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MODELING THE ATMOSPHERIC DYNAMICS WITHIN AND ABOVE VEGETATION LAYERS

W.E. Heilman and J.C. Zasada[1]

ABSTRACT.—A critical component of any silvicultural treatment is the creation of suitable microclimatic conditions for desired plant and animal species. One of the most useful tools for examining the microclimatic implications of different vegetation treatments is the use of atmospheric boundary-layer models that can simulate resulting micrometeorological conditions within and above vegetation layers. A two-dimensional atmospheric boundary-layer model has been successful in simulating the atmospheric environments within and above forest vegetation layers that have undergone different types of silvicultural treatments. Model simulations in conjunction with current observations reaffirm the importance of forest overstory vegetation in affecting the dynamic and thermodynamic properties of the atmosphere near the surface.

INTRODUCTION

Natural and human-caused disturbances are an integral part of ecosystem dynamics in the upper Great Lakes region. The scales at which disturbances occur vary from the level of seedlings to the landscape level. The responses of plant species to changing conditions brought on by natural and human-caused disturbances may be positive or negative depending on growth requirements for the individual plant species and the nature of the disturbances. Responses to disturbances will ultimately produce changes in primary productivity, abundance, structure, and composition of plant species.

Altered microclimate conditions resulting from natural and human-caused disturbances that add, remove, or modify existing vegetation may be more favorable for some plant species while increasing environmental stress for others. The vegetation characteristics and patterns that result from these disturbances in turn can further modify the near-surface dynamic and thermodynamic properties of the atmosphere. For example, early growing-season frost episodes in vegetation-managed areas of the upper Great Lakes region depend to a large degree on the types of vegetation management treatments that have been applied. Frost episodes are particularly important in red oak (*Quercus rubra*) regeneration in the upper Great Lakes region (McGee 1975, Crow 1992) because they can damage young red oak and associated species during bud break in the spring. Management treatments that specifically alter forest overstory conditions may be especially important in influencing the frequency and severity of early growing-season frost episodes.

A full understanding of the implications of forest management practices on forest microclimates requires an assessment of the relevant dynamic atmosphere-forest interactions that occur in managed areas. This study focuses on the dynamic behavior of the atmospheric boundary layer in response to different intensities of forest overstory cutting through both observations and numerical model simulations. An atmospheric boundary-layer research model that utilizes appropriate vegetation and turbulence parameterizations was used to examine how different forest overstory densities impact the dynamic turbulent and non-turbulent behavior within and above forest vegetation layers, and to provide more in-depth atmospheric information than what is possible from limited instrument measurements alone. Emphasis was placed on examining the dynamics of a specific frost episode and the evolution of the nocturnal boundary layer under different soil-moisture conditions at a study site on the Chequamegon National Forest near Park Falls, WI.

MODEL DESCRIPTION

Simulating the small-scale atmospheric dynamics within and above vegetation layers requires an atmospheric model that can resolve critical atmospheric-vegetation interactions, including both atmospheric turbulent and non-turbulent effects. Atmospheric models of this type are referred to as boundary-layer models. For this study,

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the two-dimensional boundary-layer model developed by Heilman and Takle (1991) is used; it incorporates vegetation parameterizations from the one-dimensional boundary-layer model developed by Heilman (1984). Previous applications of the model include simulations of nocturnal turbulence characteristics associated with small-scale drainage flows over sloping terrain (Heilman and Takle 1991) and the simulation of daytime upslope flows in response to surface heating (Heilman 1988).

Atmospheric Mean Variables

The non-turbulent atmospheric variables predicted by the level-3 model include horizontal and vertical wind components, temperature, specific humidity, and dew. The horizontal wind components are simulated by solving prognostic equations that account for wind-speed changes due to advection, changes in the atmospheric pressure gradients (including temperature effects), the Coriolis effect, vertical fluxes of momentum, and drag effects due to the presence of canopy elements. The vertical wind component is computed from the incompressible form of the atmospheric continuity equation. Temperature is predicted with a prognostic equation that includes advection effects, diffusion effects, and heating and cooling effects due to the flux of heat between vegetation elements and the air and between the ground and the air. Similarly, the specific humidity is predicted with a prognostic equation that accounts for advection and diffusion effects, as well as the transfer of moisture between vegetation elements and the air, and between the ground and the air. Nocturnal dew formation on vegetation is predicted with a prognostic equation that includes precipitation, transpiration, and evaporation effects.

Atmospheric Turbulence Variables

The turbulence portion of the level-3 model consists of four prognostic equations that are used to define the temporal evolution of turbulence in the atmospheric boundary layer. Turbulent kinetic energy (TKE), defined as the sum of the variances of the horizontal and vertical wind speed components, is predicted with a prognostic equation that includes the effects of advection, diffusion, buoyancy production or dissipation, production of turbulence due to airflow around canopy elements, and non-buoyant dissipation of turbulence. The non-buoyant dissipation of turbulence in the atmosphere is dependent on the characteristic sizes of turbulent eddies, with dissipation being much more prevalent at small eddy sizes. A prognostic equation for the characteristic length-scale of turbulent eddies at a particular location is included in the model. It takes into account the effects of advection, diffusion, enhancement of eddy sizes due to vertical wind shears, and the natural breakdown of turbulent eddies once they have formed. Finally, parameterizations of the numerous diffusion coefficients used in the model include both temperature variances and temperature/specific humidity covariances. In order to close the set of model equations, temperature variance and temperature/specific humidity covariance prognostic equations are included. Diagnostic equations are incorporated for simulating all other turbulent quantities, including the horizontal and vertical TKE components, and the horizontal and vertical turbulent fluxes of momentum, heat, and moisture. Within the numerous prognostic and diagnostic equations for the atmospheric turbulence variables are parameterizations that account for vegetation effects on turbulence generation.

Radiation and Soil Parameterizations

Radiation processes play an important role in the diurnal evolution of the atmospheric boundary layer. Upward and downward fluxes of longwave and shortwave radiation at the ground and at the top of vegetation layers contribute to the heating and cooling of the boundary layer. The force-restore method of Deardorff (1978) is applied in the model to calculate surface temperatures. This method calculates an energy balance at the ground based on longwave radiation flux contributions from vegetation, the ground, and atmospheric moisture, and on the solar shortwave radiation flux. Surface temperatures are predicted using net radiation, sensible heat flux, and latent heat flux values at the ground surface, along with deep-soil temperatures. The accurate predictive capabilities and relative simplicity of the force-restore method make it an attractive method for surface temperature prediction. Because soil moisture affects the energy balance at the surface through latent heat fluxes and altered radiation fluxes, the force-restore method also includes a prognostic equation for the soil volumetric moisture concentration. This equation includes evaporation, transpiration, precipitation, and deep-soil moisture effects.

STUDY SITE DESCRIPTION

In 1987, the USDA Forest Service, North Central Research Station in Rhinelander, WI and the Chequamegon, Nicolet, and Ottawa National Forests developed an Oak Administrative Study (OAS) to focus on improving the quality of northern red oak seedlings in nurseries and on monitoring the growth of red oak seedlings on selected research sites in northern Wisconsin. One particular research site established as part of the OAS was the Willow Springs Oak Regeneration Study site on the Park Falls District of the Chequamegon National Forest in May, 1989. This study site is situated on an 80 acre mixed hardwood region (Acer-Viola/Osmorhiza vegetative habitat type) with sandy loam soil that is moderately drained. The terrain is generally flat (0-5 percent slope). The study site was divided into four 20-acre plots. One plot was thinned to 75 percent of the original crown cover (canopy area index (CAI) = 3.9) and another plot was thinned to 50 percent of the original crown cover (CAI = 2.1). A third plot was clearcut (CAI = 0.0) while the final plot was left untouched to act as a control (CAI = 5.7). Overstory tree heights are approximately 20 m. The understory vegetation was treated in the logged plots using various combinations of disking and spraying with a herbicide. Following the understory treatments, 1-year-old bare-root and containerized red oak seedlings and pre-germinated acorns were planted in all the study plots in May, 1989. Since the time of seedling and acorn planting, the growth and survival of the red oak seedlings and other understory vegetation has been and continues to be monitored.

In order to better understand the impacts of the different silvicultural treatments on the micrometeorological environments within the study plots, a micrometeorological monitoring network was set up on three of the four study plots in 1994. A 10-m tower was installed and instrumented in the control, 50 percent overstory-reduced, and clearcut plots. Instruments were placed on the towers at heights of 2.5 m and 10 m to measure air temperature, relative humidity, wind speed, and wind direction. Thermocouples were mounted on stakes at three locations near each tower at heights of 2 m, 1 m, 0.5 m, and 0.25 m to obtain characteristic profiles of near-surface temperatures. Thermocouples were also placed at depths of 0.05 m, 0.1 m, 0.2 m, 0.5 m, and 1 m at the stake locations to obtain characteristic soil-temperature profiles. Photosynthetically active radiation (PAR) and net radiation sensors were placed near each tower to determine the radiation characteristics within the study plots. Scan times for the different sensors ranged from 10 seconds to 10 minutes, and average conditions were reported hourly to data loggers in each study plot.

Micrometeorological data from the sensors have been collected every day from 1 January 1994 to the present, with a few minor data gaps.

OBSERVATIONS AND SIMULATION RESULTS

The presence of overstory vegetation layers influences the atmospheric environments within and above these layers during both daytime and nocturnal periods. During the daytime, overstory vegetation layers reduce the amount of solar radiation reaching the surface, and alter the radiation and energy balances at the surface. The daytime evolution of surface temperatures depends to a large extent on these radiation and energy balances. The daytime heating of the atmospheric boundary layer, in turn, depends to a large extent on the upward flux of heat from the surface when surface temperatures exceed lower atmospheric temperatures. Vegetation elements also act as a source of moisture for the atmospheric boundary layer through transpiration processes. Moisture in the atmospheric boundary layer influences the longwave radiation fluxes and the evolution of both daytime and nocturnal temperatures. Examples of the effects of different overstory vegetation densities on nocturnal near-surface temperatures as measured at the Willow Springs study site are shown in figure 1. From about Day 150 (30 May 1994) till Day 290 (17 October 1994) when leaf-area densities in the overstory vegetation were significant, large nocturnal temperature differences were observed between the 50 percent overstory-reduced plot and the clearcut plot, and between the control plot and clearcut plot. Temperature difference maxima reached 5 °C for the 50 percent overstory-reduced plot vs. the clearcut plot, and exceeded 6 °C for the control plot vs. the clearcut plot on three occasions. The higher nocturnal

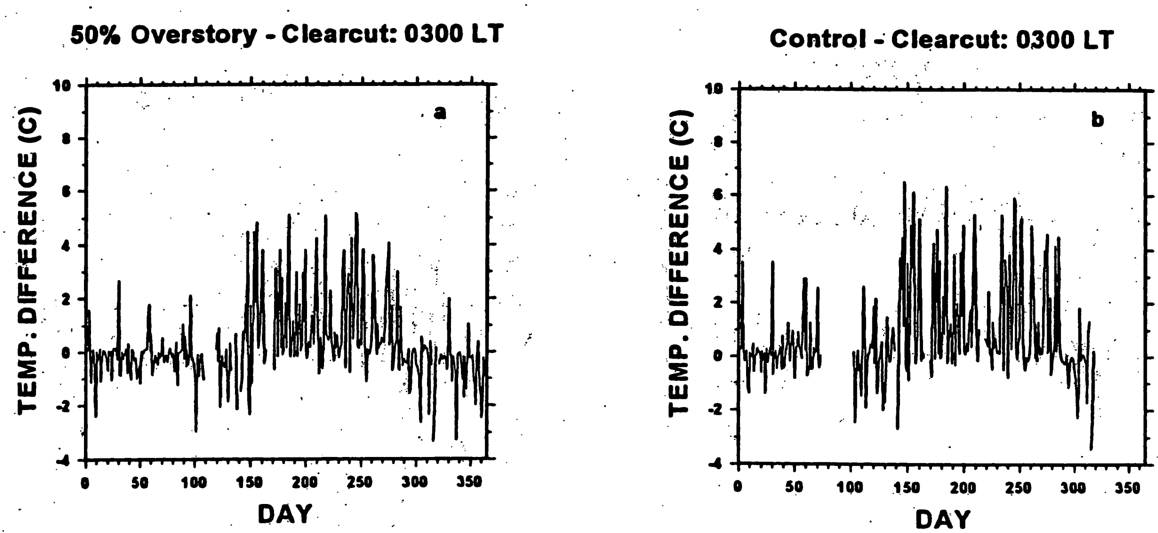

Figure 1.—*Temperature differences in 1994 at 0300 LT between (a) the 50 percent overstory-reduced plot and the clearcut plot, and between (b) the control plot and the clearcut plot at 0.5 m above the surface at the Willow Springs study site.*

temperatures observed in the 50 percent overstory-reduced and control plots on numerous nights during the Day 150-290 period are due to the increased downward flux of longwave radiation resulting from the overstory vegetation, the increased downward flux of longwave radiation resulting from enhanced atmospheric moisture contents within the vegetation layers, and from the thermal inertia provided by the overstory vegetation (Potter 1999). Observed temperature differences increased from the 2.5 m level to the 0.5 m level. The night-to-night fluctuations in temperature differences can be attributed to wind-speed changes and cloud-cover conditions over the Willow Springs study site. Temperature differences are reduced as wind speeds increase because the increased atmospheric turbulence due to horizontal and vertical wind shears acts to minimize any spatial gradients of temperature and moisture. The presence of periodic cloud cover and increased low-level moisture also reduces the amount of cooling at the surface through enhanced downward fluxes of longwave radiation over the entire study site.

Afternoon (1500 LT) temperature differences tended to be slightly larger in magnitude, with temperatures approaching 8 °C cooler on several occasions in the control plot as compared to the clearcut plot at a height of 0.5 m during the same period from Day 150-290. As with the nocturnal temperature differences, large day-to-day fluctuations were observed and can be attributed mainly to wind speed and cloud cover/low-level moisture variations.

Overstory vegetation also has a major impact on the vertical profiles of temperature within the vegetation layers, particularly at night when turbulent mixing due to wind shear is usually less than during the daytime. During calm and cloud-free conditions at night, surface temperatures decrease rapidly after sunset due to radiational cooling if no overstory vegetation is present. The cooling of the ground produces a nocturnal inversion layer above the surface where temperatures increase rapidly with height. Atmospheric turbulence within inversion layers is suppressed, thereby diminishing the turbulent transport of warmer air from higher levels downward to the surface. This reduced atmospheric mixing further enhances the cooling of the surface. If overstory vegetation is present, the inversion layers that develop within the vegetation layers in the late afternoon or early evening are much weaker than the inversion layers that exist in clearcut areas. Figure 2 shows the observed near-surface vertical temperature gradients in the Willow Springs clearcut and control plots in 1994. In the clearcut plot (fig. 2a), vertical temperature gradients in the 0.5 - 2.5 m layer above the surface often exceeded 1.2 °C m^{-1} between Day 150 and Day 290. Prior to this period in 1994, larger temperature-gradient magnitudes were observed as a result of snow cover. In the 50 percent overstory-reduced and control plots, near-surface temperature gradients were much less between Day 150 and Day 290, with the control plot having the smallest nocturnal temperature gradients (fig. 2b). The figures clearly show the impact that leaves from the overstory vegetation have on near-surface temperature gradients. A distinct transition occurred near Day 150, corresponding to the full emergence of leaves in the overstory vegetation in the spring. Night-to-night fluctuations in the near-surface temperature gradients due to wind speed variations and cloud cover/low-level moisture conditions were also observed to be much smaller in the 50 percent overstory-reduced and control plots as compared to the clearcut plot from Day 150 until Day 290.

The evolution of nocturnal inversion layers within and above forest overstory layers is an important atmospheric

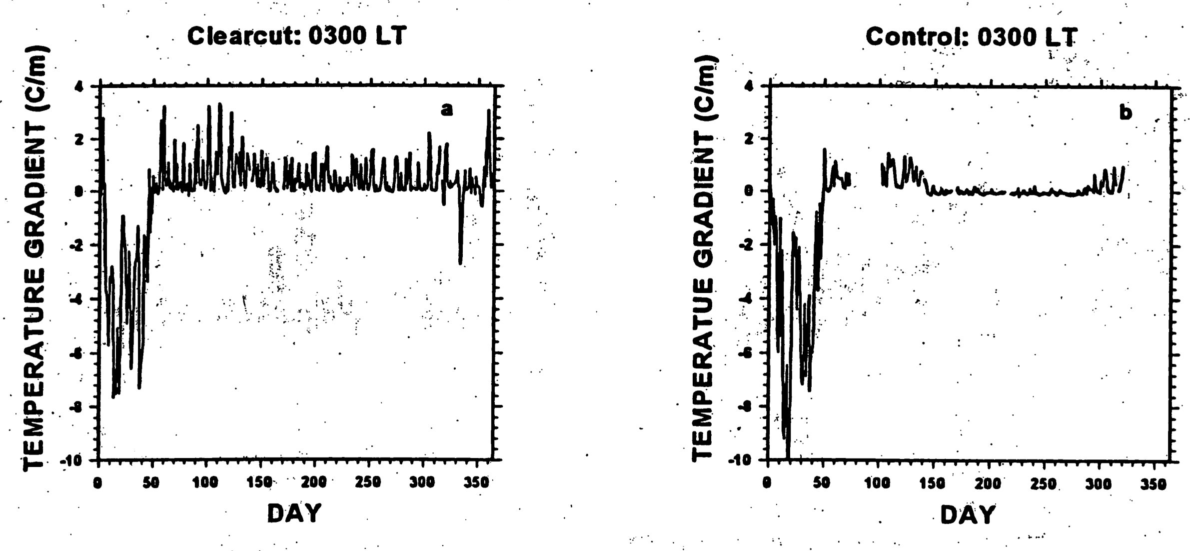

Figure 2.—*Near-surface vertical temperature gradients in 1994 at 0300 LT in (a) the clearcut plot, (b) the 50 percent overstory-reduced plot, and (c) the control plot at the Willow Springs study site.*

dynamic process that results from cooling of the surface and vegetation elements, and is strongly influenced by the overstory vegetation characteristics. A particular disturbance that depends to a large degree on the evolution of the nocturnal inversion layer is frost. Observations and model simulation results are presented for the night of 1-2 June 1994 (Day 152-153) when a significant frost episode under calm conditions occurred in the Willow Springs clearcut plot, but no frost was reported in the 50 percent overstory-reduced or control plots. Figure 3a shows the observed evolution of the near-surface temperatures (0.25 m above the surface) in the control, 50 percent overstory-reduced, and clearcut plots on this particular night. Temperatures in the clearcut plot decreased rapidly after 1800 CDT (Day 152.75) and dropped below 0 °C by 2100 CDT. However, near-surface temperatures in the 50 percent overstory-reduced and control plots decreased less rapidly after 1800 CDT and never dropped below 0 °C that night. Differences in radiational cooling of the surface after sunset in the different overstory treatment plots resulted in maximum temperature differences among the plots during the night. The stable inversion layers that developed over the study plots on this evening acted to suppress the turbulence within them and inhibited any mixing of warmer air from above into the inversion layers. This led to maximum temperature differences among the plots after sunset. After sunrise, the nocturnal inversion layer eroded from below due to surface heating which then increased near-surface turbulent mixing and reduced any temperature differences between the plots. Temperature differences between the plots decreased rapidly after sunrise and remained relatively small throughout the daytime hours of Day 153. The strength of the nocturnal inversion layers within the individual study plots is reflected in the near-surface vertical temperature gradients that developed during the evening and early-morning hours of Day 152-153 (fig. 3b). Large positive near-surface vertical temperature gradients in the clearcut plot during the nighttime hours of Day 152-153 suggest the presence of a strong inversion layer over the clearcut plot resulting from significant surface cooling in the absence of any overstory vegetation. Temperature gradients in the 50 percent overstory-reduced and control plots were much smaller in magnitude, with temperatures at 0.25 m observed to be slightly warmer than the 2 m temperatures in the control plot during the nighttime hours. Diminished surface radiational cooling in the non-clearcut plots resulted in very weak inversion layers underneath the forest overstories. Although this suggests a stronger tendency for more vertical turbulent mixing of heat from above under less stable conditions, turbulence within the vegetation layers was minimal on this night due to very low-wind speeds and enhanced turbulence dissipation associated with the forced small turbulent eddy sizes within the vegetation layers.

Simulated temperature and TKE profiles corresponding to 0200 CDT on 2 June 1994 (Day 153) are shown in figure 4. At that time, the temperature gradient over the lowest 10 m in the clearcut plot was approximately 0.7 °C m^{-1}, in contrast to the 50 percent overstory-reduced and control plots where average temperature gradients were between 0.1 °C m^{-1} and 0.2 °C m^{-1} (fig. 4a). These characteristic temperature profiles were associated with simulated nighttime net radiation flux values (not shown) at the surface that ranged from about -70 W m^2 in the clearcut plot to about -40 W m^2 in the 50 percent overstory-reduced plot and -25 W m^2 in the control plot. These upward fluxes of net radiation were at a maximum

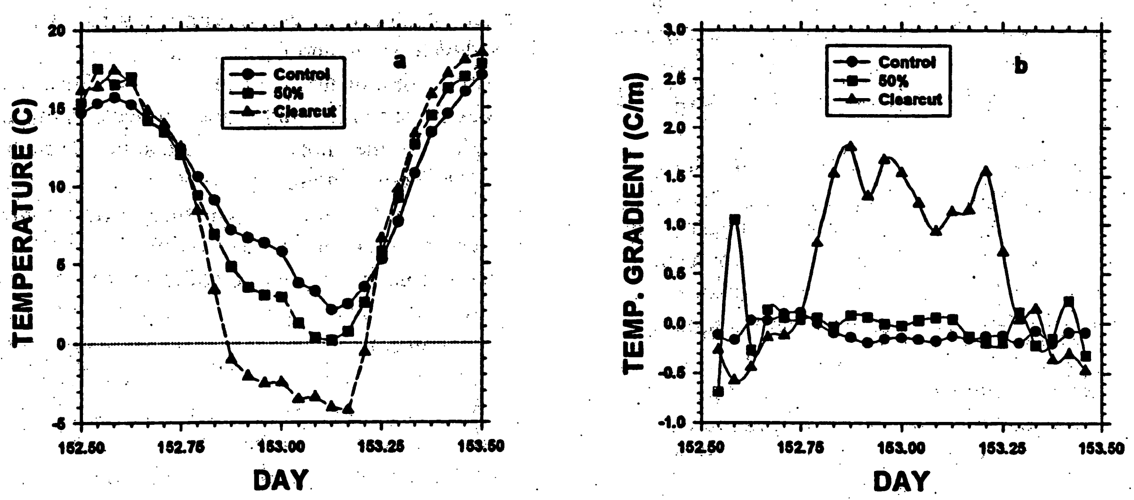

Figure 3.—*Near-surface (0.25 m) temperature evolution (a) and near-surface (2 m - 0.25 m layer) vertical temperature gradient evolution (b) in the control, 50 percent overstory-reduced, and clearcut plots from 1200 CDT on 1 June 1994 (Day 152.5) to 1200 CDT on 2 June 1994 (Day 153.5) at the Willow Springs study site.*

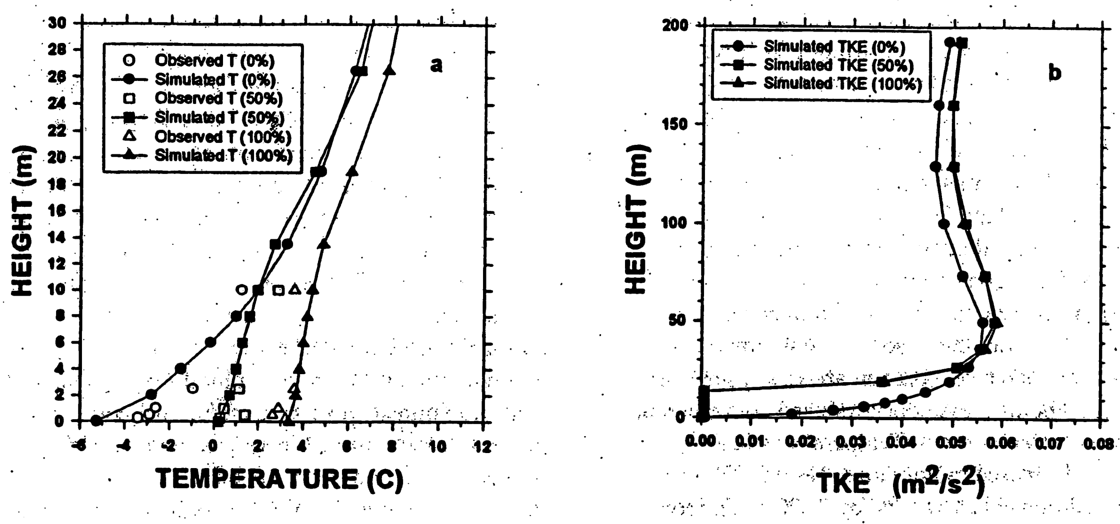

Figure 4.—*Simulated and observed profiles of (a) temperature and simulated profiles of (b) turbulent kinetic energy at 0200 CDT on 2 June 1994 (Day 153) in the clearcut (0 percent), 50 percent overstory-reduced (50 percent), and control (100 percent) plots at the Willow Springs study site.*

shortly after sunset in the simulations over all the treatment plots, and the flux slowly decreased throughout the nighttime hours. However, the decrease in the upward flux of net radiation was more significant in the clearcut plot because surface temperatures decreased more rapidly there, which reduced the upward flux of longwave radiation over time. The model simulations revealed that the presence of forest overstory vegetation in the other plots enhanced the downward flux of longwave radiation and reduced the nocturnal surface net radiation change throughout the night. Larger atmospheric moisture contents within the vegetation layers also contributed to the reduced net upward flux of radiation at the surface during the nighttime hours.

The simulated turbulence structures within the nocturnal inversion layers present over each of the plots are shown in figure 4b. The simulations indicate very low TKE values over each treatment plot compared to typical TKE values during daytime hours. This is a result of the inherent atmospheric stability and large dissipation of turbulence within the inversion layers, along with the lack of any significant turbulence generation from wind shears. Within the vegetation layers in the 50 percent overstory-reduced and control plots, TKE values are further diminished because turbulence dissipation is more significant within the vegetation layers where turbulent eddies are limited in size by the presence of canopy elements and their proximity to the ground. Maximum simulated TKE values appear near 50 m above the surface over all treatment plots.

The impact of overstory density on nocturnal vertical heat-flux profiles was also examined in the model simulations. In the clearcut plot, maximum downward fluxes of sensible heat occurred at the surface, although these fluxes were small compared to typical daytime upward fluxes of heat because of the strong stability within the nocturnal inversion layer above the clearcut plot. In the 50 percent overstory-reduced and control plots, simulated maximum downward fluxes of sensible heat occurred just above the overstory tops. This simulated behavior of heat flux was due in part to the temperature profile behavior in the different plots (see fig. 4a), with the largest lapse rate occurring just above the surface in the clearcut plot. Also contributing to the simulated smaller downward heat fluxes in the plots containing overstory vegetation is the reduced turbulence underneath the overstory vegetation (see fig. 4b).

Surface moisture conditions also influence the atmospheric dynamics associated with nocturnal inversion-layer development and frost occurrence over vegetated surfaces. Soil moisture present at or near the surface reduces the amount of nighttime surface cooling and contributes to the moistening of the atmospheric boundary layer. Model simulations were carried out to examine the sensitivity of nocturnal near-surface temperature profiles and turbulence values to different soil moisture concentrations in the presence of different forest overstory densities. The simulations reveal that nocturnal surface temperatures in clearcut areas are typically 8 °C colder if soil conditions are dry as opposed to saturated, assuming calm and clear conditions prevail. This suggests an increased probability of frost occurrence in clearcut areas with typically dry soil conditions. The presence of overstory vegetation reduces the amount of surface cooling regardless of the soil-moisture contents, but the reduction in surface cooling is more significant when soil-moisture contents are less than 33 percent saturation. As soils become wetter, the impact of increasing forest overstory densities on nocturnal surface temperatures is minimized. The simulations also reveal that weaker nocturnal inversion layers develop over areas with wetter soil. Weaker inversion layers imply less stability within them and the potential for larger TKE. Model simulations of nocturnal TKE sensitivity to soil-moisture conditions under different forest overstory densities showed that near-surface TKE values tended to be about 15 percent higher in clearcut areas under saturated soil conditions as opposed to dry soil conditions. When overstory vegetation was present, increasing soil moisture had little impact on TKE values within the overstory vegetation layer. However, above the top of the overstory vegetation, TKE values were again about 15 percent larger when the soil was saturated as opposed to dry soil conditions.

CONCLUSIONS

Observations and modeling results from this study indicate that management practices which modify overstory vegetation can alter near-surface microclimatic conditions. In particular, the evolution of nocturnal temperatures and the potential for early growing-season frost episodes are dependent on overstory vegetation densities. Large nocturnal surface temperature differences can arise between clearcut areas and areas with overstory vegetation present. Overstory vegetation contributes to the downward flux of longwave radiation at night and reduces the amount of ground-surface radiative cooling. Nocturnal inversion layers that develop within and above overstory vegetation layers are typically much weaker than the inversion layers that develop over clearcut areas. Atmospheric turbulence and associated turbulent fluxes of heat and moisture within these inversion layers also reflect the presence or absence of any forest overstory vegetation. Soil-moisture variations in clearcut and non-clearcut areas also play a role in modifying the evolution of nocturnal inversion layers. Wet soils tend to increase near-surface nocturnal turbulence values in clearcut areas and above canopy tops in non-clearcut areas. The increased turbulence values are a result of smaller vertical temperature gradients within the nocturnal inversion layers when soils are wet, thereby enhancing the amount of vertical mixing of heat and moisture.

Atmospheric boundary-layer models are useful tools for examining the effects of different forest management practices on forest microclimates. Although boundary-layer models are typically not used operationally, they can provide researchers valuable insight into the dynamic behavior of the atmosphere within and above vegetation layers. Modeling results from this particular study can also be used by forest managers in their development of silvicultural treatments that produce microclimates most suitable for enhancing the regeneration of microclimate-sensitive tree species in the upper Great Lakes region.

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LITERATURE CITED

Crow, T.R. 1992. Population dynamics and growth patterns for a cohort of northern red oak (*Quercus rubra*) seedlings. *Oecologia* 9:192-200.

Deardorff, J.W. 1978. Efficient prediction of ground surface temperatures and moisture with inclusion of a layer of vegetation. *Journal of Geophysical Research* 83:1889-1904.

Heilman, W.E. 1984. A one-dimensional numerical simulation of the boundary-layer features over a uniformly vegetated sloping surface. M.S. Thesis, Iowa State University, Ames, IA.

Heilman, W.E. 1988. Two-dimensional numerical simulations of the turbulence characteristics over Rattlesnake Mountain during stable and unstable conditions. Ph.D. Dissertation, Iowa State University, Ames, IA.

Heilman, W.E., and E.S. Takle. 1991. Numerical simulation of the nocturnal turbulence characteristics over Rattlesnake Mountain. *Journal of Applied Meteorology* 30:1106-1116.

McGee, C.E. 1975. Change in forest canopy affects phenology and development of northern red oak and scarlet oak seedlings. *Forest Science* 21:175-179.

Potter, B.E. 1999. Passive frost-risk reduction for forest management. In *Symposium on systems analysis in forest resources,* 1997 May 28-31, eds. J. Michael Vasievich, Jeremy Fried, and Larry Leefers, 236-240. General Technical Report NC-205. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station.

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KEY WORDS: Simulation, optimization, modeling, spatial analysis, heuristics, systems analysis.