

CLASSIFYING URBAN CLIMATE FIELD SITES BY “LOCAL CLIMATE ZONES”: THE CASE OF NAGANO, JAPAN

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Abstract

Classification of urban climate field sites traditionally relies on simplistic descriptors like “urban” and “rural.” While these descriptors might appropriately describe the regional setting of an investigation, they convey nothing of its micro- and local-scale site properties that actually influence surface-layer climate. We demonstrate a possible new approach to site classification using a prototype version of “local climate zones,” and we test these zones using “urban” and “rural” field sites in Nagano, Japan. The Nagano sites correspond well with local climate zones, and the new system provides a more useful interpretation of the landscape for urban climatologists. With further refinement, the local climate zone system can improve consistency and accuracy in urban climate reporting.

Key words: local climate zones; landscape classification system; urban and rural; Nagano, Japan

1. INTRODUCTION

The sites and settings of urban climate observation are remarkably diverse, from small towns to sprawling cities, and from street canyons to building rooftops. Much less diverse, however, are the descriptions of the sites and settings used in urban climate studies. Investigators traditionally lean on familiar words like “urban” and “rural” to describe their surroundings. While these words might accurately describe the regional “setting” of an urban climate investigation, they poorly describe the local “sites” of observation. The popular use of “urban” and “rural” in modern climate literature to characterize both site *and* setting has now eclipsed faithful reporting of surface properties—such as cover, exposure, and wetness—that actually determine local climate differences.

Classifying field sites as conventionally “urban” or “rural” is especially difficult in Japan, where cities and countrysides are densely populated and land uses intensely mixed (Yamashita, 1990; Ginsburg, Koppel, and McGee, 1991). “Urban” and “rural” do not transfer easily into the vernacular of Japanese landscapes. At present, urban climatologists in Japan and elsewhere have little choice but to follow this convention until an alternative approach to site classification is adopted. We propose “local climate zones” as a possible alternative, and, accordingly, test the utility of these zones using a sample of “urban” and “rural” field sites in Nagano basin, Japan. The objective of this study is to highlight the advantages of using the local climate zone system instead of a traditional urban-rural-based system. Classification of field sites can be relatively unambiguous if the system being used is appropriately defined and scaled, and is effectively universal in coverage. The physical and cultural landscapes of Japan provide a challenging test of any such classification system.

2. PREVIOUS WORK

2.1 “Local climate zone” classification system

Local climate zones derive from logical division of the landscape “universe” into a hierarchy of sub-classes, each differentiated on principles of surface cover (built fraction, soil moisture, albedo), surface structure (sky view factor, roughness height), and cultural activity (anthropogenic heat flux) (Stewart and Oke, 2009). Using these defining properties, we suggest the landscape universe comprises 19 local climate zones in 4 landscape series (Figure 1). Individually, the “zones” are local in horizontal scale (10^2 to 10^4 metres) and represent homogeneous climate regions. The city series is the largest of the system and corresponds closely with Oke’s 2004 *Urban Climate Zones*. The mixed series is smallest, but is crucial to the system because it portrays transitional city-country landscapes. The prototype local climate zones are each described and illustrated in standardized data sheets (for sample see Figure 2). Further explanation on the development and use of local climate zones is given in Stewart and Oke. The zones are given initial quantitative support through numerical modelling of surface thermal responsiveness in Krayenhoff, Stewart, and Oke (2009).

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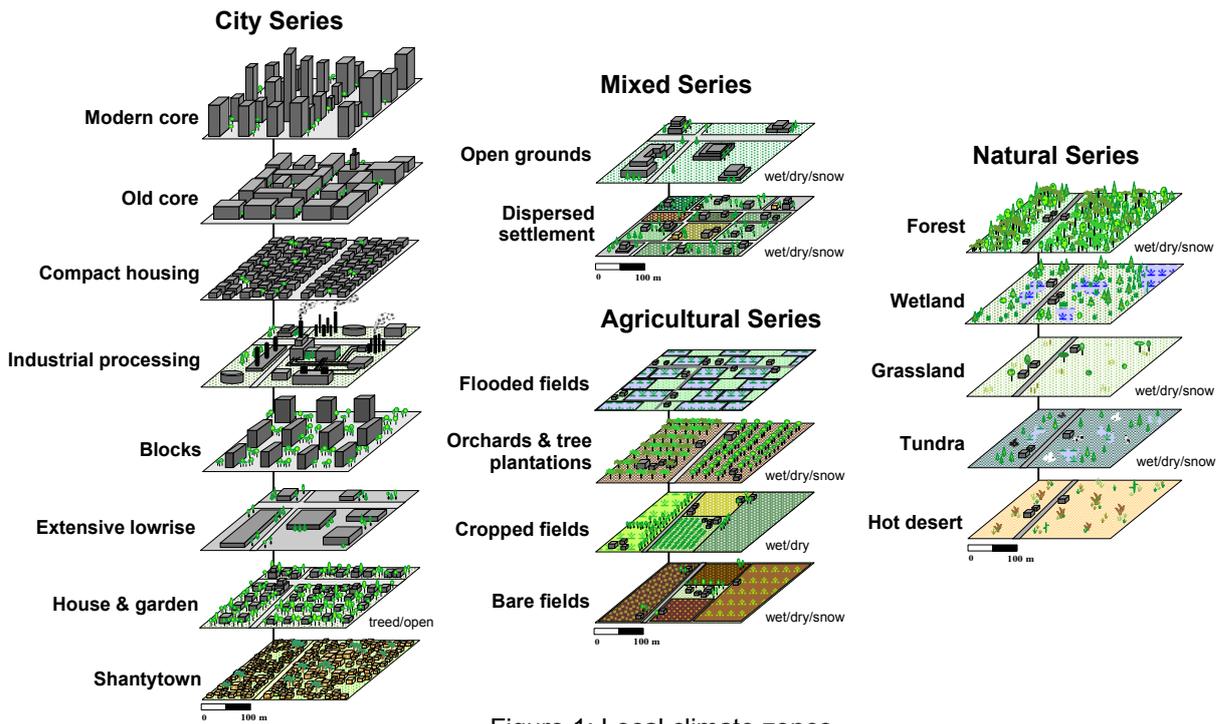


Figure 1: Local climate zones.

Zone Name: <i>Compact housing</i>		Landscape Series: <i>City</i>			
Definition: Low, uniform roofline, occasionally punctuated by trees. Mix of small, detached and semi-detached buildings, 1–3 stories tall. Buildings densely packed, separated by narrow, winding streets and alleyways. Sky view from street “canyons” significantly reduced. Tree or vegetative cover scarce. Construction materials heavy (stone, concrete, brick, tile); roofs and walls thick. Low space heating/cooling demand. Light traffic density.					
Probable Function: High-density residential (single-unit housing); commercial (small retail shops).					
Anticipated Location: Old or densely populated cities; central or inner-city sites; high-density sprawl.					
Computer Sketch					
Side View			Oblique View		
Photographs					
Eye Level			High Angle		
Zone Properties					
SVF ¹	% built ²	Z _H ³	albedo ⁴	μ ⁵	Q _F ⁶
0.30 – 0.70	> 80	5 – 10 m	0.12 – 0.20	1,200 – 1,500 J m ⁻² s ^{1/2} K ⁻¹	20 – 30 W m ⁻²
<p>1. Mean sky view factor from ground level. Varies with height and density of buildings, trees. 2. Proportion of zone surface covered by impervious materials (buildings, roads, pavement). 3. Average height of main roughness elements (trees, buildings, crops). 4. Weighted average reflectivity of zone surface. Varies with surface roughness, wetness, and materials. 5. Thermal admittance of surface materials. Varies with surface type and wetness. 6. Local-scale mean annual anthropogenic heat flux from combustion processes and space heating/cooling.</p>					

Figure 2: Sample data sheet for “compact housing.”

3. CLASSIFYING URBAN CLIMATE FIELD SITES BY LOCAL CLIMATE ZONES

3.1. Nagano, Japan

Our study area for testing the prototype local climate zones is Nagano basin of central Honshu, Japan. The cultural landscapes of Nagano basin are typical of mainland Japan, and include urban settlements of various form, and extensive rural areas of wet-rice cultivation and fruit production. Nagano's mid-latitude climate brings seasonal change to the landscape, particularly in the countryside where soil moisture, crop development, and snow cover control the thermal responsiveness of the active surface.

We selected seven field sites from the observational urban heat island (UHI) studies of Sakakibara (1999) and Sakakibara and Matsui (2005). These studies observe seasonal effects on canopy-layer UHI in Nagano basin using mobile temperature surveys across a period of one year. We chose these studies because they meet our criteria for reliable reporting of heat island observations. In addition to basic requirements regarding the accuracy of measurement systems, our criteria ensure that (1) the confounding effects of time, weather, relief, and soil moisture on UHI magnitude are sufficiently controlled; (2) surface cover, structure, and human activity are reasonably homogeneous across the local fetch of each site; and (3) site metadata are properly documented.

3.2. Data sources

The original UHI reports of Sakakibara (1999) and Sakakibara and Matsui (2005) provided most of the metadata needed to classify the sample field sites. These reports describe the regional setting of Nagano basin and the seasonal and structural characteristics of its field sites. Quantitative site metadata in the reports include building/tree height, sky view factor, fractional building cover, and soil thermal admittance. Maps, photographs, and surface measurements were obtained directly from the lead investigator of the Nagano studies. In November 2007, the lead investigator guided us to his field sites, where we documented the exposure, land cover, land use, and major sources of anthropogenic heat (if any) of the sites. Away from the field, additional metadata were obtained from online portals for digital mapping and satellite imagery, such as Google Earth,[®] and from measurement, modelling, and classification studies of landscapes similar to those of Nagano basin (e.g., Susaki *et al.*, 2007).

3.3. Methods

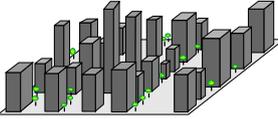
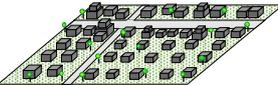
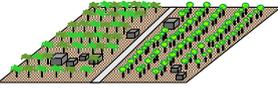
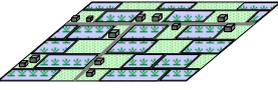
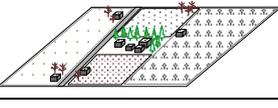
Scale is paramount in the classification process, and especially in the parameterization of field sites. All field sites are essentially defined by a "circle of influence" (also known as source area or "footprint") whose radius extends from metres to kilometres, depending on instrument height, boundary-layer conditions, and surface geometry (Oke, 2004). Temperature measurements at shelter height (1–2 m agl) and among close-set highrise buildings, for example, are representative of smaller source areas than measurements high above open, bare fields. The spatial dimensions of the "local" climate zones are therefore flexible to the measurement conditions imposed by the site, and to the measurement set-up of a particular investigation.

Using Sakakibara and Matsui's (2005) radius of 250 metres, we parameterized the "circles of influence" for the Nagano sites by the general properties of the local climate zones. We then selected local climate zones that best match the measured (or estimated) parameters of each field site. Photographs alone can substantiate a reasonably accurate match between field site and local climate zone, but a direct relation between the measured parameters and the zone datasheets ultimately supports a more objective and reproducible outcome. The most important parameters to consider in this process are sky view factor, built fraction, and soil moisture. Like all classifications, the local climate zone system is a simplification of reality. We therefore sought the *best*, not the *exact*, representation of the Nagano field sites using the information provided in the zone datasheets. In some cases, site metadata were incomplete or poorly aligned with the datasheets, and so the process of selecting "best fit" zones became one of skilled judgement rather than automated matching.

3.4. Results

The results of the classification process are summarized in Table 1. Overall, the Nagano field sites appear to be well represented by local climate zones. In other words, with minor exceptions the metadata for each site compare favourably with the general zone properties. The zones capture the ephemeral nature of the Nagano countryside, such that "rural" sites are placed into separate classes for dry, wet, flooded, and snow-cover conditions. Differences in built form are also captured by the zones, such that "urban" sites are placed into separate classes for high and low building density.

Table 1: Classification of Nagano field sites by local climate zones.

Site Photograph	Traditional Classification & Site Metadata	Local Climate Zone	Zone properties ¹				
			SVF	% built	Z _H	μ	Q _F
	Urban Busy downtown area near Nagano city railway station. Buildings 6–10 stories. Vegetation scarce. SVF=0.78. Built fraction > 95 %. μ=1,241	Modern core 	0.40 – 0.60	> 90	> 25	1,200 – 1,700	> 100
	Urban Quiet residential/business area of Toyono town. Buildings 1–2 stories. Few trees. SVF=0.87. Built fraction 60 %. μ=1,222	House & garden - open canopy - 	0.70 – 0.90	40 – 70	5 – 10	500 – 1,500	10 – 15
	Rural Apple orchards in spring. Soils dry. Tree height 3–5 m. SVF from orchard road 0.80. Road fraction < 5 %. Albedo 0.20	Orchards & tree plantations - dry case - 	0.60 – 0.90	< 10	< 5	600 – 1,400	0
	Rural Irrigated paddy fields in spring. Green rice in water ponds. SVF=1. Road fraction < 5 %. Albedo 0.08 – 0.10	Flooded fields 	> 0.95	< 10	< 1	2,000 – 2,500	0
	Rural Drained paddy fields in summer. Mature rice in wet soils. Crop height 1m. SVF=1. Road fraction < 5 %. Albedo 0.18.	Cropped fields - wet case - 	> 0.95	< 10	< 2	1,400 – 2,200	0
	Rural Harvested paddy fields in autumn. Dry, uncovered soils. SVF=1. Road fraction < 5 %. Albedo 0.10 – 0.15	Bare fields - dry case - 	> 0.95	< 10	0.1	600 – 1,400	0
	Rural Snow-covered paddy fields in winter. Snow depth 10 cm. SVF=1. Road fraction < 5 %. Albedo 0.70 – 0.80	Bare fields - snow case - 	> 0.95	< 10	0.05	200 – 600	0

1. Properties and units same as Figure 2.

4. IMPLICATIONS AND FUTURE WORK

Using local climate zones to classify the landscape offers an improvement over traditional “urban-rural” classification. The zones are suitably detailed to the site properties that influence near-surface climate, and they communicate these properties in clear, standardized format. Substantiating inter-city and cross-seasonal differences in surface-layer climate is a useful application of the system. UHI magnitude, for instance, is expressed more objectively through inter-zone temperature differences than through arbitrary urban-rural differences (Stewart and Oke, 2009). If UHI magnitude is defined in this way, it becomes a more robust indicator of urban climate modification than existing indicators (e.g., ΔT_{u-r}). The temptation to interpret inter-city differences in UHI magnitude through surrogates like population or land use is less enticing if the surface properties that control UHI formation are implicit in the site classification system.

Our goal in developing the local climate zone system is to standardize reporting of urban climate sites. In approaching this goal, we continue to refine the nomenclature, definition, and organizational structure of the system. Computer modeling is underway to further quantify the thermal climatology of the individual zones. We believe the system offers an appropriate level of simplicity and inclusiveness, and for that reason should appeal to a wide range of users. To promote universal acceptance of the local climate zone system, we encourage interested users to test the zones with “urban” and “rural” field sites, as we have done in Nagano basin. We welcome feedback from any attempts at applying local climate zones to urban climate field sites in regions worldwide.

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