Local Influences on Winter Minimum Air Temperatures

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ABSTRACT

Previous experiments have developed the hypothesis that a frozen, snow-covered river impoundment can provide an air temperature reference plane in complex terrain. This reference plane facilitates analysis of surface temperature variability and the temperature–height structure of the boundary layer with respect to slope and aspect in the vicinity of the plane. We apply these results to analysis of the influence of local surface snow cover on the morning air temperature, and the vertical temperature structure observed.

INTRODUCTION

A hypothesis has been presented (Hogan and Ferrick, 1990) that considers a level snow-covered river impoundment to be a reference plane, which can be used to define local topographic and land use influences on winter air temperatures. Initial experiments (Hogan and Ferrick, 1991) indicated that this hypothesis provided a method of extrapolation of surface air temperatures, within a basin, over distances of 30 km. These experiments also indicated that cross-basin temperature transects could define vertical temperature structure within the basin, which could be applied to atmospheric dispersion estimates.

Additional experiments were conducted during the winter of 1991–92 to examine differences in temperature structure, and to attempt to isolate the influence of snow cover on near-surface air temperature, relative to tropospheric temperature. The paucity of snow cover in New Hampshire during the 1991–92 winter facilitated some examination of the influence of snow cover on minimum air temperature, and on temperature structure in the lower 300 m of the boundary layer in complex terrain.

Miller (1956) showed that snow cover very effectively couples heat exchange from air to ground in Rocky Mountain forests. Cooling of the lower layer effectively decouples it from the troposphere above, reducing surface wind speed and often isolating very cold surface air from air 10° to 40°C warmer only a few tens or hundreds of meters above. Nakamura and Magono (1982) showed that while air temperature just above a snow surface diminishes with wind speed, the air temperature at a conventional measurement height of 1.25 m becomes minimal when the wind speed at 9 m above the surface is about 1 m/s. This dependence of the 1.25-m "surface" air temperature on wind speed a few meters above apparently contributes to the production of "surface" temperature differences of a few degrees over horizontal distances of a few tens or hundreds of meters in snow-covered complex terrain. It also induces "surface" temperature variation in conjunction with slope, aspect, and surface roughness, which destroys the conventional lapse rate temperature structure along or in the vicinity of hills or mountains. The idea that "surface" temperature variability is related to the presence of snow cover is well founded in theory, but difficult to verify through observation. An observational test of the theory requires frozen, but not snow-covered, ground to be overlain by typical winter circulation; a snowfall of a few centimeters is then required on this surface to examine the influence of surface snow cover on local temperature. Several periods with these conditions occurred in the Connecticut River valley during the winter of 1991–92, and are presented in the next section.

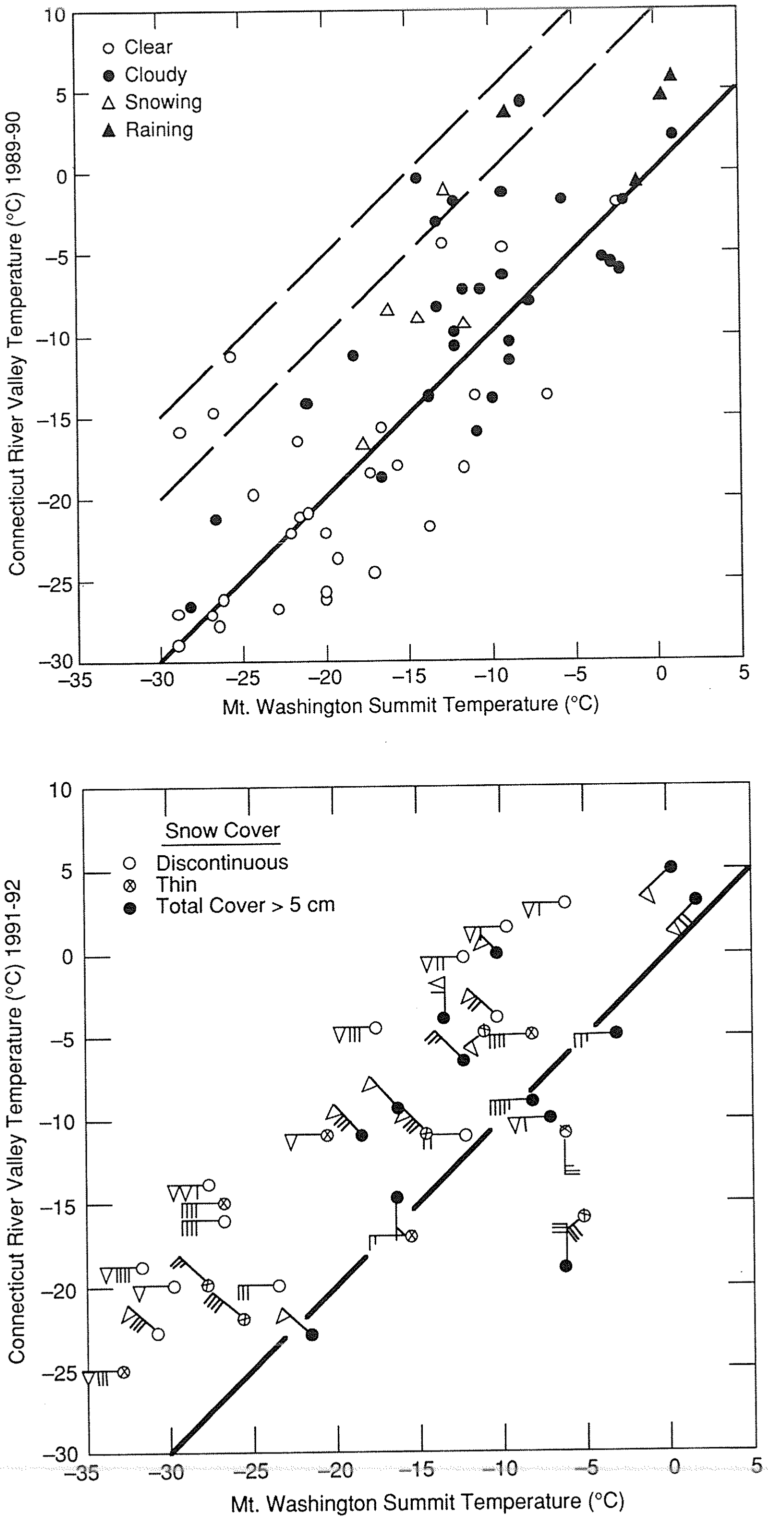

Figure 1. Comparison of 0700 EST air temperature at 230 m asl in the Connecticut River valley, with the Mt. Washington summit (1920 m asl) temperature, during two winter periods. The data in the top panel are from 1989–90 when the ground was continously covered by more than 10 cm of snow, and those in the bottom panel are from 1991–92 when the snow cover was thin and intermittent. Only clear, or nearly clear, sky conditions at the time of observations are included. The broken lines in the top panel indicate the range of temperature conditions expected if continuous lapse conditions were present below the Mt. Washington summit.

RESULTS OF EXPERIMENTS

A comparison of Mount Washington (elevation 1920 m) and Connecticut River valley (elevation 230 m) 0700 EST air temperatures during winter 1989–90 was presented by Hogan and Ferrick (1990), which includes a map and description of the experiment site. The first half of that period was charactarized by cold advection and the second half by warm advection, but the surface in the experiment area was continuously snow covered. This comparison is reproduced in the top panel of Figure 1, and shows the temperature in the Connecticut River valley to be frequently lower than on Mount Washington. The period December 1991–January 1992 was a time of frequent cold advection, but characterized by sparse and infrequent snow cover, and frequent frozen or glazed surfaces. A similar comparison of mountain and valley temperatures for this period is given in the bottom panel of Figure 1 which shows the Mount Washington temperature to be frequently the lower quantity. The mountaintop temperature range is similar, and mountaintop winds are most frequently strong northwesterlies during both periods.

The vertical temperature structure in the experiment area is compared in Figure 2, where the left panel shows temperatures observed on the clear morning of 14 January 1991, which followed 30 cm of snowfall on 12–13 January. There appears to be a temperature lapse in the lower portion of the valley and an inversion based at 250 m in the hills enclosing the basin. Note that "flats" occurring at 125, 230, and 345 m have large variations in surface temperature.

The right panel of Figure 2 shows the vertical structure of temperatures observed at the same points on 16,17, and 19 January 1992 in which the temperature scale length has been doubled to provide separation for the original traces. The ground was deeply frozen and considerably glazed by recent

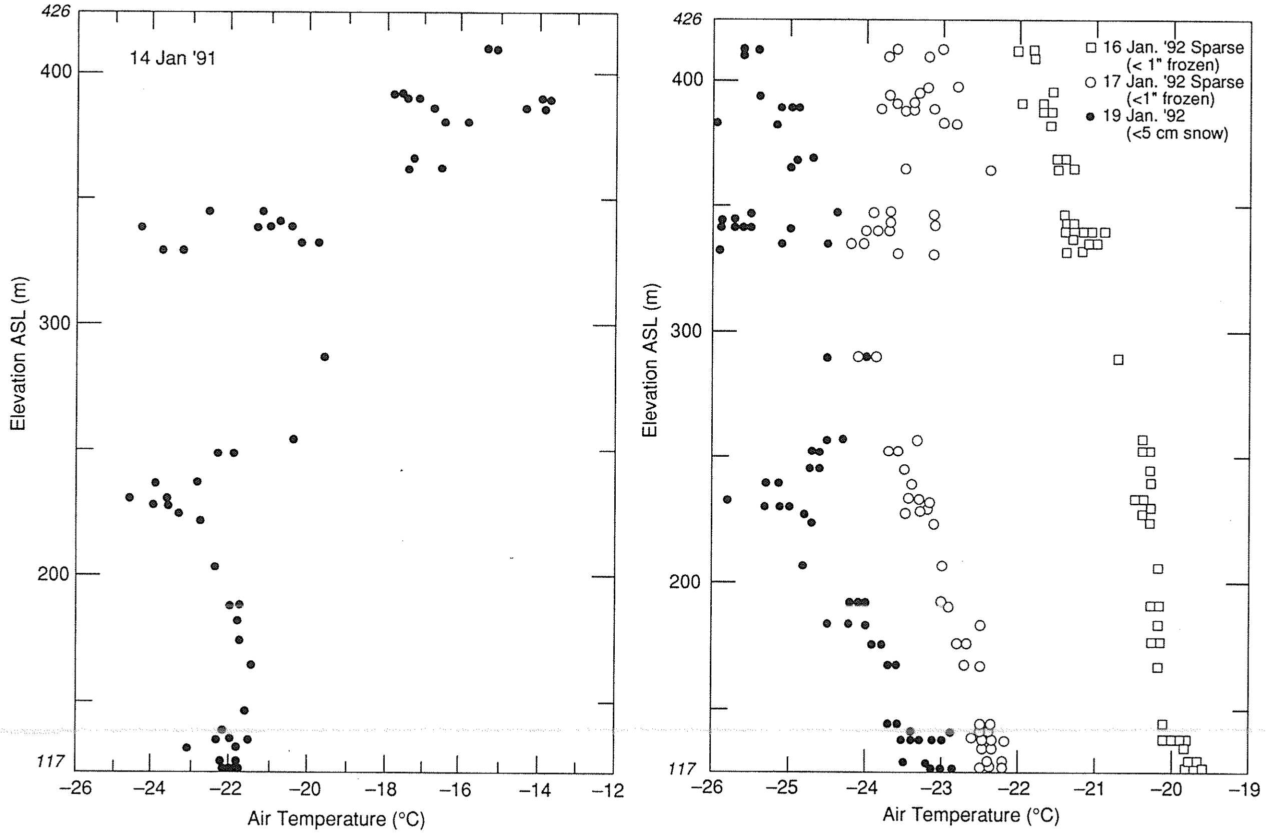

Figure 2. Comparison of vertical temperature structure in the Connecticut River valley with early morning temperatures of less than −20°C, and varying amounts of snow cover.The data in the left panel were obtained when the snow cover thickness exceeded 30 cm, and those in the right panel were obtained when thin and discontinuous snow cover existed. Note that the air temperature scale on the right panel has been expanded to separate the data.

freezing rain prior to 16 January 1992. Only a few remnants of snow survived this rain and these were present as gray glaze patches. About 5 cm of snow was deposited on the glaze on 18 January. Cold advection occurred on the three days plotted; Mount Washington reported –29°C with west winds of 25 m/s on 16 January; –30°C with northwest winds of 30 m/s on 17 January; and –33°C with west winds of 35 m/s on 19 January. The warmest air observed during the period was found near river level on 16 January; the valley below 250 m was nearly isothermal, with a lapse above this level. The warmest air was again adjacent to the river on 17 January, with a lapse to 250 m and an isothermal or very weak inversion layer above this level. The warmest air is again adjacent to the river on 19 January, with a lapse below 230 m and above 350 m. Inversions occur at 230 and 300 m and the "flats" at 125, 230 and 340 m display a wider variation in surface temperature than on the preceding days.

DISCUSSION

Only a few clear nights with a vertical temperature structure similar to those shown in the right panel of Figure 2 have been observed during the 1989–1992 winters. These nights were characterized by vertical lapse and isothermal conditions with no well-defined inversions, and have only occurred when snow cover has been sparse or fragmentary. Thin inversions occur on 19 January 1992 with only 5 cm of fresh snow cover, and similar structure occurred in cold advection on 8 and 11 January 1991 (Hogan and Ferrick, 1991) with 10 cm of snow present. These observations do not counter the concept that a strong inversion may form over a non-snow surface, but similar valley temperatures of –25°C were observed tens of times each winter over snow-covered ground concurrent with air temperatures more than 10°C greater at 100 to 200 m above.

There are several ways in which snow cover influences local and mesoscale meteorology (Walsh and Ross, 1988), and alters climate (Robinson and Kukla, 1988) on the same scale. The absence of snow cover could introduce an apparent but anomolous warming in climate statistics by maintaining higher surface air temperatures during cold advection than would exist over snow-covered ground. This supports the forecast rule proposed by Bosart (1980), which requires continuous surface snow cover when forecasting surface air temperatures of less than –18°C (0°F) in the northeastern U.S.

CONCLUSIONS

Analysis of early winter morning temperature observations along a transect of the Connecticut River valley indicates that multiple inversions are frequent when the ground is snow covered, and infrequent when snow is sparse or discontinuous. Places at the same elevation may have early morning surface air temperature differences of 5°C if the ground is snow covered and the sky above is nearly cloudless.This amount of temperature difference may reflect weak terrain-induced winds a few meters above the surface, proposed by Nakamura and Magono (1982), as the amount of difference diminishes with inversion strength.

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