Spatial Patterns of Urban Dew and Surface Moisture in Vancouver, Canada, During Summer

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ABSTRACT

Boundary layer climatology is often concerned with processes on an idealised extensive, homogeneous plain, where a single point sample suffices to characterise surface conditions. Such landscapes are rare but a large, flat field or pasture can be a reasonable approximation. In a patchy landscape, surface characteristics vary spatially and a single point measurement is inadequate. Dew is seldom measured in cities but its accumulation is expected to vary spatially in interesting ways because the city surface is a complicated mosaic of different materials. This study presents the results of a hardware modelling project to study dew (condensation) and surface water (dew + guttation) in an urban residential neighbourhood. A 1/8th scale, out-of-doors model with a simplified geometry was constructed and run in Vancouver, BC, Canada, during summer. The Internal Thermal Mass (ITM) approach to scaling was used to modify the thermal inertia of the model buildings so that nocturnal surface temperatures would be duplicated in real time. It was postulated that dew accumulation (mm d^{-1}) would be also duplicated. Dew, surface temperature and sky view factor in the model varied in explainable patterns, i.e. grass was cooler and wetter at open sites with large sky view, and was warmer and accumulated less dew close to buildings and under trees, where sky view was reduced. This strong association suggests that maps of site geometry expressed as sky view factor could potentially be used to create maps of dew in cities and other patchy landscapes.

Keywords and phrases**:** dew, urban dew, spatial data, inhomogeneous, patchy landscapes

1.0 INTRODUCTION

Boundary layer climatology, the study of radiation, energy and water balances at the surface of the Earth, is often concerned with processes on an idealised extensive, homogeneous plain, where a single point sample suffices to characterise surface conditions. Such landscapes are rare in reality. Certain desert salt pans and the surfaces of some large frozen lakes come close to the ideal. A large, flat field or pasture can be a reasonable approximation.

Most landscapes are neither extensive nor flat, and inhomogeneity – not homogeneity – is the norm. Some of the more obviously patchy landscapes include a savannah with grassland and scattered trees, a partly milled forest made up of stands of trees and clearcuts, and a city neighbourhood consisting of a mosaic of houses, trees, lawns and streets. In these patchy landscapes, surface characteristics such as soil moisture, surface temperature, vegetation type and dewfall can be expected to vary spatially in interesting ways. However, the logistics of sampling become less straightforward because multiple measurements are required.

1.1 Dew and Surface Moisture

In the absence of rain and fog, droplets of water that appear overnight on grass and other surfaces tend to be called ‘dew’. Strictly dew is water due solely to condensation. For many plants, including lawn grasses, it more rigorous to call this wetness ‘surface moisture’ because the moisture may include fluid exuded from plant tissue through leaf pores, i.e., guttation. Dew is commonly sub-divided into dewfall (dew deposited directly from vapour in the lower atmosphere) and distillation, the recent origin of which is nearby moist soil or wet leaves.

Dew forms when surfaces cool below the dew-point temperature of adjacent air, and moisture (humidity) and wind speed are not limiting. Dew is a small flux compared to rainfall and evaporation. The theoretical maximum rate of deposition on vegetation is 0.08 mm h^{-1} (Garratt and Segal, 1988), but this is seldom reached. Accumulation on leaves seldom exceeds 0.3–0.5 mm per night. Nevertheless, the energy required to dry even 0.5 mm of water (1.24 MJ m^2 at 10^oC) is not trivial, and wetting by dew is associated with fungal diseases on many crops, so has economic importance for farmers.

Relatively few studies of dew have been undertaken in patchy landscapes. Lloyd (1961) correlated spatial patterns of dew with the patchy distribution of blister rust disease (*Cronartium ribicola*) in a pine forest. A few researchers have described the spatial variation of dew in a woodland clearing or around a shelterbelt. They report that, on calm nights more dew was typically seen at open sites and less close to tall vegetation. On windy nights, shelter was important (Steubing, 1952; van Eimern, 1953/54; Mattsson, 1979). Jacobs *et al*. (1998) describe spatial variation in the persistence of dew after sunrise for a desert dune landscape. There the spatial variation was associated with shading. These studies, although few in number, suggest strongly that site geometry has an important role in controlling the spatial distributions of dew on an otherwise homogeneous surface, e.g. grass or sand.

1.2 Urban Dew

The vast majority of studies of dew involve rural locations, but there is growing interest in urban dew and its implications for urban climate and air pollution deposition. Urban dew data are rare and studies of urban dew can be counted on one hand (Myers, 1974; Mattsson, 1979; Richards, 1999). Despite this lack of data, it is commonly held that urban dew is absent, reduced or delayed in cities, compared to their rural surroundings (Oke, 1987). Cities are often relatively warm at night due to the urban heat island phenomenon and this is thought to inhibit dewfall. There is some observational evidence to support this assumption, at least for grassed surfaces (Myers, 1974; Mattsson, 1979; Richards, 1999).

Nevertheless, we know dew occurs in cities. Most urban dwellers have seen dew on their vehicles or on urban lawns and parks. Surveys of urban surface temperature (e.g. Spronken-Smith, 1994) show that open grassed urban parks, isolated tree tops and large lawns cool rapidly after sunset. Hence they are potential sites for the formation of dew. Shingle or metal roofs in residential areas that are well insulated and have, because of their height above their surroundings, an unobstructed horizon also cool strongly overnight. Field observations in Vancouver, BC, Canada (Richards, 1999) show that an asphalt-shingle roof can be a significant site of dewfall deposition (~0.4 mm per night).

The city surface is a complicated and three-dimensional mosaic of different materials, e.g. concrete, stone, metal, soil and vegetation. Processes of dew formation are the same in the city and surrounding rural areas, but in the city spatial patterns of dew are expected to be more complicated. This makes the observation of urban dew an interesting proposition for a climatologist.

This paper describes a hardware modelling project to study dew in an urban residential neighbourhood. Modelling is often a useful approach to examine processes in complicated landscapes, such as a city. For example, it is easier to sample a small (i.e. scaled) house than to instrument a full-scale home and, in a model, experiments such as removing street trees can be accomplished more easily. Artificial dew is impractical to create in a laboratory, and few attempt to do so. Scale models to study dew – such as the one described below – must operate out-of-doors where dew forms naturally.

2.0 METHODS

2.1 Thermal Scaling

Thermal scaling is critical for a dew model because condensation is driven largely by surface temperature and an outdoor model operates in real time. Most hardware models are scaled geometrically. That is, they are scaled by a universal factor F, e.g. 0.125 or 1/8th. Thus, length (height, width, wall thickness) scales by F, area by F^2 and volume by F^3. However, a building scaled in this manner would cool too fast and accumulate excess dew if exposed out-of-doors overnight.

Consequently, in this study the Internal Thermal Mass (ITM) approach to scaling (McPherson *et al.*, 1989; Richards, 1999) was used, rather than strict geometric scaling. Briefly, under ITM overall dimensions (height, width) are scaled geometrically but the thermal behaviour of objects is modified by inflating the internal thermal mass (c_{Mim}) in the model compared to its full-scale equivalent (c_{Mih}). For a model building, this means that the walls, floor and roof are constructed at full-scale thickness using real building materials, and a calculated mass is added to the model's interior, e.g. of bottled water. The exact amount of mass added is a function of F, building form, c_{Mih} and the intrinsic thermal mass of the added material. For most wooden houses with relatively thin walls and roughly cubic form, the ratio c_{Mim}:c_{Mih} approaches F^2. The theoretical outcome of ITM is that surface temperatures are duplicated in real time. Hence it was postulated that dew accumulation (mm d^{-1}) would be also duplicated.

2.2 The Model

The hardware model (Figure 1) was constructed out-of-doors at the University of British Columbia campus in Vancouver, BC, Canada (Richards, 1999; Richards and Oke, 2000). Three wooden houses and two false walls were constructed and placed along the north edge of a grassed plot (9 × 12 m in width). Each house was 1.08 m tall with a steeply pitched (45°) roof covered with brown asphalt shingles. Dewfall is strongly linked to radiative cooling and, thus, is sensitive to sky view, which describes the openness of a site to the heat sink of the sky hemisphere. In this study, stereographic plots of urban landscapes were used to specify the shape and placement of the false walls so that, from the perspective of a central point on the lawn, similitude in sky view was achieved. The false walls effectively increased 'street' length by using false perspective.

Concrete paving slabs were used to model a street (1.0 m wide). This divided the turf in the model into two areas: a 2.5 m wide lawn in front of the row of houses and an urban park (7.5 m in half-width). The theoretical park was symmetrical and elongated parallel to the street direction, so it was necessary to model only half its width; the half-width was chosen to be sufficient that the trees that were in theory present at the far sides of the park could be ignored.

When trees were present in the model, they consisted of a row of five Japanese maples (1.5 m tall) planted at the south edge of the street pavement to model both street and park-edge trees, and five Pyramidal cedars (1.2 m tall) planted between the houses to model yard trees.

The model was run during the summer of 1996, after a trial in 1994. During June-July, 1996, twenty nights with a variety of weather conditions, but no rain, were selected for intensive study. Two configurations were used: a) with trees in the model to represent street/park-edge and yard trees (on Year Days (YD) 153–182) and b) without trees but with the model configuration otherwise unchanged (YD 183–207).

According to ITM, real building materials (wood, asphalt roof shingles, insulation) were used at full-scale thickness and 43.1 litres of bottled water was added to inflate the thermal inertia of each scaled house. This provided 0.18 M J K^{-1} of interior thermal mass (c_{Mim}) for each model house and simulated the existence of otherwise absent internal free-standing walls and furnishings, the assumed thermal mass of which was scaled by 0.0156, according to the ITM approach. It was assumed that c_{Mih} for a single-family dwelling was ~12.8 MJ K^{-1} (McPherson *et al.*, 1989).

Figure 1: The 1/8-scale urban model run at the University of British Columbia, Vancouver to study urban dew.

3.0 VALIDATION AND RESULTS

Ambient conditions in the model (air temperature, humidity and wind speed and direction) were similar to those seen at the full-scale sites, except the model site was more windy. Sky view factor (SVF) values in the modelled landscape were also realistic. SVF describes the proportion of the sky hemisphere visible from a point on the surface. It varies from 1.00 for a flat and completely open site, to 0.00 under a full tree canopy. Moisture accumulation on the model was also realistic, and surface temperatures appeared to mimic reasonably well those observed at the full-scale. Some residual effects of shading differences were evident in the early evening, e.g. for roof surface temperatures (Figure 2). Since ITM had not previously been tried to simulate moisture conditions (only temperatures) these results are encouraging.

3.1 Dewfall on the Model

Dewfall (i.e. dew sourced from the lower atmosphere) can be measured using lysimetry, since it is a mass gain to the surface. A lysimeter is essentially a representative portion of the surface of interest, which can be weighed. The sides and base of the lysimeter are sealed so that, in the absence of rain and irrigation, gains in mass can be attributed dewfall. In this study dewfall was measured using electronic mini-lysimeters (area = 0.11 m^2) installed under a lawn (grass), park (grass) and roof (asphalt shingle) surface. The results are shown in Figure 3.

Daily accumulation of dewfall was strongly governed by nocturnal weather, especially cloud and wind conditions. When the trees were present (Figure 3a), no dewfall was seen on the lawn. However, when the trees were removed (Figure 3b), dewfall was measured on the lawn on almost all nights studied. These patterns are inferred to be due to SVF effects on radiative cooling and, perhaps, shelter effects on vapour transport. Dewfall was more frequent and (almost always) heavier on the model roof, compared to that sensed on the open park. This agreed with observations made at the full-scale in a nearby suburb.

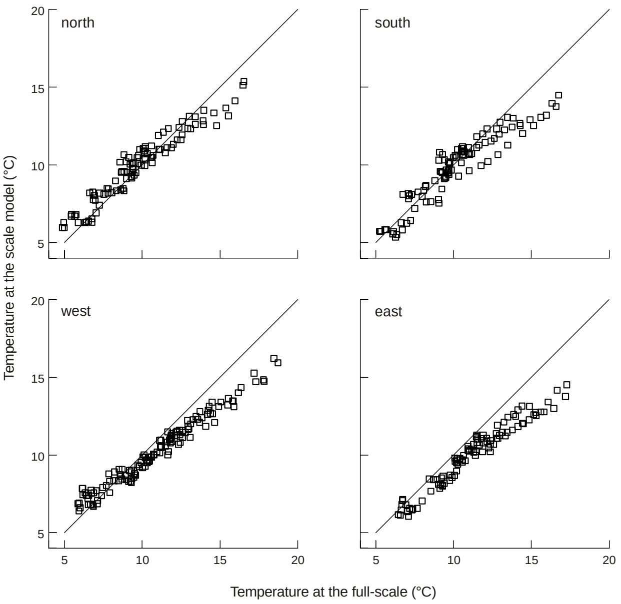

Figure 2: Agreement between 15-min mean surface temperatures (ºC) on north-, south-, west- and east-facing roof facets at the model and full-scale sites, for four nights in 1996.

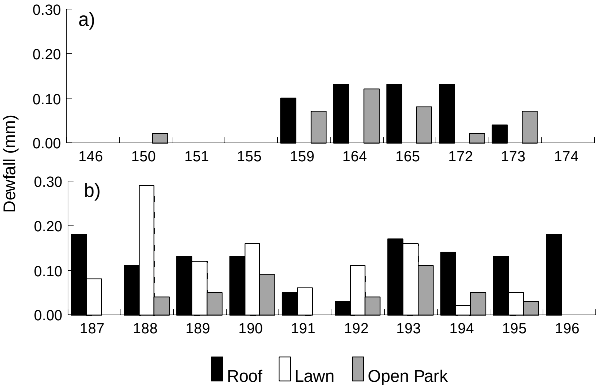

Figure 3: Dewfall (mm) on the model at dawn; a) with trees (YD 146-174) and b) with the trees removed (YD 187-196). NB: No bar means zero dewfall; the sequence of days is discontinuous.and fish-eye lens photography (grey circle).

3.2 Surface Moisture on Grass in the Model

Surface moisture (i.e. dew + guttation) on grass at dawn was measured by blotting. That is, sheets of pre-weighed blotting paper were pressed onto the wet grass. The papers were then re-weighed to determine the mass of water absorbed. At the same time, along the same transect, grass canopy temperature was sensed using an infrared thermometer. Strong spatial variation (Figure 4) was measured in both these variables. The grass canopy was cooler, and accumulated more surface moisture at sites with large SVF, i.e. the open park (SVF = 0.98) and the middle of the lawn (SVF = 0.92). The grass was warmer and surface moisture less where SVF was reduced, i.e. beside the house (0.50) and under the trees (0.70). The trends were consistent when the trees were removed (Figure 5) but the patterns were more simple. This reflected the reduced complexity of the modelled landscape. The underlying mechanism for these patterns is inferred to be increased longwave radiation loss when less of the sky heat sink is obscured.

On nights with less favourable conditions for dew, patterns associated with SVF were muted. No surface wetness was sensed on the relatively warm house walls and the concrete paving. Air movement at the site seemed to inhibit dew on the maple leaves which remained close to air temperature at night.

4.0 CONCLUSIONS

In complicated environments such as cities, modelling can be a useful alternative to measurement. The model presented here shows that in environments possessing complex geometry, spatial patterns of dew are also complex. This is due, in part, to juxtaposition of the basic structural elements (i.e. trees, buildings, grass and concrete paving) in a complex mosaic.

In this study, the urban environment was reduced to a few simple elements (houses, trees, grass, paving) arranged into a few representative units (house sections, street, park). This greatly simplified sampling since the essentially linear landscape could be adequately represented by a vertical cross-section, i.e. at right angles to street direction.

The main findings of the study can be summarised:

- The presence and amount of surface moisture and dewfall on the model was primarily controlled by weather and the nature of the substrate.
- These effects were overlain by effects relating to the net radiation balance of the surface (especially site geometry, as expressed by SVF) and whether surfaces were in contact with heat sources.
- When weather conditions were favourable, significant amounts of dewfall were deposited on grass at open sites in the model and on asphalt-shingle roofs which cooled rapidly after sunset.
- This study, and observational studies by the author, show that roof surfaces should not be overlooked as sites of urban dew accumulation.

On nights with moderate-heavy dew, patterns of surface moisture in the model were well explained by patterns of SVF. This suggests that maps of site geometry expressed as sky view factor, and knowledge of dew accumulation at an open site, could potentially be used to create maps of dew distribution in urban and other complex environments.

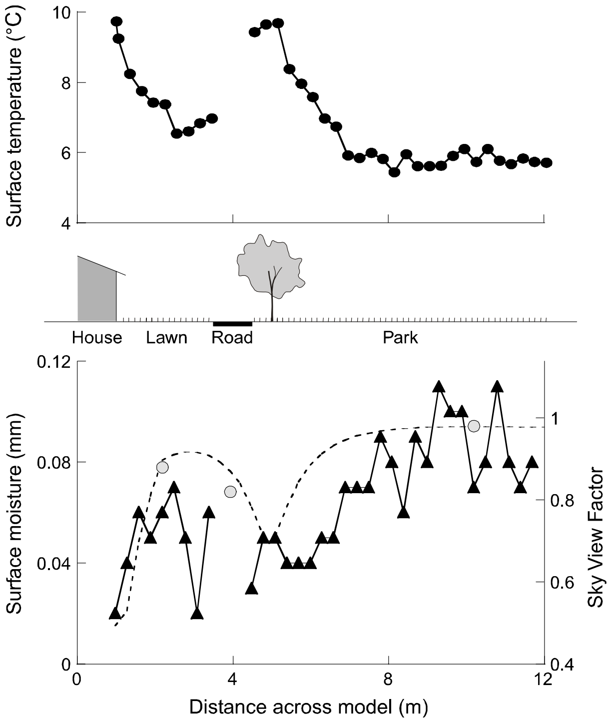

Figure 5: Conditions in the model at dawn on YD 188 with no trees present (see Figure 4 for symbols).

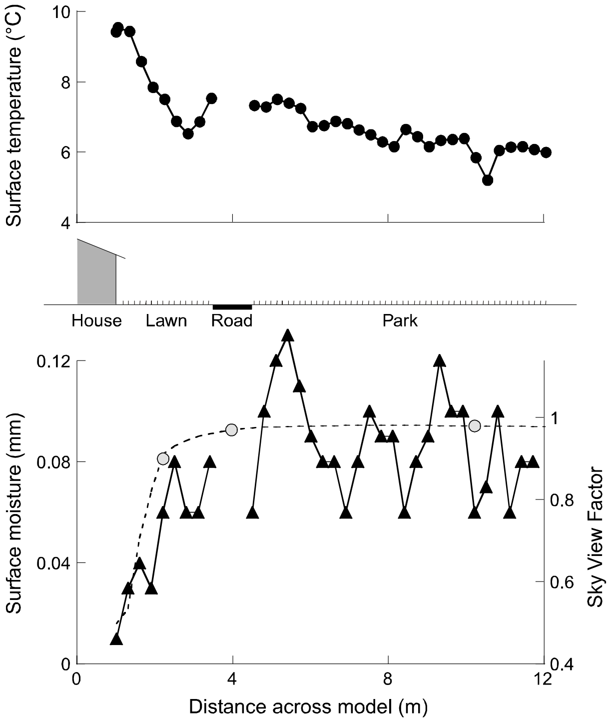

Figure 4: Conditions at dawn on YD 172 with trees in the model, showing grass temperature (black circle), surface moisture (black triangle), and sky view factor derived from site geometry (dashed line)

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