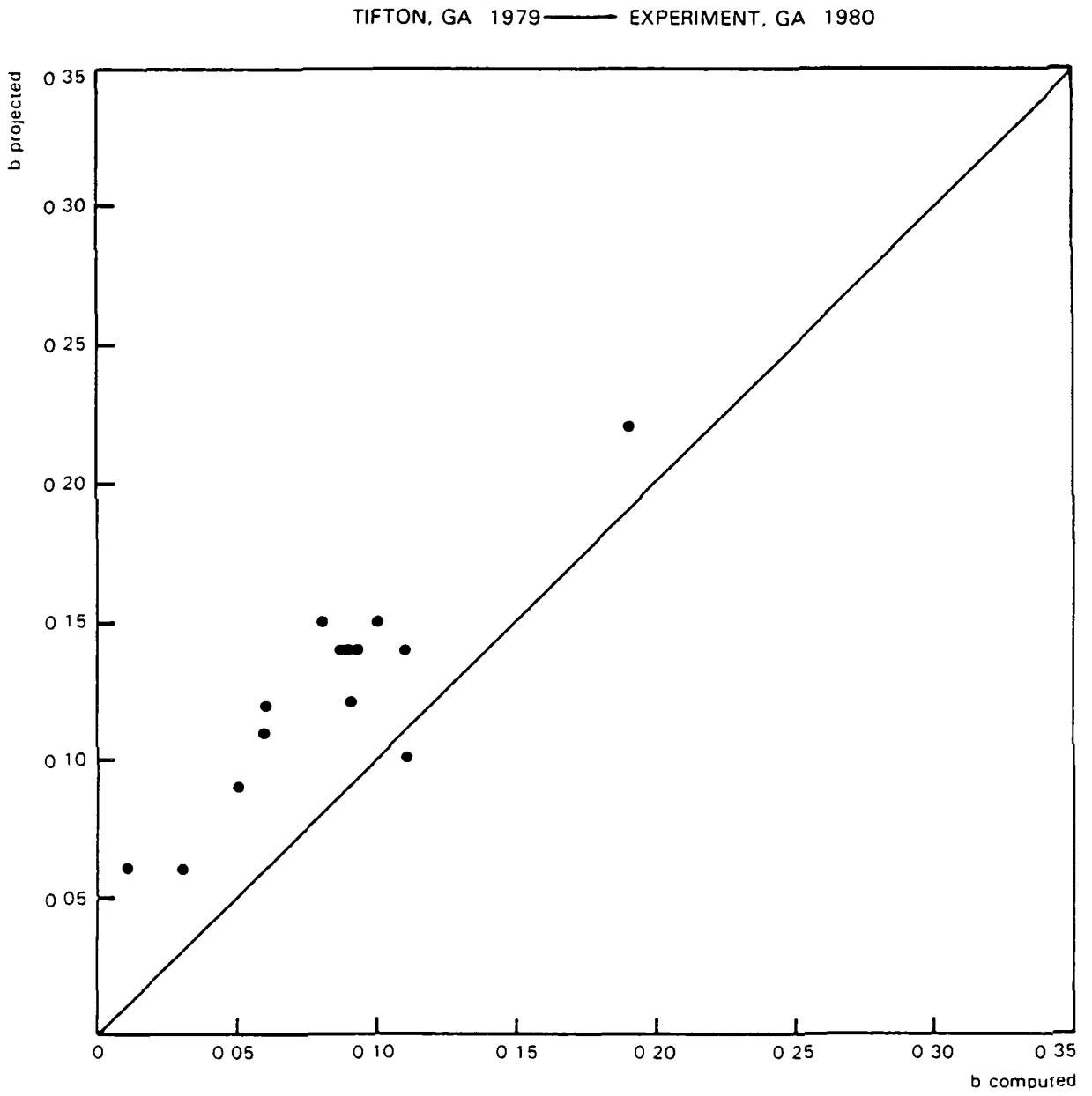

Figure 6 The projected power, $b_{projected}$, of the soil temperature recovery curve for Experiment, Ga in 1980 using the 1979 Tifton, Ga data set Line of slope 1 indicates $b_{computed} = b_{projected}$ The $b_{projected}$ values were obtained from a multivariate linear regression model of three variables, $\Delta T'_D$, a, and $\Delta T'_R$ which was established using the 1979 Tifton, Ga data set from March through July

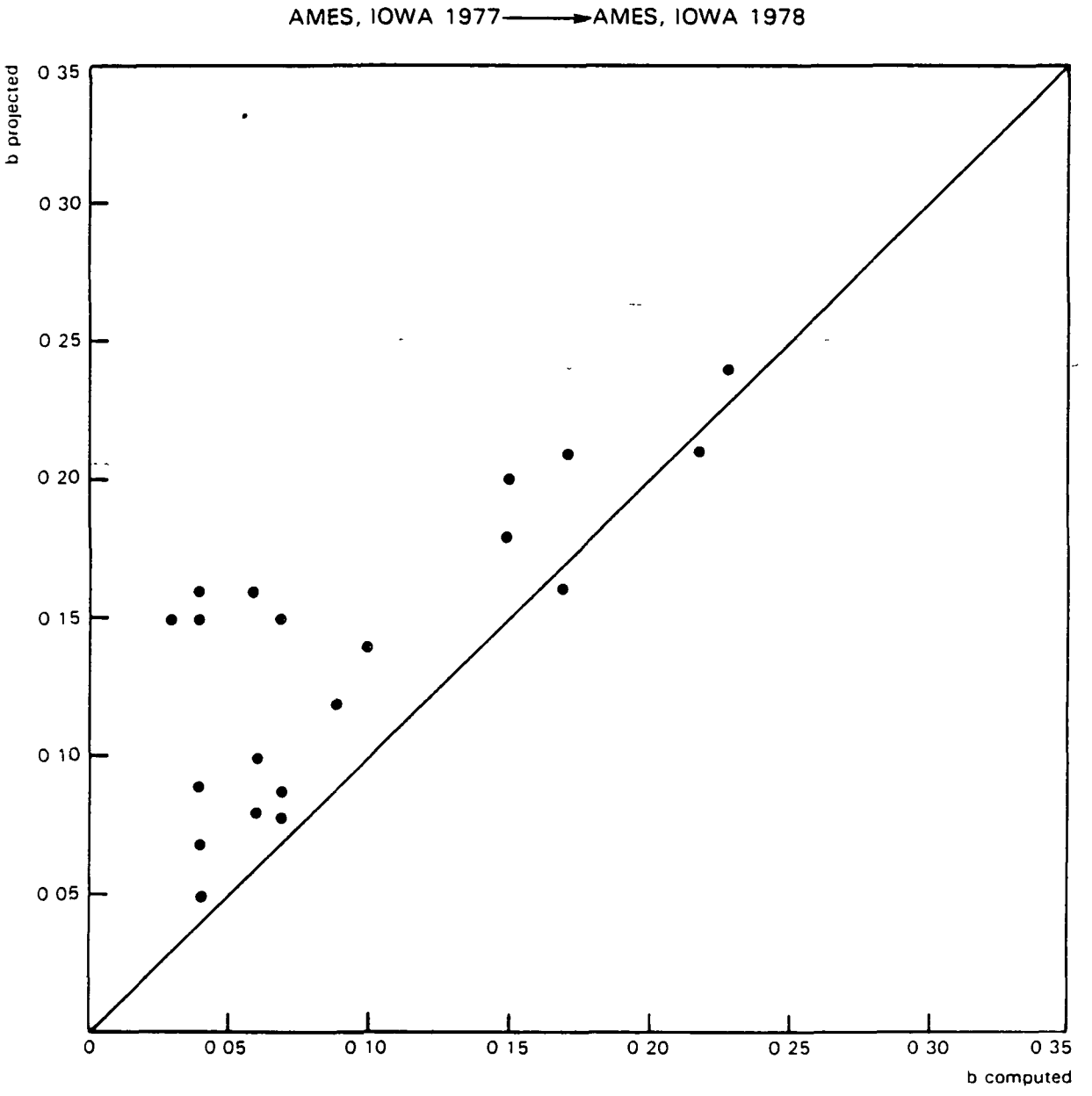

Figure 7 The projected power, $b_{projected}$, of the soil temperature recovery curve for Ames, Iowa in 1978 using the 1979 Tifton, Ga , data set and the 1977 Ames, Iowa data set Line of slope 1 indicates $b_{computed} = b_{projected}$ and the 1977 Ames, Iowa data set for the same months

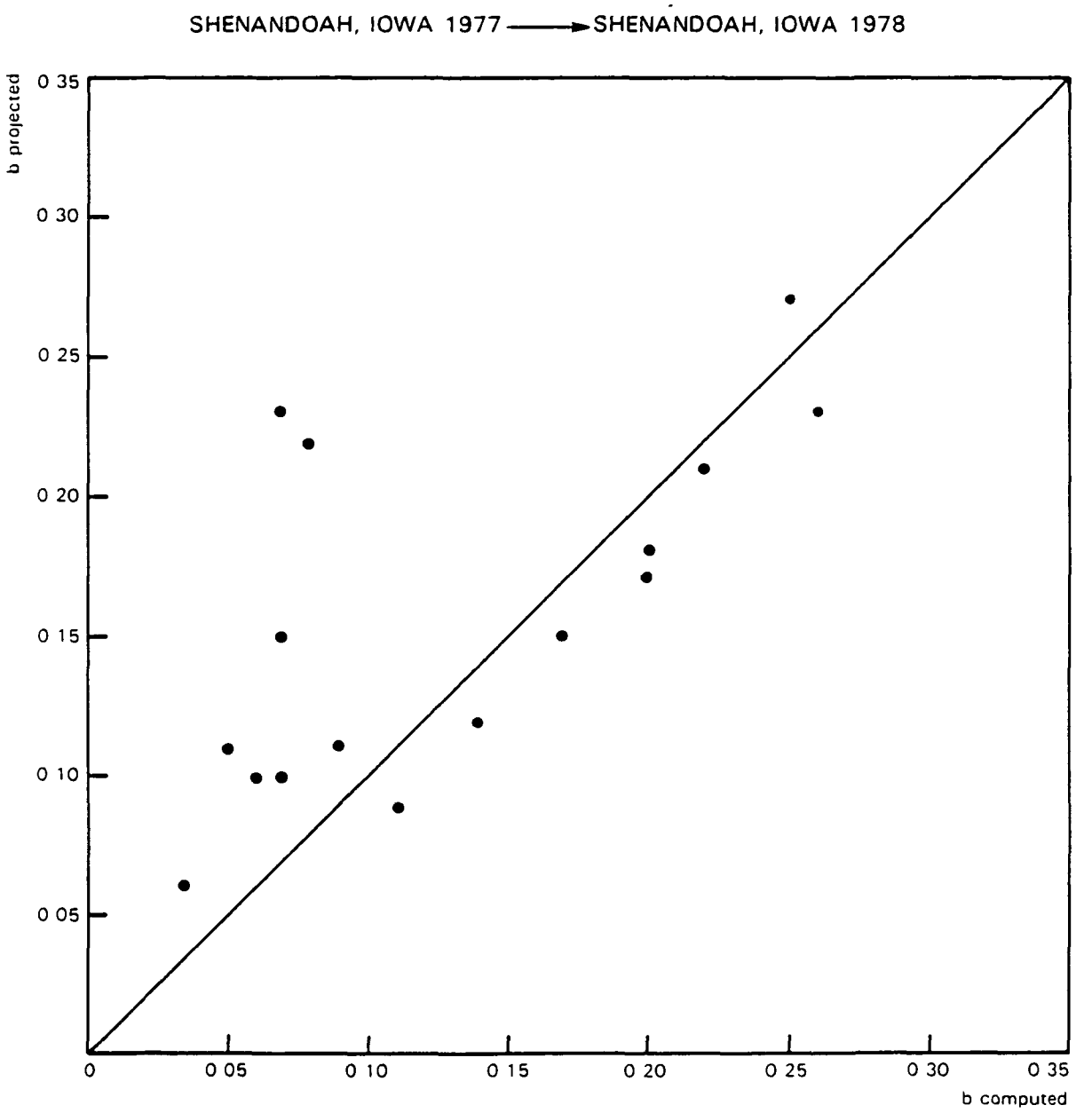

Figure 8 The projected power, $b_{projected}$, of the soil temperature recovery curve for Shenandoah, Iowa in 1978 using the 1979 Tifton, Ga data set and the 1977 Shenandoah, Iowa data set Line of slope 1 indicates $b_{computed} = b_{projected}$ and the 1977 Shenandoah, Iowa data set for the same months

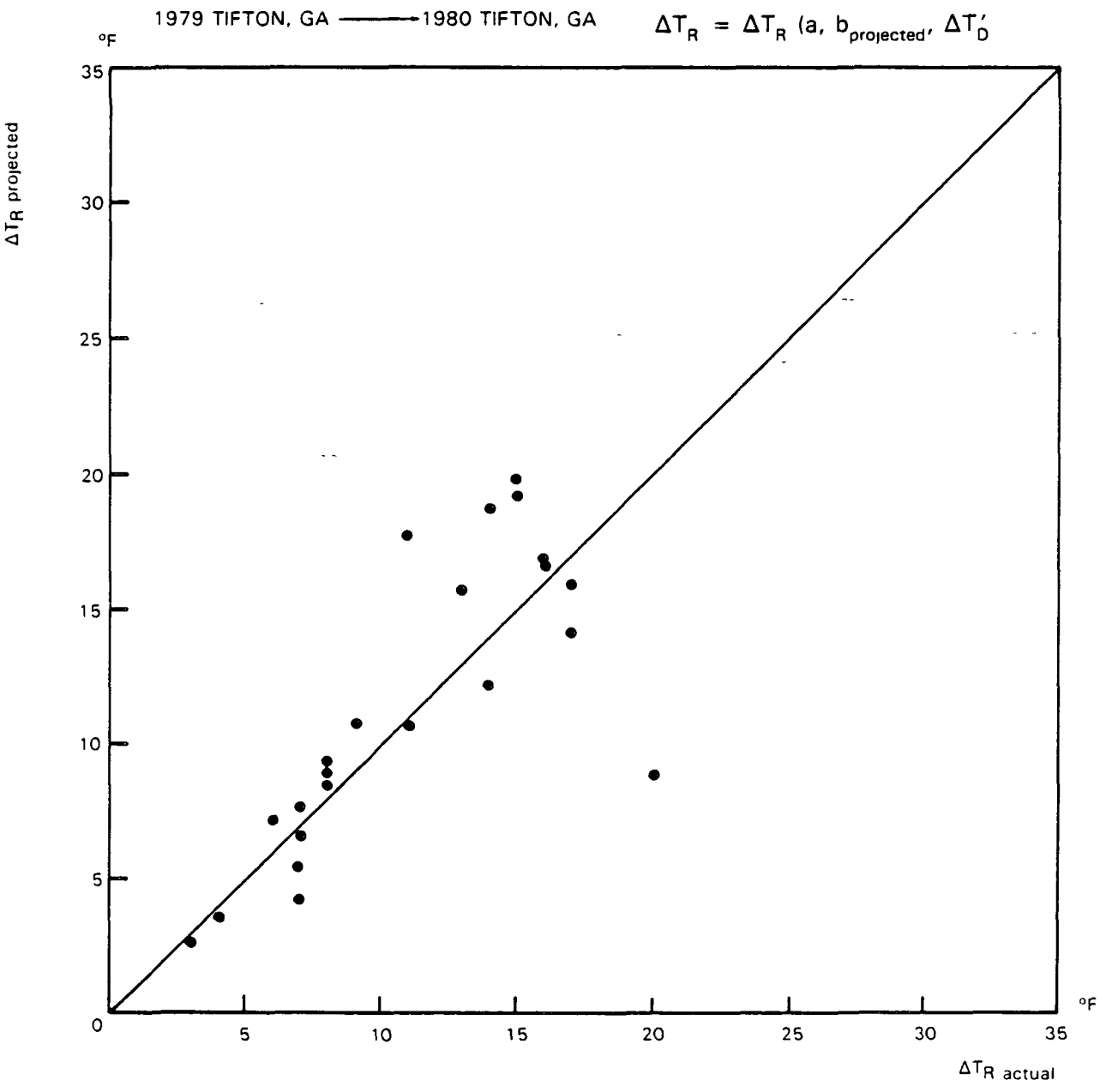

Figure 9 The projected total monotonically increasing temperature rise, $\Delta T_{R\ projected}$, of the Soil Temperature Recovery Curve for Tifton, Ga. in 1980 compared to the actual raw data values of ΔT_R for the same station for that year The $\Delta T_{R\ projected}$ values were obtained from a multivariate linear regression model of three variables, $\Delta T'_D$, a, and $b_{projected}$, which was established using the 1979 Tifton, Ga data set from March through July

BIBLIOGRAPHIC DATA SHEET

1 Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM 86163		

4. Title and Subtitle	5. Report Date
Soil Temperature Extrema Recovery Rates After Precipitation Cooling	October 1984
	6. Performing Organization Code 621

7. Author(s)	8. Performing Organization Report No.
Jean E. Welker	

9. Performing Organization Name and Address	10. Work Unit No.
Goddard Space Flight Center Greenbelt, Maryland 20771	11. Contract or Grant No.
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Technical Memorandum
National Aeronautics and Space Administration Washington, DC 20546	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

From a one dimensional view of temperature alone variations at the earth's surface manifest themselves in two cyclic patterns of diurnal and annual periods, due principally to the effects of diurnal and seasonal changes in solar heating as well as gains and losses of available moisture. Beside these two well known cyclic patterns, a third cycle has been identified which occurs in values of diurnal maxima and minima soil temperature extrema at 10cm depth usually over a mesoscale period of roughly 3 to 14 days. This mesoscale period cycle starts with precipitation cooling of soil and is followed by a power curve temperature recovery. The temperature recovery clearly depends on solar heating of the soil with an increased soil moisture content from precipitation combined with evaporation cooling at soil temperatures lowered by precipitation cooling, but is quite regular and universal for vastly different geographical locations, and soil types and structures. The regularity of the pwer curve recovery allows a predictive model approach over the recovery period. Multivariable linear regression models allow predictions of both the power of the temperature recovery curve as well as the total temperature recovery amplitude of the mesoscale temperature recovery, from data available one day after the temperature recovery begins.

17 Key Words (Selected by Author(s))	18 Distribution Statement
Soil temperature models, Precipitations, cooling models, predictive Micro-clamatic model.	

19 Security Classif (of this report)	20 Security Classif (of this page)	21 No of Pages	22 Price*

*For sale by the National Technical Information Service Springfield, Virginia 22151