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THE EFFECT OF SUMMER THUNDERSTORMS ON THE NEAR-GROUND TEMPERATURE REGIMEN WITHIN A SUBURBAN FOREST

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ABSTRACT

Recording three-point thermographs were used to gather time-series data on a 24-hour basis on the near-ground temperature regimen in a suburban deciduous forest and in a storm-created opening within the forest. Preliminary analysis of the data revealed a definite and well-defined near-ground temperature pattern occurring during intense summer thunderstorms. The preliminary analysis further suggested that differences in temperature between the daily maximum temperature and the post-storm re-stabilization temperature might be meaningful indicators of environmental differences between the two experimental areas and between the above-ground heights within each area. Detailed analysis of such difference values suggested considerable variation in individual storm influence on near-ground temperature patterns, and further suggested that we could differentiate on a thermal basis between the storm-created opening and the shaded areas, as well as between different near-ground heights (25 and 75 cm). Possible consequences of these differences for the extant biological community are discussed.

INTRODUCTION

In the course of evaluating time-series data on the micro climatic regime of a small (375 m^2), naturally-created opening within a mature suburban deciduous forest, our attention became focused upon the magnitude and pattern of near-ground temperature variation during the course of summer thunderstorms. Our comprehensive review of the ecological, meterological, and micrometerological literature revealed a void of information on micrometerological parameters during thunderstorm activity within the area of the Eastern Deciduous Forest of the United States. Since our data consisted of continuously recorded temperature variations at various levels (as well as ground-level solar radiation) under the canopy and within a clearing of a mature Piedmont forest, we decided to subject the temperature data to a detailed analysis for type and magnitude of changes which occur during summer thunderstorm activity.

The Atlanta, Georgia, metropolitan area—and the southeastern Piedmont in general—is an area in which the summer weather pattern is characterized by locally intense mid-afternoon thunderstorms of relatively short duration (generally < 1 hour). Our observations of the pattern of these storms revealed that they typically induce a variation in local air temperature similar to the pattern depicted in Fig. 1. In general, a gradual rise occurs in air temperature toward a daily maximum which is reached sometime after solar noon (stage 1, Fig. 1). Immediately prior to the onset of precipitation a slight but rapid increase occurs (seldom as much as 5°C) in air temperature (stage 2, Fig. 1)—a "pre-storm temperature peak." With the onset of precipitation and the consequent atmospheric cooling there is a rapid, ofttimes precipitous drop in ambient air temperature (stage 3, Fig. 1). As the storm passes, air temperature will reach a post-storm minimum (stage 4, Fig. 1) and will re-equilibrate to a relatively stable level slightly higher than the post-storm trough but several degrees cooler than the daily maximum prior to the thunderstorm's onset (stage 5, Fig. 1). Since each major summer thunderstorm followed this general pat-

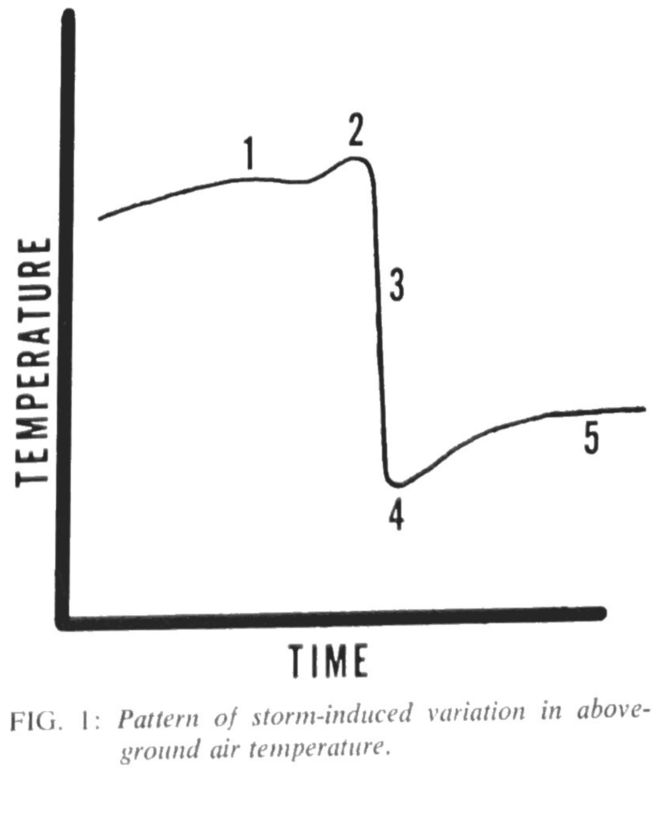

FIG. 1: *Pattern of storm-induced variation in above-ground air temperature.*

tern with differences only in magnitude, the various stages or phases provided easily manageable data comparison categories.

METHODS

Study Area

The study area, located in metropolitan Atlanta, Georgia (33° 46' N, 85° 19' W), is a suburban DeKalb County woodland known locally as Fernbank Forest. The forest has been described previously (Skeen, 1974) as a relatively mature hardwood forest, dominated by tulip poplar *(Liriodendron tulipifera)*, white oak *(Quercus alba)*, hickory *(Carya* spp.), American beech *(Fagus grandifolia)*, and northern red oak *(Quercus rubra)* and interspersed with many old post-mature pines *(Pinus taeda* and *Pinus echinata)*. Wind and storm damage have been locally severe in certain parts of the forest leading to opening of the canopy and subsequent pine regeneration. The particular study site utilized in the present study was situated within and adjacent to the largest of these storm-created openings. The rectangular clearing lay 30 m inside the eastern boundary of the woodland and was approximately 25 m in east-west dimension with a north-south width of 15 m. A predominantly deciduous upper canopy (25-30 m above the forest floor) bordered the clearing. The younger more westerly portion of the clearing in which our open area measurements were concentrated was dominated by loblolly pine saplings grading to 1.5 m in height. The clearing and adjacent canopy-dominated lands lay at an elevation of approximately 340 m and had a 5% southwesterly-facing slope.

Data Collection and Experimental Design

Near-ground temperature data were continuously monitored and recorded on a 24-hour basis by means of two three-point recording thermographs (Weathermeasure Model T602-S-32), one with sensors located within the clearing and the other with sensors located beneath the canopied portion of the forest. The recording bodies of both instruments were housed in a single standard U.S. Weather Bureau "cotton region type" instrument shelter (Weathermeasure ISI-MRD) 48 in (122 cm) above ground level. All sensors of both instruments were calibrated at 0°C using an ice slurry. Open area sensors were shaded from direct solar radiation by white cardboard shields. In both opening and canopied areas, sensors were mounted at three levels: (1) between 75 and 80 cm above the forest floor, (2) between 25 and 30 cm above the forest floor, and (3) immediately beneath the litter layer in the upper 5 cm of mineral soil.

Criteria Utilized in Selecting Thunderstorms for Evaluation

To be considered for intensive analysis, thunderstorms were required to conform to several criteria: (1) They had to occur long enough after solar noon that a daily maximum temperature prior to the storm's onset could be established. (2) They had to occur sufficiently before day's end and be of short enough duration that the re-equilibration/restabilization phenomenon would not be masked by the normal atmospheric cooling of nightfall. (3) They had to be of sufficient intensity to produce the characteristic well-defined temperature depression normally associated with intense thunderstorms and/or frontal system movement. Nine storms occurred between June 1 and August 29, 1974, which satisfied these criteria. Consequently, discrete temperature data were available for each of four well-delineated phases (daily maximum temperature, pre-storm peak temperature, post-storm trough temperature, and re-stabilization temperature) at three levels (within the mineral soil, 25 cm, and 75 cm) within the two contrasting areas (open vs. canopied) of our suburban forest ecosystem.

Study Objectives

Our overall study objectives centered on answering such questions as: (1) Do measurable temperature variations occur at close interval (50 cm) near-ground levels (25 cm, 75 cm) during intense summer thunderstorms? (2) If such differences do occur between such close intervals, do they in fact differ between shaded and open portions of the forest? (3) If detectable temperature variations do occur near the ground during thunderstorms, might they have any ecological significance for the extant biological community?

RESULTS

Difference values between the respective data categories previously enumerated (e.g., daily maximum temperatures, pre-storm peak temperatures, etc.) were established as the dependent variables in order to account for storms occurring on days with widely differing ambient temperatures. Consequently, difference values were determined (1) between the daily temperature maximum and pre-storm temperature peak, (2) between the pre-storm temperature peak and the post-storm trough or minimum temperature and (3) between the daily maximum temperature and the re-stabilization temperature following passage of the storm. We subjected these difference values to preliminary statistical analyses (Student's t-test) to ascertain (1) if statistically significant differences occurred in difference values between discrete parameter measurements obtained from the two above-ground heights, and (2) if statistically significant differences existed for difference values between discrete parameter measurements obtained from the canopied part of the forest versus the relatively open study area. Paired t-tests, applied to the appropriate data classes, revealed the relationships summarized in Table I. Table I depicts our ability to differentiate with some statistical certainty the near-ground temperature differences between daily maximum temperature and pre-storm peak temperature between both above-ground heights and between the two experimental areas. However, we decided to focus our detailed analysis on the statistically more significant and ecologically more meaningful difference between the daily maximum temperature and post-storm re-stabilization temperature. A randomized block factorial analysis of variance (ANOVA) was performed on the daily maximum to re-stabilization difference values from the nine storms, considering both above-ground levels (25 and 75 cm) and the two experimental areas (open vs. canopied). Partitioning of the variation by the ANOVA suggested the following: (1) Difference values obtained from individual storms differed considerably ($P<0.01$) from one another—i.e., considerable variability was encountered in storm influence—probably reflective of differences in storm intensity—on the near-ground temperature regimen ($F = 27.68$, $df = 8$). (2) Daily maximum to re-stabilization differences differed greatly ($P<0.01$) between the experimental areas (open vs. canopied) ($F = 53.07$, $df = 1$) and were also greatly different ($P<0.01$) between the two above-ground heights (25 and 75 cm) ($F = 8.23$, $df = 1$). (3) There was no significant interaction between the two above-ground heights and the two experimental areas ($F = 0.44$, $df = 1$). Mean differences (and dispersion from the mean) between mean maximum and mean re-stabilization temperatures for both above-ground and below-ground levels in both open and shaded areas are depicted in Fig. 2. Daily maximum to post-storm re-stabilization temperature differences in the open area averaged 10.67 ± 1.94, 10.11 ± 2.62, and 3.67 ± 1.00 for the 75 cm, 25 cm, and -2.5 cm levels respectively. Corresponding values in the canopied area were 9.00 ± 2:00, 8.11 ± 1.69, and 1.44 ± 0.53. While Fig. 2 stresses the relationships between the levels, Fig. 3 more clearly depicts the relationships between the two areas at which temperatures were measured. It can be noted from Fig. 3 that the mean difference between daily maximum and post-storm re-stabilization temperature is greatest (2.23) between the two areas at the below-ground level. This difference is less (2.00) between the two areas at 25 cm and least (1.67) at the 75 cm level.

TABLE 1: *Summary of preliminary analyses (paired t-tests) for three difference classes between two different heights and two different areas.*

	t values	
	25 vs. 75 cm level[1]	open vs. shaded area[2]
Difference between:		
Pre-storm peak temperature and post-storm minimum temperature	1.84 n.s.	3.04**
Daily maximum temperature and pre-storm peak temperature	2.56*	3.17**
Daily maximum temperature and post-storm re-stabilization temperature	3.20**	10.02***

[1] all analysis classes with 17 degrees of freedom
[2] all analysis classes with 27 degrees of freedom
* statistically significant at $P<0.05$ level
** statistically significant at $P<0.01$ level
*** statistically significant at $P<0.001$ level
n.s. not statistically significant

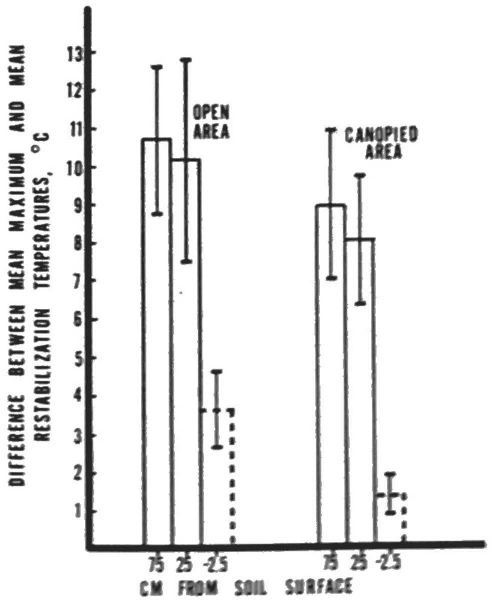

FIG. 2: *Mean differences between mean maximum and mean re-stabilization temperatures for three levels (two above-ground and one below-ground). (Vertical lines through bars denote ± 1 s.d.)*

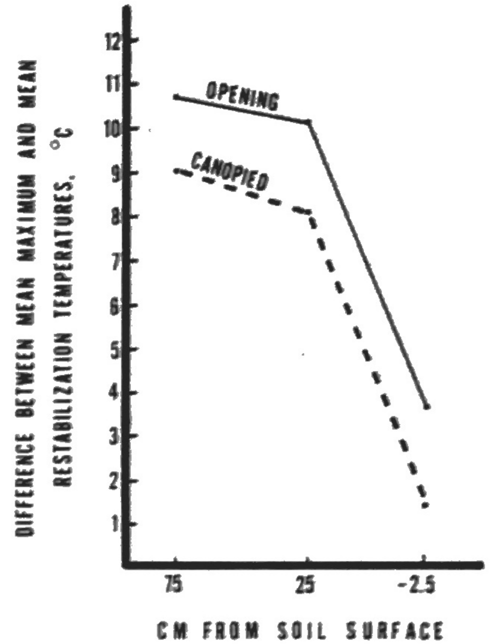

FIG. 3: *Mean differences between mean maximum and mean re-stabilization temperatures for opening vs. canopied sites.*

DISCUSSION

There have been few previous micro-scale studies in which multiple-level near-ground temperature measurements have been made and virtually no attempts to make short-term (<1 day) comparisons of these measurements. Cooper (1961) recorded daily maximum and minimum at 10 and 50 cm above-ground and at below-ground depths of 2 and 20 cm at several Michigan study sites. From the data obtained at 50 cm he determined weekly average air temperatures on north and south slopes and differences between these averages for a period from late March to mid-October. Comparisons of the 10 and 50 cm data were utilized to document the occurrence and magnitude of late spring temperature inversions. Soil temperature values were likewise used to determine weekly averages and differences between the 2 cm (A_1) and 20 cm (A_2) horizons. Getz (1961), also working in Michigan, obtained maximum and minimum temperatures on an alternate-day basis at 3 ft (91 cm) and 1 in (2.5 cm) above the soil surface and 1½ in (3.8 cm) beneath the surface in six different vegetational types including an oak-hickory forest. These data were used to compute average monthly minimum and maximum temperatures at the three levels in the six different communities. The monthly average temperature patterns were compared between forested and non-forested community-types. Sparkes and Buell (1955), working in and near a small oak-hickory forest on the New Jersey Piedmont, measured weekly maximum and minimum temperatures at 2 m, 20 cm, and 5 cm above-ground and at 4 cm below the soil surface in the forest and in a grassy opening and in a thicket of small trees and large shrubs within a 40 year abandoned field nearby. Their data suggested definite differences between the three above-ground levels but no systematic, detailed analysis was made to elicit the nature and pattern of the differences. Baum (1949), confronting the problem often encountered in agricultural, ecological, and micro-meteorological studies of attempting to utilize temperature data originally collected to meet the requirements of synoptic meteorology (and generally obtained at heights of 4-6 feet above-ground), made above-ground temperature measurements at heights of 6 ft (183 cm), 5 ft (152 cm), 6 in (15 cm) and 3 in (7.5 cm) and offered correction factors to be applied to readings obtained at 6 ft and 5 ft levels to convert them to near-ground (6 in and 3 in) values. Other workers (Oosting and Hess, 1956; Shanks and Norris, 1950) have made single-level, near-ground temperature measurements in micro-scale studies.

The problem in making rigorous comparisons between the current study and the near-ground temperature measurements made in these previous studies is mainly twofold: (1) In general, the literature values reported are relatively long-term (weekly or monthly) averages of maximum and/or minimum temperatures. (2) In no instance, to our knowledge, has there been any attempt to undertake a systematic, rigorous analysis of a body of data in a manner which might emphasize the pattern and magnitude of short-term temperature differences between different near-ground heights. Consequently, we can now turn our attention to the possible biological and environmental implications of our findings.

The effects of moderate, non-limiting (within the physiological tolerance limits) temperatures are well-documented in the biological literature, particularly the literature dealing with plant growth responses. Consequently, several generalizations may be made regarding temperature effects and influences. In general, moderate warming tends to speed up such basic processes as cell division and cell elongation, hormone synthesis, and the manufacture of chlorophyll and accessory photosynthetic pigments. Enzyme-mediated physiological reactions are likewise accelerated as well as such complex, integrated processes as photosynthesis, respiration, and transpiration. Conversely, moderate environmental cooling tends to slow such processes. The rates of all these processes are doubtless altered by temperature fluctuations of the magnitudes demonstrated to occur during thunderstorm activity (approximately 8-11 degrees C). However, since temperature fluctuations of similar or even greater magnitudes occur in normal diurnal cycles, the net effect upon the biological community of storm-induced cooling is a longer (2-4 hour) cool phase in the daily cycle with a consequent slowing of metabolic and physiologic processes. Such slowing is probably of little consequence, assuming that the storms are separated, as normally is the case, by several intervening days in which no storms occur to upset the thermal regimen and consequently lengthen the cool phase of the diurnal cycle. It is conceivable that several successive days with intense afternoon thunderstorms could appreciably alter the long-term (weekly or monthly) thermal pattern and consequently affect the community's patterns of growth and synthesis. Such an alteration seems unlikely, however, since it would require several successive days of intense afternoon thunderstorms and our data revealed only nine such storms in an entire summer. Rather than materially affecting the growth and synthesis patterns of the entire multi-stratal community, what seems more likely is that the seedlings and saplings inhabiting the near-ground levels would be most markedly affected. As might be expected, more seedlings and saplings inhabit the well-lighted open area and many of these individuals had their growing points in this 25-75 cm (above-ground) zone during the course of this study. Many of these individuals represent pioneer or colonizing species (e.g., loblolly pine, sweetgum, black cherry) which will likely not persist as major components of the eventual deciduous community. Consequently, alteration of the diurnal heat balance, as by afternoon thunderstorm activity, might conceivably affect the differential survival of certain species, particularly those which might be growing under conditions near their physiological limits. Obviously, a separate, well-defined and highly controlled study would be necessary to delineate any such short-term temperature effects. Studies of differential survival and mortality are currently underway; but at present, no attempt has been made to interrelate observed mortality and specific environmental effects.

Probably equal in consequence to the biological effects of storm-induced cooling are the effects noted in the purely physical environment. Our data suggest that a definite temperature effect gradient occurs with increasing distance from the soil surface. The high specific heat of soil and the effects of long-term (several hour) daily solar insolation is reflected in the mean difference noted between daily maximum and post-storm re-stabilization temperature (2.23 C) between the two below-ground levels. The decreasing effect of near-ground convection and increasing atmospheric mixing is noted at 25 cm (difference between open and closed areas = 2.00 C) and 75 cm (differences = 1.67 C).

Consequently the temperature regimen of ground-level residents, plant or animal, would be considerably mediated by proximity to the soil system while the above-ground environment is increasingly more variable, even at these near-ground levels, as the distance from the soil is increased. Whether these detectable differences in the near-ground physical environment are of sufficient magnitude to measurably affect or alter the extant biological community remains to be demonstrated by a separate series of well-defined and closely controlled studies.

ACKNOWLEDGMENTS

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The 28th annual Fisk Institute will be held on the campus of Vanderbilt University, Nashville, Tennessee, during the week of July 25-29, 1977. The three concurrent Fisk Institute courses are Interpretation of Infrared and Raman Spectra, Gas-Liquid Chromatography, and Pollution Control.

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ERDA ANNOUNCES PROCEEDINGS OF 2ND THERMAL ECOLOGY SYMPOSIUM

The Energy Research and Development Administration in Oak Ridge has announced the release of Thermal Ecology II, which includes manuscripts and proceedings of the 2nd annual meeting which was sponsored by Savannah River Ecology Laboratory, University of Georgia and ERDA.

The book is available as CONF-750425 for $11.00 from the National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia 22161.