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LANDSCAPE REPRESENTATION AND THE URBAN-RURAL DICHOTOMY IN EMPIRICAL URBAN HEAT ISLAND LITERATURE, 1950–2006

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Összefoglalás – A városi hősziget (UHI) mérésével kapcsolatos irodalom áttekintése széleskörű ellentmondásokat tár fel a hősziget erősségének számszerűsítéséhez felhasznált városi és külterületi mérési helyeknek az értelmezésében és osztályozásában. Bizonyított, hogy ezeknek az eltéréseknek a gyökere a városklimatológia tér-osztályozási rendszerében régóta fennálló paradigmában, a városi-külterületi kettőségben keresendő. Kidolgozatlan természetének és különösen annak a szerepének köszönhetően, amely a bizonytalanná teszi az UHI irodalomban a városok közötti hősziget-összehasonlításokat, felvetődik a kérdés a városi-külterületi kettősség módszertanával kapcsolatban. Ez a dolgozat egy kezdeti lépést jelent abban az irányában, hogy a többdimenziós helyi léptékű tájosztályozási rendszer jobban illeszkedjen a különböző városokban és régiókban megjelenő UHI-t jellemző felszíni klímatípusok változatosságához. A kapcsolódó történeti irodalom áttekintése és a városföldrajz rokon szakterületének vele párhuzamos fejlődése ösztönzést ennek a rendszernek a kialakítására és fejlesztésére.

Summary – A review of observational urban heat island (UHI) literature uncovers widespread discrepancies in the representation and classification of so-called urban and rural measurement sites defining heat island magnitude. It is argued that the root of this discrepancy is urban climatology's long-standing paradigm for space classification, the urban-rural dichotomy. Due to its crude and amorphous nature, and more specifically for its role in generating unsubstantiated inter-city heat island comparisons in UHI literature, the heuristic value of the urban-rural dichotomy is brought into question. This paper initiates movement toward a multidimensional, local-scale landscape-classification scheme better suited to the complexity of surface climates characterising UHI in cities and regions worldwide. The design and development of this scheme has found impetus in historical literature review and through parallel advancements in the cognate field of urban geography.

Key words: urban heat island, urban-rural dichotomy, landscape classification, field methodology, literature review

1. INTRODUCTION

As the world's population shifts to an urban majority for the first time in human history, our towns, cities, and megacities, and the spaces that surround them, are becoming increasingly complex and interactive. Driven by a half-century of rapid population growth, massive rural-urban migration, and a globalizing economy, this urban "revolution" has triggered a spectacular surge in empirical urban heat island (UHI) literature. City climate investigations of the modern era, dating from *Sundborg's* (1951) classic study of Uppsala, Sweden, have observed and documented the heat island effect at every level of the settlement hierarchy, from agrarian village to post-industrial supercity. This voluminous literature remains coherent in its aim and is impressive in its geographic purview—urban climatology is indeed fortunate to have such diversity of place represented in its ground observations of UHI. However, in looking more critically at the foundations of this literature, we uncover a less coherent, and consequently more concerning, dimension to our representation of urban and rural space.

Essentially a nocturnal phenomenon, the canopy-layer UHI is defined as the region of screen-level warmth created by a city; the surrounding countryside, by comparison, is relatively cool (*Oke*, 1976). The primary causes of the UHI effect are well described in urban climate literature. The thermal, moisture, aerodynamic, and radiation properties of a city are dramatically different from those of the country, due primarily to the replacement and vertical screening of natural surfaces with perpendicular structures and building materials of high heat capacity and low permeability (*Oke*, 1982). Pollutant emissions and anthropogenic heat discharge into the urban atmosphere also contribute to an artificially warm city environment.

The magnitude, or "intensity," of the canopy-layer UHI effect invokes a seemingly intuitive testing procedure of synchronous screen-level air temperature differences between pairs of *in situ* "urban" and "rural" climate stations, or among purposively selected "urban" and "rural" measurement sites along a mobile traverse route. Denoted universally as ΔT_{u-r}, this testing procedure has been the backbone of UHI field methodology since *Luke Howard's* (1833) pioneering observations of the London heat island nearly two centuries ago. Despite the timeless and universal appeal of ΔT_{u-r} as an empirical test of urban impact on thermal climate, the very landscapes (i.e., urban and rural) that give meaning and method to the heat island effect have not been defined in clear, objective, or climatologically germane terms.

A cursory review of modern UHI literature from 1950 to 2006 exposes an alarming diversity of "urban" and "rural" measurement sites characterising UHI. The apparent simplicity behind urban-rural site classification is obscuring the complex array of surfaces and near-surface climates that actually define UHI magnitude; in turn, the tendency of UHI investigators to overlook the micro- and local-scale peculiarities of these surfaces has generated untenable and unconfirmed inter-city comparisons of UHI magnitude in empirical climate literature. This paper invites compelling arguments for a reassessment of the urban-rural dichotomy and its critical role in UHI field methodology.

2. UHI OBSERVATION AND THE URBAN-RURAL DICHOTOMY

Like all branches of natural science, the empirical study of urban heat islands is bound by an experimental method of observation, measurement, analysis, and classification of the "facts" behind the "phenomenon." Beneath this rubric, each case study of UHI embodies a distinct blend of geographic, topographic, and cultural controls on its observed patterns. Not surprisingly, the micro- and local-scale settings of the measurement sites chosen to quantify the UHI effect are remarkably diverse in their exposure and surface characteristics. In describing these sites and their screen-level temperature regimes with such overarching constructs as "urban" and "rural," our investigations of UHI are presupposing the efficacy of this grossly simplified and poorly understood dichotomy.

Table 1 provides a sample of "urban" and "rural" sites used in estimating the magnitude of UHI in modern heat island literature. Although the studies differ slightly in their specific aims, they have common purpose insofar as each seeks an estimate of canopy-layer UHI magnitude based on an "urban-rural" temperature difference from fixed weather stations or mobile temperature surveys. The problem highlighted by *Table 1* relates not to the variety or number of sites classified as "urban" or "rural," but to the representation of sites by an ambiguous and inclusive taxonomy. The geometry, surface materials, and anthropogenic heat flux of a street canyon, for example, are radically different from a botanical garden or a rail station, yet, ironically, all of these settings correspond with "urban" in UHI literature. Likewise, a range of agricultural and undisturbed landscapes are captured by a single (rural) class, while their surface and exposure properties are nothing alike. And perhaps most concerning is the widespread use of airports, college campuses, and meteorological observatories and institutes to represent either "urban" or "rural." This overlap in landscape representation has led to confusion and indiscretion surrounding the classification of measurement sites—especially those on the urban periphery—defining UHI magnitude, and now underscores a need for breakdown and re-examination of the urban-rural dichotomy and its heuristic value to urban climatology.

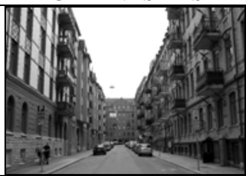
Table 1 "Urban" and "rural" sites representing T_u and T_r in UHI literature, 1950–2006.

URBAN	RURAL	URBAN *AND* RURAL*
botanical garden (*Syrakova and Zaharieva*, 1998)	paddy fields (*Sakakibara and Matsui*, 2005)	airports (U: *Adebayo*, 1991; R: *Klysik and Fortuniak*, 1999)
city square (*Unger*, 1996)	experimental farm (*Bohm*, 1988)	
building rooftop (*Lee*, 1979)	grain fields (*Stewart*, 2000)	college campuses (U: *Parry*, 1956; R: *Chandler*, 1961)
shipyard (*Moreno-Garcia*, 1994)	fruit farm (*Tso*, 1996)	
rail station (*Mukherjee and Daniel*, 1976)	rubber plantation (*Emmanuel and Johansson*, 2006)	school yards (U: *Hisada et al*., 2006; R: *Okoola*, 1980)
city park (*Gedzelman et al*., 2003)	desert (*Hedquist and Brazel,* 2006)	
shopping centre (*Landsberg and Maisel*, 1972)	ecological preserve (*Jauregui*, 1997)	meteorological institutes (U: *Robaa*, 2003; R: *Tumanov et al*., 1999)
housing estate (*Giridharan et al*., 2005)	farming village (*Sakakibara and Owa*, 2005)	
street canyon (*Eliasson*, 1994)	tropical rainforest (*Chow and Roth*, 2006)	weather observatories (U: *Figuerola and Mazzeo*, 1998; R: *Zhou*, 1990)
hospital (*Tumanov et al*., 1995)	ranchland (*Norwine*, 1976)	
fire station (*Yudcovitch*, 1966-7)	moorland (*Lyall*, 1977)	
golf course (*Jonsson*, 2004)	pine flatwoods (*Yow and Carbone*, 2006)	
parking lot (*Bowling and Benson*, 1978)	Arctic tundra (*Hinkel et al*., 2003)	

*U: "urban" reference; R: "rural" reference.

To illustrate the micro- and local-scale surroundings of typical UHI measurement points such as those listed in *Table 1*, photographs of so-called urban and rural sites have been assembled in *Fig. 1*. Pictured here are data-collection sites-classified by the investigators themselves as "urban" and "rural" of modern UHI studies in European, North American, and Asian cities. The "urban" photographs in particular expose the heterogeneity of instrument sitings found in a city environment, from a sheltered town-square (*Unger*,

1996) to a featureless airstrip (*Hedquist and Brazel*, 2006). The "rural" photographs, although less contrasting, also reveal landscapes of distinct character, as seen in *Yow and Carbone's* (2006) native pine forest and *Böhm's* (1998) experimental farm.

	"URBAN" SITES	**UCZ***		**"RURAL" SITES**	**UCZ***
Goteborg SWEDEN (*Eliasson*, 1994)		2	Vienna AUSTRIA (*Böhm*, 1998)		6
Hong Kong (*Giridharan et al.*, 2005)		1	Lodz POLAND (*Klysik and Fortuniak*, 1999)		6
Phoenix USA (*Hedquist and Brazel*, 2006)		NC	Orlando USA (*Yow and Carbone*, 2006)		NC
Szeged HUNGARY (*Unger*, 1996)		2	Szeged HUNGARY (*Unger*, 1996)		NC
Regina CANADA (*Stewart*, 2000)		1	Singapore (*Chow and Roth*, 2006)		NC
Vienna AUSTRIA (*Böhm*, 1998)		2	Wroclaw POLAND (*Szymanowski*, 2005)		7

UCZ* 1: Intensely developed, detached high-rise buildings; 2: Intensely developed, attached low-rise buildings; 3: Highly developed, medium density; 4: Highly developed, low density; 5: Medium development, low-density suburban; 6: Mixed use with open landscapes; 7: Semi-rural development; NC: Site can not be classified.

Fig. 1 "Urban" and "rural" reference sites used in estimating UHI magnitude in observational heat island literature. Each site is classified according to *Oke's* (2004) Urban Climate Zone (UCZ) scheme.

The site locations displayed in *Fig. 1* have been carefully selected by the investigators to ensure, first, that the instruments are secure, and, second, that the immediate surroundings are representative of the local-scale setting. Paradoxically, conventional UHI methodology prescribes these sites, along with countless others in the literature, as universally "urban" or "rural," when in fact the sites have no identical match in any other city. Without aid of photographs, maps, site sketches, and other important metadata, the detailed character of these sites is lost behind a seemingly opaque urban-rural taxonomy. Studies of UHI must therefore report site-specific properties such as surface roughness, extent of impermeable cover, sky view, soil moisture, and artificial heat; otherwise, generalisations and cross-study comparisons of UHI have little or no basis. Indeed, abstracting UHI relationships from among cities and countrysides so diverse in form, function, and setting is made difficult by the fact that the heterogeneity of these landscapes precludes the direct transfer of results from one region to another.

UHI investigators must, then, consider to what extent the micro-scale properties of their selected sites are representative of the larger local-scale setting. If the aim of a UHI investigation is to induce generalisations from the temperature data of specific sites, it is crucial that the temperatures be representative of the thermal conditions across a wider area; if the temperatures are not representative, then subsequent estimates of UHI magnitude are likely to be erroneous. Here, again, we are reminded that the inclusion of detailed metadata with observational UHI studies is essential to meaningful exchange and public understanding of experimental results. The representativeness of a UHI measurement site can only be assessed in the context of its micro- and local-scale properties of surface geometry (sky view factor, height-to-width ratios, roughness class), cover (percentage of built material, albedo, thermal admittance), and artificial heat (space heating/cooling, traffic density). Topographic and climatic influences at both scales must also be documented for all sites. *Oke* (2004) provides a useful template for recording these and other metadata describing the local- and micro-scale environment of a climate station.

3. A PROBLEM OF DEFINITION

Definitions are an important feature of scientific inquiry: they give basis to our hypotheses and sharpen our experimental tests. Despite the long history of UHI observation, urban climate literature has yet to impart a thorough and systematic explanation, from a climate science perspective, of the terms "rural" and "urban." In contrast, literature on urbanisation theory historically distinguishes "urban" from "rural" by population size and density, territorial limits, type of local government, and by various forms of material culture, all of which change by state and region (*Gugler*, 1997). Common to all accounts is that "rural" traditionally denotes a cultural landscape of predominantly agrarian-based employment or peasant-based production. Urban climatologists have yet to translate this basic interpretation into concepts of relevance to natural science. Our definition of UHI as an "urban-rural" temperature difference (ΔT_{u-r}) is therefore flawed because its constituent terms have no operational grounding.

Investigations of UHI consistently define "urban" and "rural" through narrative descriptions, and occasionally through provision of appropriate metadata. The latter is imperative because conventional narratives alone tend to incite tautological, or circular, accounts of site surroundings. Throughout UHI literature we find clumsy definitions and redundant use of synonyms portraying so-called urban and rural spaces: "*rural* measurements were carried out in *open surroundings* typical of the *countryside,*" for example, or "*urban* temperatures are representative of the *built-up* environment of the *city*."

Regardless of how intuitive the terms "urban" and "rural" may be, the reader in these cases is not remotely apprised of the micro- and local-scale surface conditions known to influence screen-level air temperatures.

$\Delta T_{u\text{-}r}$ has given rise to a host of methodological interpretations of its testing procedure. The most basic of these interpretations invokes a temperature difference between pairs of single-point measurements, often at airports and downtown observatories (eg., *Moreno-Garcia*, 1994), although any combination of so-called urban and rural points is possible. A second interpretation invokes a maximum temperature difference between any two points (usually, but not always, an "urban-rural" pair) along a linear traverse route or within a spatial network of stations (eg., *Chandler*, 1961). *Lowry* (1977) provides a different interpretation of $\Delta T_{u\text{-}r}$ as an urban-preurban temperature anomaly ("preurban" here denoting an undisturbed, natural landscape beyond the average urban-affected area, or existing prior to urban development). Preurban sites are difficult to locate because undisturbed landscapes scarcely exist in or near most towns and cities; some investigators have, nevertheless, identified preurban landscapes in their study area (eg., *Yow and Carbone*, 2006). And finally, $\Delta T_{u\text{-}r}$ is often construed as a temperature difference between spatial averages of several "urban" and several "rural" points along a traverse (eg., *Sundborg*, 1951) or within a fixed station network (eg., *Hinkel et al*., 2003). In all cases, the choice of sites for quantifying $\Delta T_{u\text{-}r}$ is balanced on criteria of representativeness, known temperature regimes, *in situ* station networks, access to land and data, and instrument safety.

If each of the above interpretations of $\Delta T_{u\text{-}r}$ is tested in the same city, at the same time, estimates of that city's UHI magnitude will disagree completely. One can only imagine, then, the scatter of results ensuing from a test of all methodological interpretations of $\Delta T_{u\text{-}r}$ across the continuum of micro-scale settings found in any given city. This prospect alone undermines the validity with which inter-study comparisons of UHI can be made. More fundamentally, it demonstrates a need for increased rigour and standardisation in UHI field methodology.

4. A NEW SCHEME FOR UHI LANDSCAPE CLASSIFICATION

The studies depicted in *Fig. 1* have made valuable contributions to our understanding of city climates, each one describing the time and space patterns of UHI for a particular geographic and cultural milieu. Yet as a community of scientists we are not communicating the findings of these and countless other studies as best we can. The urban-rural dichotomy − our long-standing paradigm for space classification − is diverting attention away from the specific methods, assumptions, definitions, landscapes, and temperature regimes embodied in each study. In turn, we are creating a false impression that all UHI investigations observe a similar combination of "urban" and "rural" climates, and each combination is therefore amenable to inter-city comparison. This impression was confronted by *Parry* (1967) in his discussion of the heat island effect in Reading, England. He correctly warns of the danger in failing to identify micro-scale features of UHI:

> Consideration of the diverse ways in which information has been gathered regarding urban "heat islands" compels one to doubt if the same feature has been measured in all cases... The conditions of exposure at fixed recording stations are ... highly significant and the dangers of unrepresentative siting are stressed. A

> plea is made for the recognition of the essentially micro-climatic character of the so-called "urban climate."

Chandler (1962) also addresses issues of scale in his description of the London heat island:

> Local urban morphologies are almost certainly dominant over larger-scale considerations in determining the [urban-rural] temperature anomaly. This may well be true of all occasions, the local heat island intensity being more dependent on the geography of the immediate environment than on the size of the whole urban complex.

The insightful words of *Parry* and *Chandler* some four decades ago give hint of discordance among the "regional-scale" urban-rural dichotomy, the "local-scale" urban heat island phenomenon, and the "micro-scale" influences on our instruments readings. In reconciling these differences of scale, urban climatology must adopt an analytical, multidimensional site characterisation scheme that accommodates the complexity of surface types found in cities and hinterlands around the world (*Stewart and Oke*, 2006). The scheme should be referenced not by the subjective and overly simplistic assessment of landscapes as either "urban" or "rural," but by quantitative, objective measures of surface climate impact. Shifting our experiments into a framework of this nature will guarantee proper assessment and communication of UHI estimates.

No direct attempts have been made at developing a classification system specifically for use in ground-based UHI studies. *Auer* (1978) proposed a scheme for identifying "meteorologically significant" land uses in urban areas.Although some features of his classification system are useful to UHI field methodology, such as the percentage of vegetative cover in a given land-use type, his portrayal of urban and rural land use is less informative because it relates more to land function than to surface form. *Ellefsen* (1990/1) devised a detailed classification system of urban morphological units based on building geometry and materials, and *Davenport et al.* (2000) categorized the aerodynamic roughness of various urban and rural landscapes based on surface form. Neither of these schemes, however, takes account of the urban fabric and its thermal, radiative, and moisture properties. Most recently, *Oke* (2004) blended elements of each of the above schemes into a simple classification of Urban Climate Zones (UCZ). His schematic model divides urban areas into discrete, homogenous units, or "zones," defined only by their ability (in terms of surface geometry and cover) to modify the local surface climate. Each of his seven UCZs is assigned a representative roughness class, aspect ratio, and percentage of impermeable cover. The zones are intended for use at the local scale and as a general guide for the siting and exposure of urban climate stations.

The sites depicted in *Fig. 1* have each been classified according to *Oke's* (2004) UCZ model. Metadata to appropriately classify the sites were obtained from the original studies and through site visitations. Superimposing *Oke's* model on the settings represented in *Fig. 1* quickly exposes the inadequacy of the urban-rural dichotomy. For the most part, the "urban" sites fall into Zones 1 and 2, depending on the general cover and geometry of the local area (<1 km^2) surrounding each site. But on the "rural" side the scheme is much less effective, as only two of the six sites correspond to UCZs, while the remainder can not be classified based on their known site properties. It must be remembered that *Oke's* scheme is not intended for rural site classification, and therefore it specifies only the amount of natural surface cover at a site and not the thermal nature of that cover. Furthermore, *Oke's* (2004) and *Ellefsen's* (1990) schemes are modeled on the built forms of modern, industrialized cities, and thus their application to ancient or underdeveloped settlements is awkward. Nevertheless, the UCZ template provides an ideal framework on which to construct a universal definition of, and measurement protocol for, UHI magnitude. Although not designed specifically for heat island assessment, *Oke's* climate zones can be adapted to this purpose with a complementary and expanded set of agricultural and undisturbed zones. *Stewart and Oke* (2006) have commenced this effort.

In pursuit of a local-scale climate-zone model with universal appeal, climatologists have much to learn from urban theorists and cultural geographers. Substantive literature points to increasingly complex and dispersed metropolitan forms in both the developed and developing worlds: poly-nucleated, decentralized, and dispersed cities have become definitive features of global urbanization (*Lo and Yeung*, 1998). Meanwhile, the urban-rural distinction has become ever more ambiguous. In fact, decades ago social scientists abandoned the urban-rural dichotomy as a policy paradigm in the developing world. It was argued that the space economy in peri-urban regions could no longer be distinguished by a clear city-country divide (*McGee and Robinson*, 1995). Urban theorists now contend that the spatial demarcation between "urban" and "rural" is artificial, and that this relation is better described as a continuum, or a dynamic, rather than a dichotomy: on the urban periphery of the developing world, *in situ* population densities are extremely high; traditional (i.e., small-holder agriculture) and non-traditional land uses co-exist; and people, capital, commodities, and information flow continuously between city and countryside. Urban geographers reject these peripheral spaces as universally "urban" or "rural," and instead adopt expressions like "development corridors," "growth triangles," and "extended metropolitan regions" (*Chu-Sheng Lin*, 1994). In dramatic contrast, the outskirts of localised North American and European cities are open, sparsely settled, and effectively detached from the city. Far from absolute, our interpretations of "urban" and "rural" are profoundly nuanced in culture, geography, and history.

5. CONCLUSION

As the corpus of empirical UHI studies continues to swell, unconfirmed comparisons of city climate are becoming increasingly difficult to tolerate. The need for a structured, unified, and comparative view of UHI findings is now crucial. It has been argued in this paper that a new landscape classification scheme must supersede the traditional urban-rural dichotomy as a basis for comparison and communication of canopy-layer climate observations over surfaces of particular character (such as those in cities and countrysides). The new model will dislodge our instinctive tendency to assess landscapes as crudely "urban" or "rural," and instead embody appropriate physical measures of surface climate impact. Embedded in such a model will be a multidimensional UHI testing implication better suited to the continuum of landscapes shaping city regions worldwide. Our estimates of UHI magnitude can then be anchored to a framework of generalised and standardised surface-climate zones applicable to any city and to any combination of surface types.

The immediate aim of the new classification scheme is to eclipse urban climatology's obstructive and distracting fixation with "urban" and "rural" site designations, and in the process to curtail baseless cross-study comparisons of UHI behaviour. The intent is not, incidentally, to encourage repeated (and redundant) case studies of UHI. Urban climate literature is overstocked with descriptive and confirmatory cases of UHI, each retesting and restating in predictable fashion what has been known for decades of the heat island effect. In spite of their often elaborate and extensive measurement programs, these investigations are primarily of local interest.

The new climate-zone model will steer critical experiments toward sharp, provocative, and novel disclosures of canopy-layer climates and their underlying causes. This prospect bears important implications for climate studies of a much larger context that require intimate understanding of local-scale surface types, especially those of the city and its environs. Attempts to remove urban bias from long-term climate trends, for example, must find improved techniques. Traditional approaches have used surrogate measures of urbanisation, such as population (e.g., *Kukla et al*., 1986) and satellite night-light data (eg., *Peterson*, 2003), to separate "urban" and "rural" temperature series. Future studies must instead take into consideration the structural and climatological character of individual measurement sites. The proposed scheme described in this paper will provide the initial steps toward more definitive assessments of urban impact on regional and global climates.

In closing, there are historical lessons to be learned from urban theorists who contend that the urban-rural divide has collapsed altogether in many parts of the world, and that its heuristic value as a policy paradigm has greatly diminished. Arguably, historical developments in urban geography give impetus to climatologists uprooting this same dichotomy as an operational testing procedure of urban impact on thermal climate. Landscape classification, whether "urban," "rural," or otherwise, is fundamental to UHI definition, experimentation, and explanation. Thought should therefore be given to the progress made in cognate fields before dismantling a shared tradition of space classification.

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