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Have New England Heat Waves Been Influenced by Forest Cover Trends?

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1. INTRODUCTION

In the late 1700s, as the population of southern New England began to grow, large numbers of trees were cut down for building, heating and cooking, and to provide room for agriculture and livestock grazing. Figure 1, taken from Hall et al. (2002) shows the overall trend in forest cover over the last 200 years in Massachusetts. By 1880, forest cover had dropped to less than 50% of what it had been in the middle 1700s. Beginning in the early 1900s, as reliance on wood diminished, forest cover began to recover, reaching early 1700s levels by 1980.

Grasslands have a very different surface energy balance compared to forests, which would suggest that heat waves might be measurably affected by the presence or absence of forest cover. For instance, the summertime albedo of grassland is larger than that of forest cover, while the summertime surface roughness length is smaller, and the moisture availability is much lower. The larger albedo would reflect more energy away from the surface, leading to cooler temperatures, but the larger roughness length would lead to larger surface sensible and latent heat fluxes, and thus warmer surface air temperatures. The fluxes are also affected by the vertical temperature gradient, which could be smaller given the larger surface albedo for grasslands. In addition, the surface fluxes will vary with the surface wind speed, which can be affected by the size of the daytime convective mixed layer, which in turn is affected by the surface fluxes. Evapotranspiration also can vary greatly between forest and field. Hence, there are many non-linear forcing mechanisms at work.

Some recent observational data has suggested that forested areas are cooler than grasslands. Juang, et al. (2007) studied data from three different ecosystems, and found that the forested areas were cooler in all three.

To determine how these forcing mechanisms interact, we have performed a series of exploratory model simulations, using the Fifth Generation National Center for Atmospheric Research/Pennsylvania State University Mesoscale Model (MM5).

2. METHODOLOGY

The MM5 was run with three nested domains, with the innermost shown in Fig. 2. The outermost domain had a 36 km grid spacing. The first nest used 12 km grid spacing, and the innermost domain 4 km grid spacing. There were 33 levels in the vertical, with 12 below 850 hPa. Two-way interaction was allowed between all nests, and the MRF boundary layer (Hong and Pan, 1996), and Grell (1993) convective parameterizations were used, although no convective scheme was used in the innermost domain.

We began with three pairs of runs. One member of each pair used the current forest cover and the other member of the pair ran without the presence of forests in Massachusetts and southern New Hampshire. The simulations were initialized at 0000 UTC, with initial and boundary weather conditions taken from the Global Forecast System analysis grib files for three days (May 25, 2007, August 3, 2007, and June 9, 2008) each of which were characterized by afternoon temperatures above 33°C (91°F) throughout much of Massachusetts and southern New Hampshire. Each of these days were part of a multi-day period of high temperatures of at least 32°C (90°F or more), with the June case the longest at four days. The highs for each day in the warm periods are shown in Table 1 below.

MONTH	DAY	HIGH (°F)
May 2007	24	90
	25	93
August 2007	2	92
	3	94
June 2008	7	93
	8	92
	9	94
	10	97

Table 1. High temperatures for the three periods which were simulated.

The land use characteristics were changed from the present forest cover (deciduous broadleaf forest) to grassland, and the simulations were run for 24 hours. These runs were considered the extreme changes, since every bit of forest cover was removed. The key changes in the land use were:

1. albedo changes from 16% to 19%
2. summer surface roughness length changes from 50 cm to 12 cm
3. soil moisture availability changes from 30% to 15%

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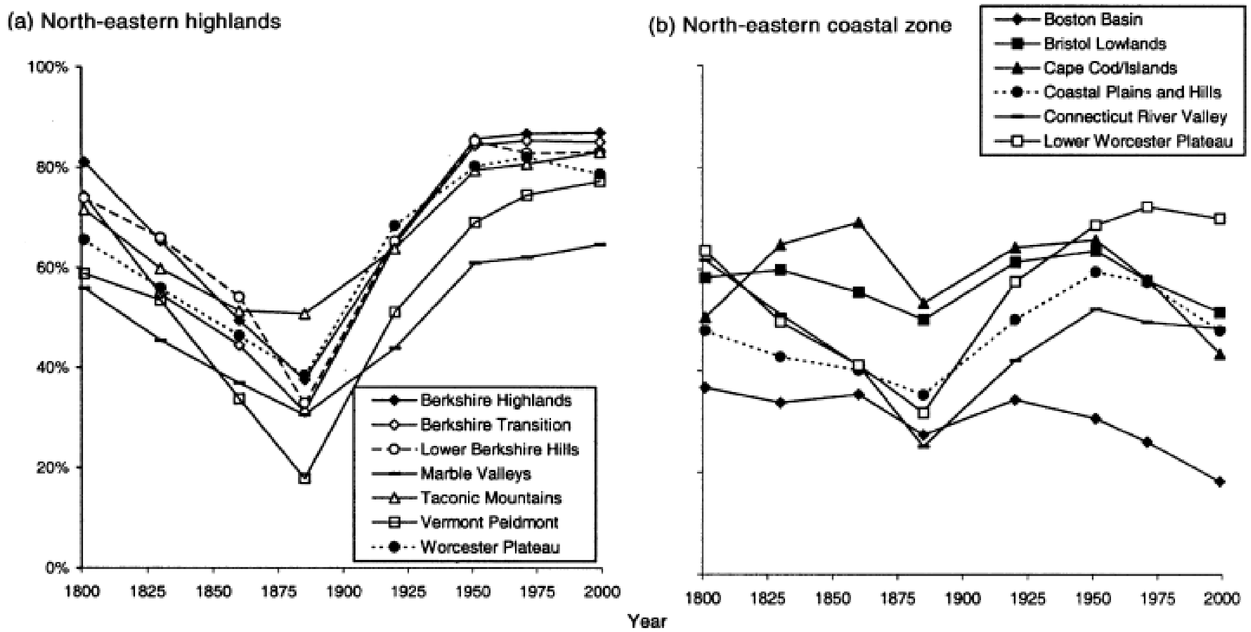

Figure 1. Percentage of forest cover from 1801 to 1999 for two ecological regions of Massachusetts. Taken from Hall, et al., 2002.

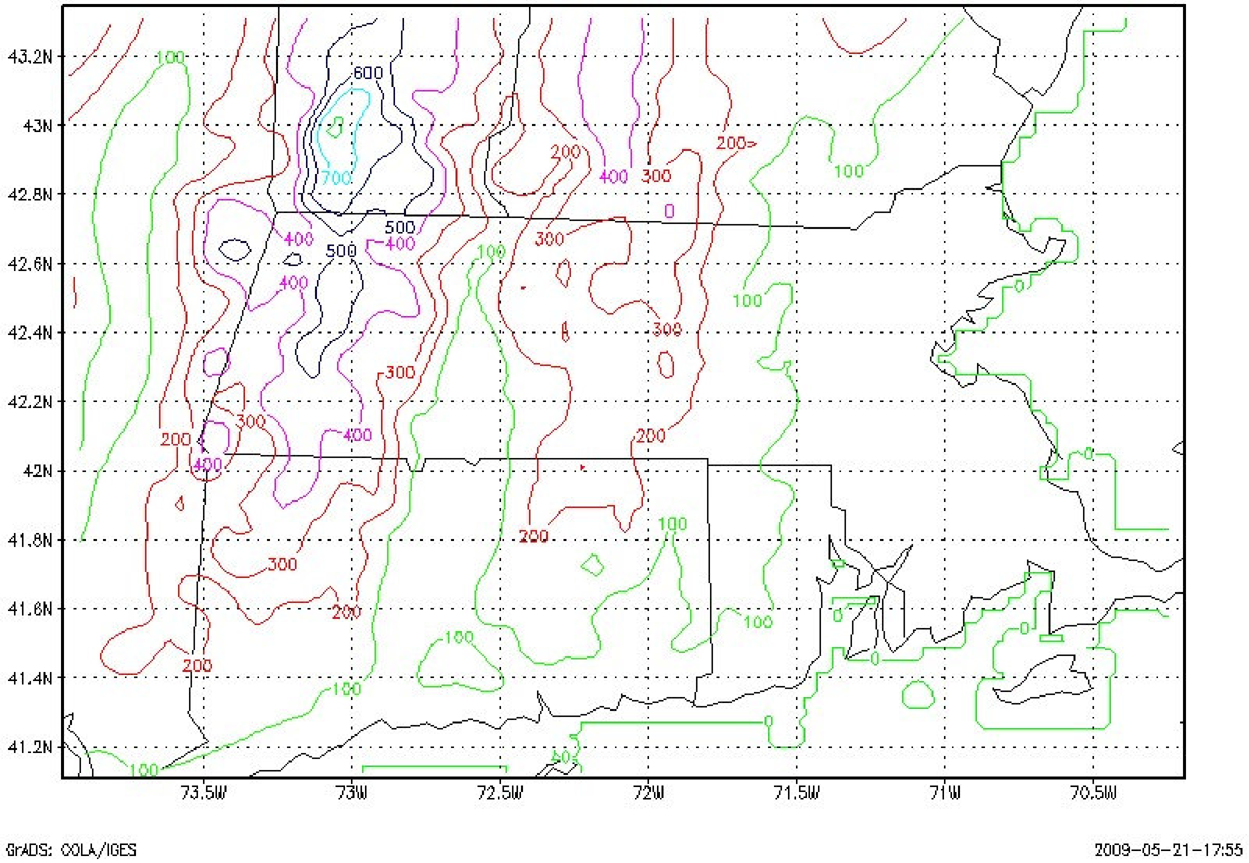

Figure 2. Innermost domain for MM5 model runs. Grid spacing is 4km.

For the June, 2008 case, a more realistic change was made to the forest cover. Using a mean of 40% forest cover as a realistic amount in the middle 1800s, we used a random number generator to determine if a particular grid box with forest would change to grassland. This resulted in a splotchy change in the land use. The result is shown for the innermost domain in Fig. 3, and in

Fig. 4, we reproduce the forest cover for Massachusetts in1830, taken from Hall et al (2002). The resulting pattern of land use appears, at least, to be realistic. We are aware that it would be even more realistic to use historical maps of forest cover, and we are working on obtaining these.

Finally, one simulation of two days length for the June case was performed, to see if the changes observed in the first 24 hours would carry over into the second. These results are still being analyzed and won't appear here.

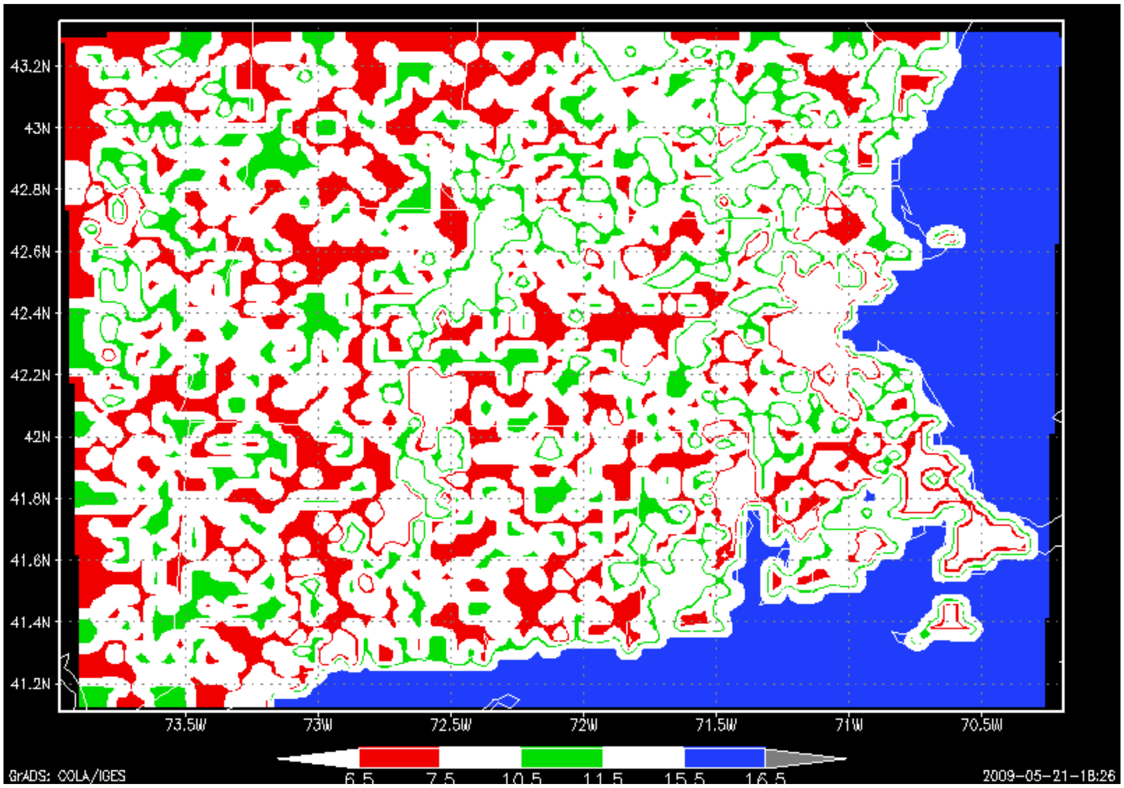

Figure 3. Land use summary for randomized MM5 simulation. Red is grassland, green is forest.

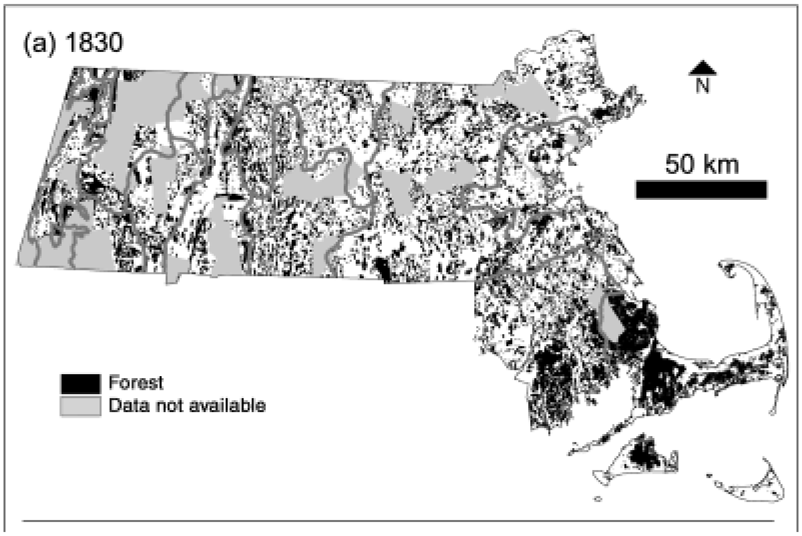

Figure 4. Forest cover for 1830. Taken from Hall et al (2002).

3. Results For No Forest Simulations

Generally, the results were quite clear. The simulations with more grassland produced warmer, less humid surface conditions. All three of the extreme cases showed this tendency, with the typical difference between forest and grassland being a little more than 1ºC.

Dewpoints were 1-2°C lower as well, and the daytime boundary layers generally 25 hPa deeper.

3.1 *Horizontal View*

Figure 5 shows the temperature and Fig. 6 the dewpoint differences in the lowest model level (about 50 m above the ground level) between the current and no-forest simulations for the June case at 22 UTC. With all of the forest cover gone, the air warmer and much drier. With the changes in temperatures, the winds are different. Figure 7 shows the windspeed differences at 22 UTC, with differences of up to 4 m/s evident.

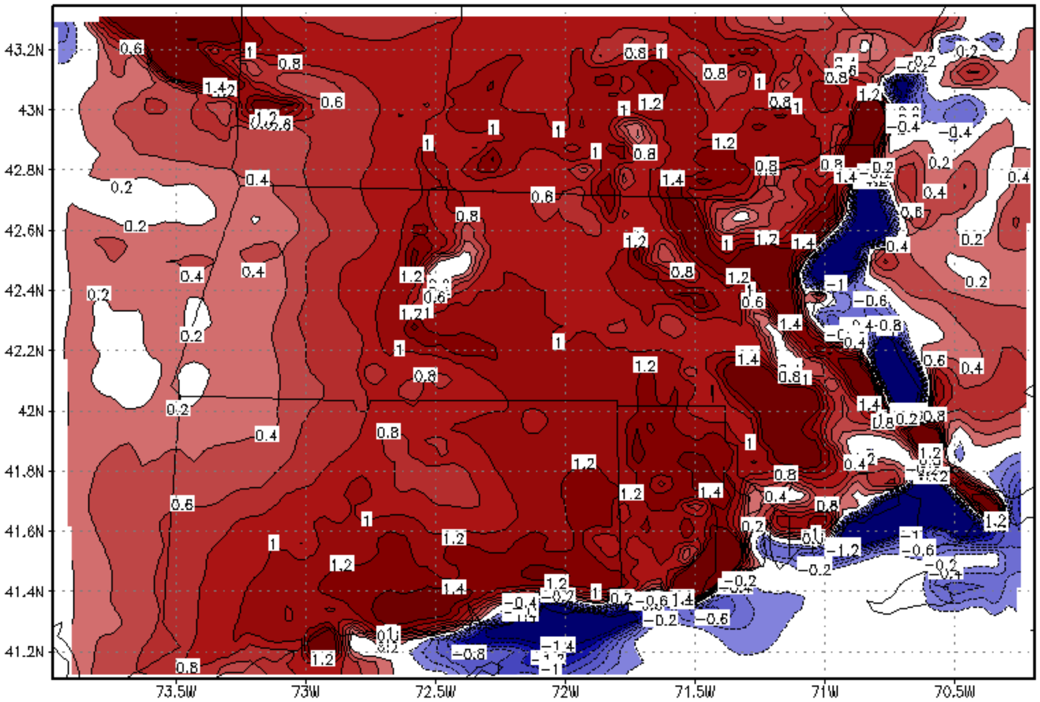

Figure 5. Near-surface temperature difference (°C) between simulations with no forest and with current forest cover. Image valid for 21 UTC, June 9, 2008.

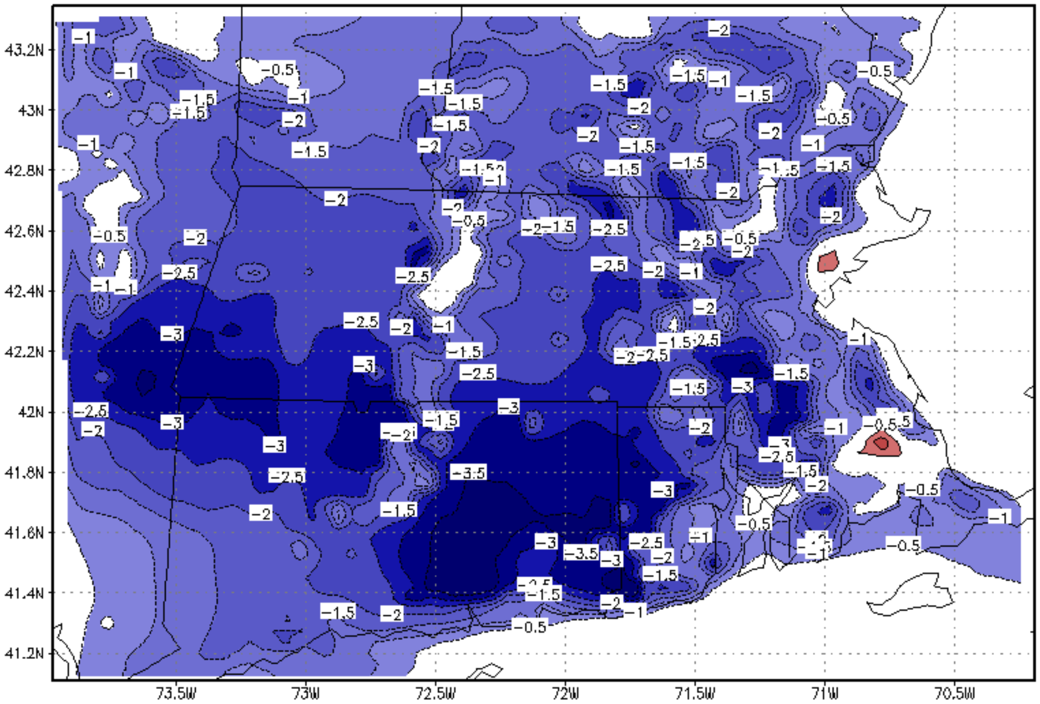

Figure 6. As in Fig. 5, except for near-surface dewpoint.

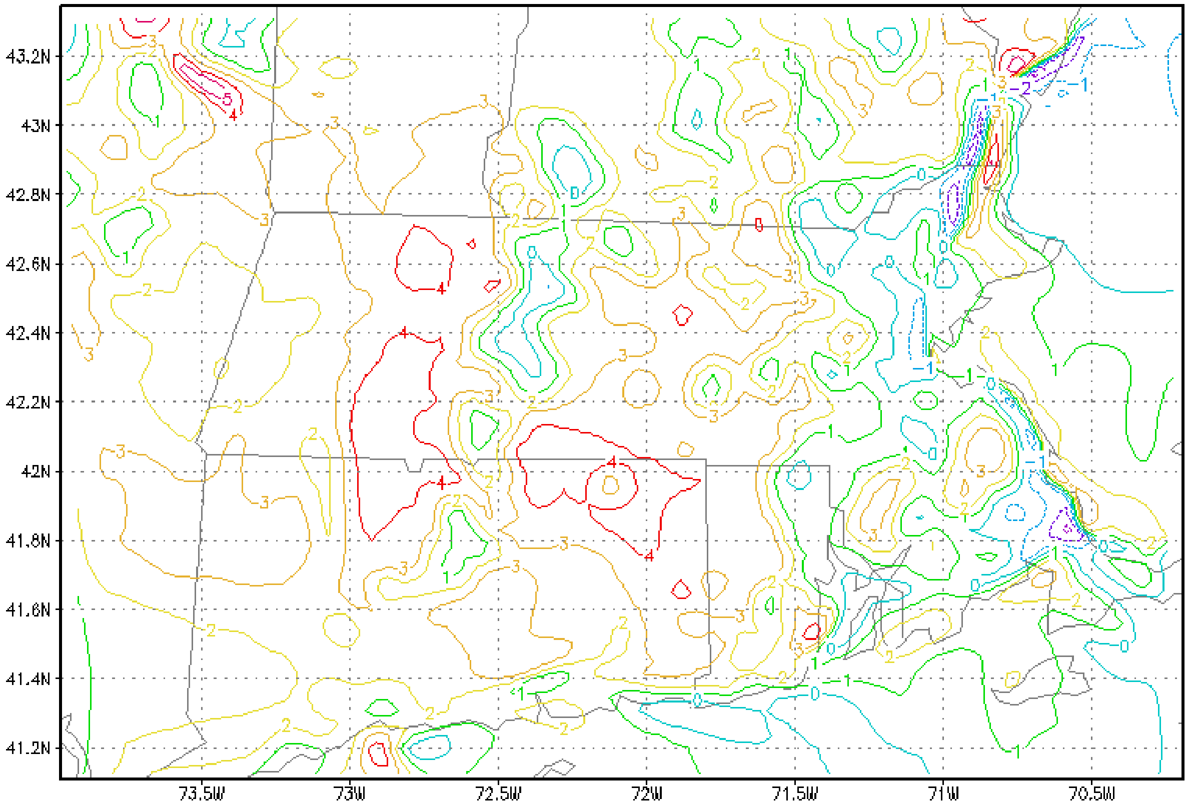

Figure 7. As in Fig. 5, except for near-surface wind speed (m/s).

3.2 *Vertical Profiles*

The vertical profiles show a less dramatic change, mainly associated with the temperature and dewpoint differences already noted. Figure 8 shows the soundings at 22 UTC for the forest and no-forest simulations, and the differences are subtle. The no-forest run is dryer and warmer, and the resulting convective mixed boundary layer is about 10 – 25 hPa deeper.

3.3 *Random Forest – Grassland*

The differences between current forest cover and the simulation with the randomized changes, amounting to about 40% forest cover, are, as expected, smaller than those for the more extreme case, but show the same characteristics. Figure 9 shows the temperature differences for the random change simulation and Fig. 10 the dewpoint differences. Although clearly smaller in magnitude, the sense is still the same – warmer and dryer without forest.

Figure 11 shows the sensible heat flux difference between the randomized run and the current conditions simulation, while Fig. 12 shows the latent heat flux difference. The tendencies go along with the surface temperature and dewpoint differences – higher sensible heat fluxes and lower latent heat fluxes.

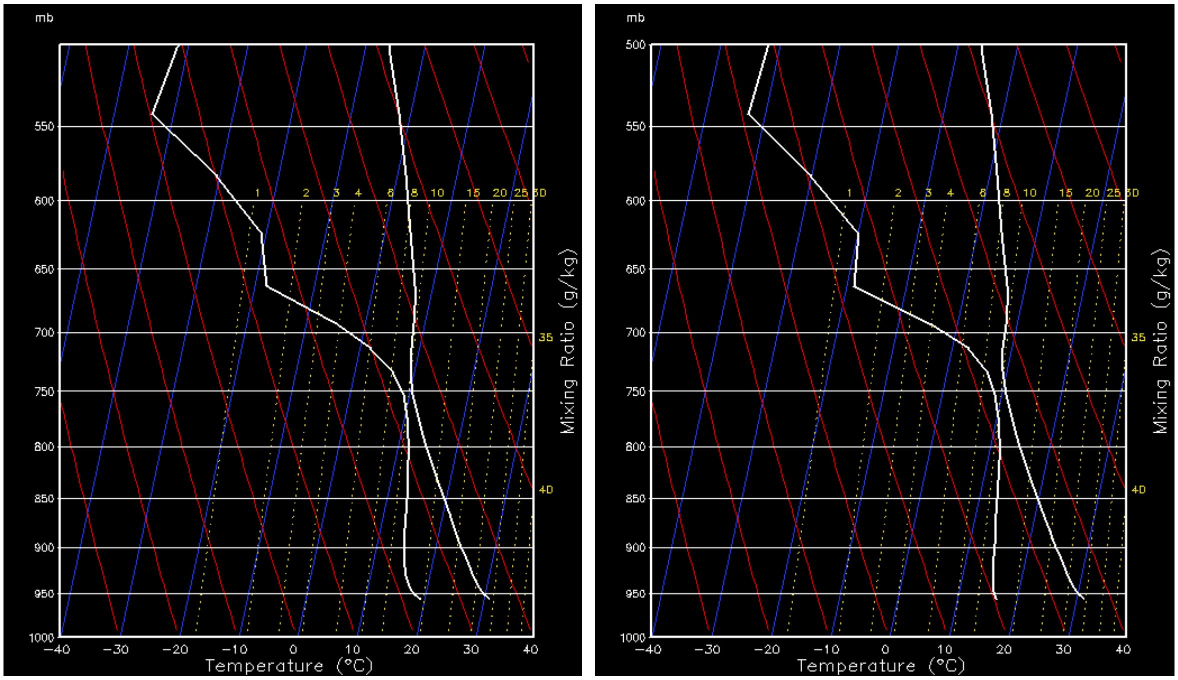

Figure 8 Soundings from simulation with current forest cover (left) and no-forest simulation (right).

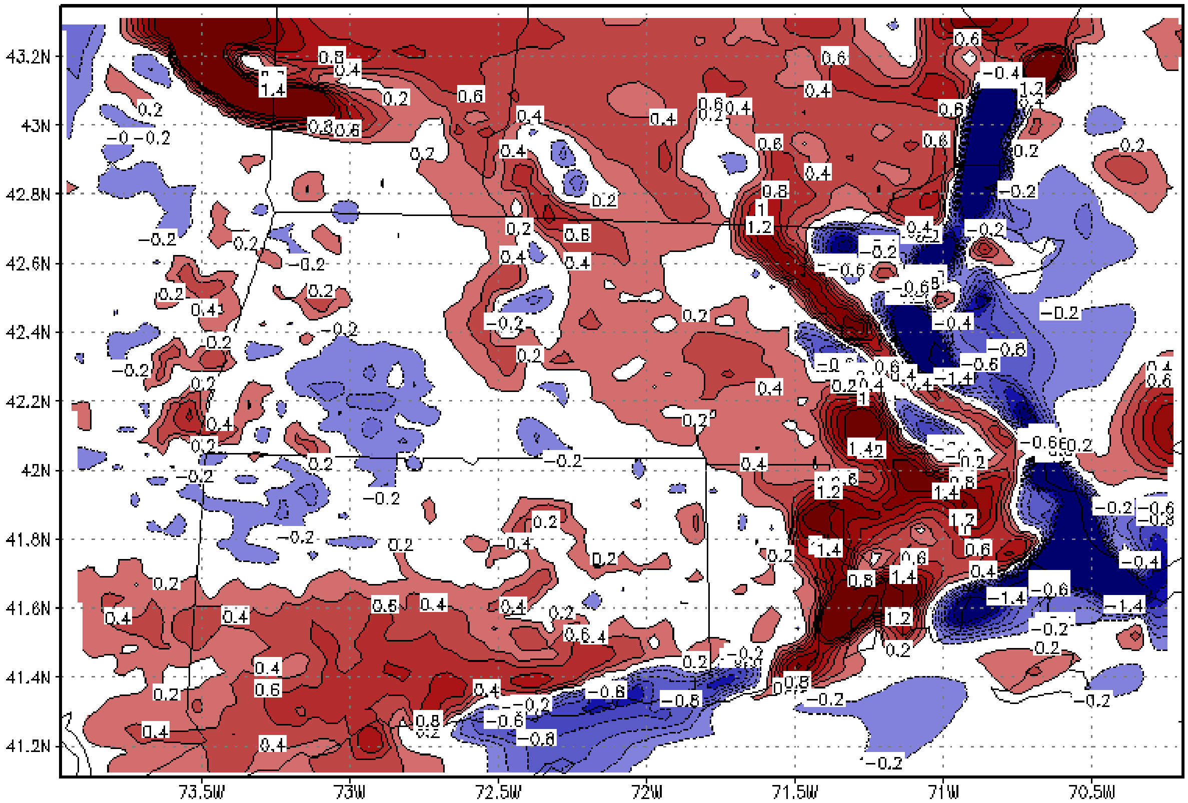

Figure 9. As in Fig. 5, except for difference between randomized forest cover simulation and current forest cover simulation.

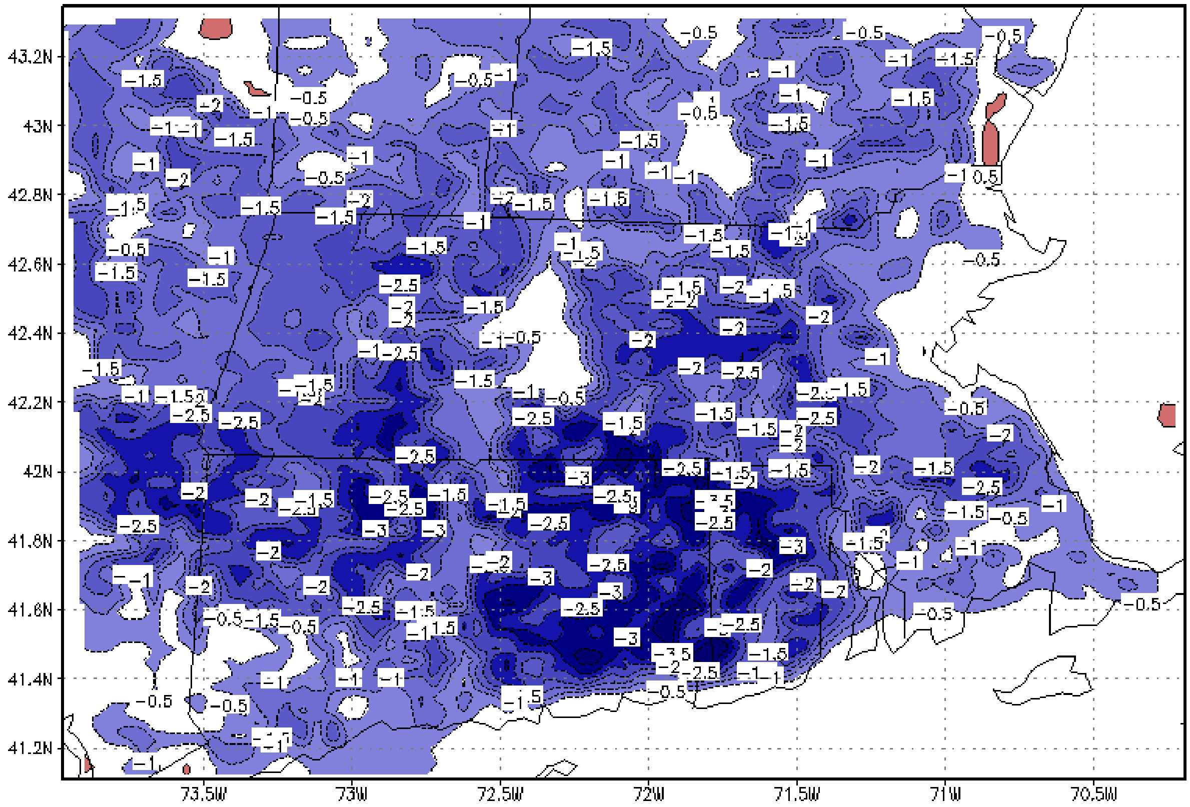

Figure 10. As in Fig. 9 except for near-surface dewpoint.

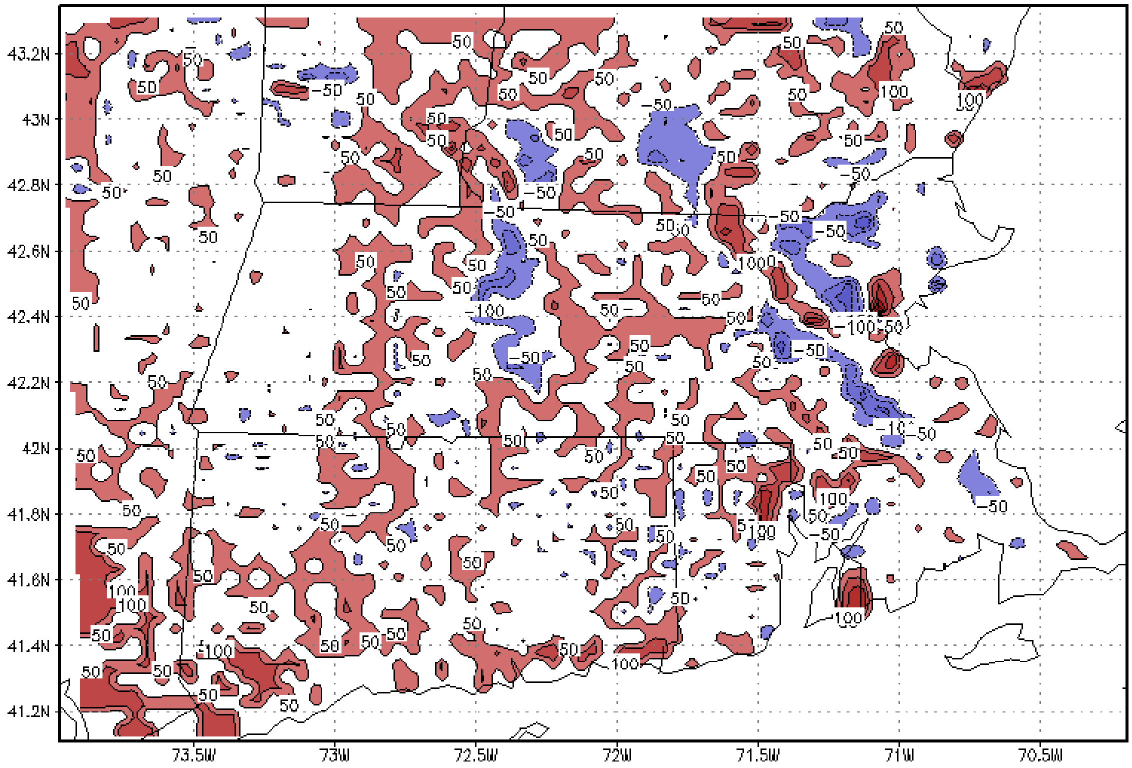

Figure 11. As in Fig. 9 except for sensible heat flux differences (w/m^2).

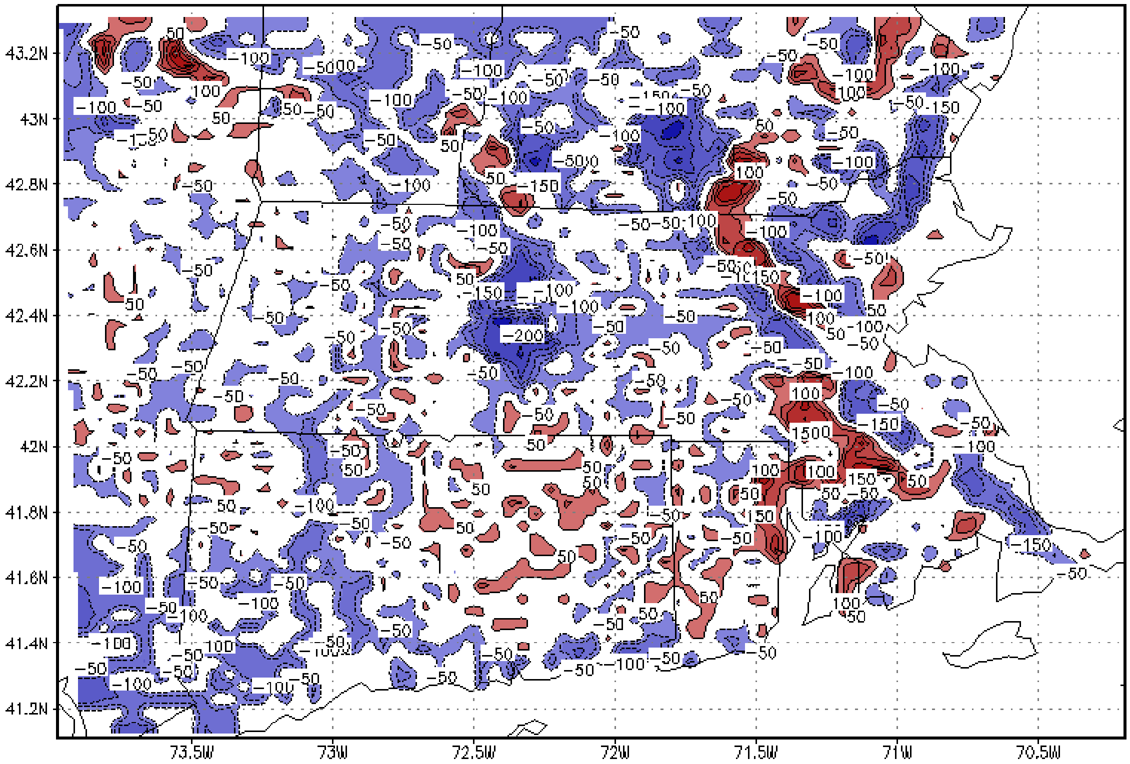

Figure 12. As in Fig. 11 except for latent heat flux differences.

4. Summary and Conclusions

The results shown briefly here indicate that the replacement of forest cover with grassland changes the surface energy balance in favor of higher near-surface temperatures, lower near-surface dewpoints, higher surface sensible heat fluxes and lower surface latent heat fluxes. The resulting well-mixed daytime boundary layers carry these changes throughout their depth and the no-forest boundary layers were slightly deeper as a result. In addition,the thermal changes resulted in windspeed changes with the no-forest simulation generally showing higher wind speeds near the surface.

We are continuing to explore the ramifications of these early model results, to see what the longer term, larger-scale changes might be.

5. REFERENCES

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