Urban Climate News

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From the IAUC President

Colleagues, welcome to the 46th edition of *Urban Climate News*, which is the last issue of 2012. This publication now enters its now entering its 10th year as the main source of news for the urban climate community. The first edition appeared in October 2003 following on ICUC5 (Łodz, Poland), was just 4 pages in length and asked members to select the IAUC logo! It is a testament to the diligence and vision of David Pearlmutter that *Urban Climate News* has developed and grown in stature in the intervening period.

This edition focuses on a rich vein of research presented by PhD students at ICUC8 in Dublin during August. The ICUC8 event was able to provide 13 student awards of $200 each. Seven of these were provided by the Board of the Urban Environment (a committee of the American Meteorological Society) that co-sponsored ICUC8. Three are provided by the IAUC out of support received for ICUC8 by the WMO, the EPA (Ireland) and SFI (Ireland). The remaining three awards are provided by the Lowry family in honour of William P. Lowry, who made significant contributions to the urban climatology and to biometeorology. In this edition, the recipients of the IAUC and Lowry awards present their work.

The book of proceedings consisting of short papers submitted to ICUC8 will, following a delay, be available in the next couple of weeks on the conference website. An announcement will be made when it is available. Eventually, it will be moved to the IAUC website where it will join those of the ICUC5, ICUC6 and ICUC7. Just as one ICUC event comes to a close, preparations for the next one begin. I would like to congratulate **Valery Masson** and his team who were the successful bidders to host ICUC9 in Toulouse, France during 2015. The competition to host these triennial events was very strong on this occasion and I would like to thank all those that submitted a bid.

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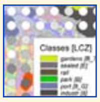

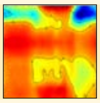

Finally, I would draw the attention of the membership to changes that are taking place on our website. It is planned to create a portal that will allow IAUC members to join, create a personal profile and engage in online conversations with others on topics of interest. The ethos of the IAUC is founded on the principle of a free association of individuals interested in the field of urban climatology and this initiative is designed to develop this community and facilitate the sharing of ideas.

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The IAUC regrets to announce the passing of fellow urban climatologist **Henrique Andrade** on January 8, 2013. Henrique's colleagues from Lisbon commemorate his legacy on page 39.

Tony Brazel honored for four decades of seminal research in urban climatology

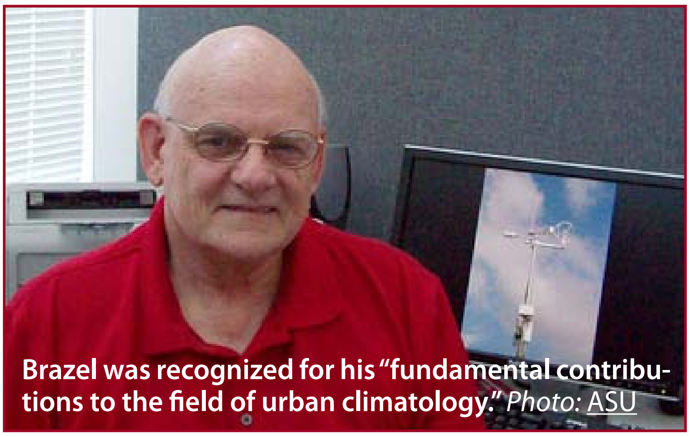
October 2012 — Anthony J. Brazel, Arizona State University professor emeritus, has received the **Helmet E. Landsberg Award** for 2013 from the American Meteorological Society's Board on the Urban Environment.

"Tony's recognition by the American Meteorological Society highlights the prominent recognition his work has garnered across a spectrum of geophysical disciplines," said Randall Cerveny, ASU President's Professor and climatologist in the School of Geographical Sciences and Urban Planning. "His research papers, with topics that include everything from Phoenix urban dust storms to the intricacies of urban climate energy fluxes, are some of the most highly regarded works by geographical climatologists."

This award is named after Helmut E. Landsberg, a climatologist and Presidential Medal of Science winner who modernized how climate data are used to help solve societal problems. Among other accomplishments, Landsberg made ground-breaking connections between climate and urbanization by helping advance the study of urban climates from a descriptive study to one of physical understanding. In selecting Brazel for the award, the society noted the ASU professor's "fundamental contributions to the field of urban climatology, especially those related to understanding urban heat islands in desert environments."

Brazel's work in desert urban climatology began soon after he became director of ASU's Laboratory of Climatology and governor-designated Arizona State Climatologist in 1979. "With new realizations of climate change at this time, there arose many applied and fundamental research opportunities for colleagues at ASU to investigate the role of urbanization and climate change" said Brazel. "The 'research laboratory' was right in front of us – Phoenix, Ariz."

As state climatologist, a position he held until 1999, Brazel and his colleagues worked closely with stakeholders ranging from the National Weather Service to the Arizona Department of Environmental Quality, water and energy provider Salt River Project (SRP), and city and county organizations. In the 1980's, Brazel helped establish a partnership between SRP, ASU, and the State Climate Office that focused on improving short-term weather forecasting models applied to urban areas. Collaborations such as these catalyzed urban climate research, rooted in Phoenix-area and Arizona climate issues, but with implications for the understanding of urban climate globally.



Brazel was recognized for his "fundamental contributions to the field of urban climatology." *Photo:* ASU

Beginning in the late 1990s, as part of the National Science Foundation-funded Central Arizona-Phoenix Long-Term Ecological Research (CAPLTER) Project, Brazel fostered the interdisciplinary study of the region's urban climate, not only leading research initiatives but also mentoring fellow faculty, postdoctoral and graduate student researchers.

"A simple literature search shows nearly twice as many peer-reviewed research articles dealing with Phoenix's urban heat island as there are for either New York City or Houston," comments Winston Chow, a research fellow in ASU's Department of Engineering, College of Technology and Innovation, with a concurrent appointment in the National University of Singapore's Department of Geography. "This flourishing of research in Phoenix is in large part due to Brazel's success in advancing partnerships between ASU and local stakeholders."

"Another important aspect of his work," Chow adds, "is his dedication to geographical fieldwork. Tony has trained numerous students to value the importance of its proper practice, which is key to excellent research."

"Brazel's work in urban climatology – particularly in desert urban climatology – over the last four decades has, quite literally, shaped the fundamental concepts and themes for current research into this increasingly vital and important scientific and social topic," observes Luc Anselin, Regents' Professor and School of Geographical Sciences director.

Brazel is an emeritus professor in the School of Geographical Sciences and Urban Planning, an academic unit of the College of Liberal Arts and Sciences. In 2010, he received the Association of American Geographers Climate Specialty Group Lifetime Achievement Award. Brazel remains as a senior sustainability scholar with ASU's Global Institute of Sustainability, is editor of the Journal of the Arizona-Nevada Academy of Science, and serves on the Editorial Board of the Annals of the Association of American Geographers.

Brazel received the Landsberg Award at the AMS national meeting, held in Austin, Texas on January 6-10, 2013.

Source: https://asunews.asu.edu/20121015_brazel_award

Unbreathable: Air Pollution Becomes a Major Global Killer

December 2012 — The economic growth that many nations in Asia and increasingly Africa have experienced over the past couple of decades has transformed hundreds of millions of lives – almost entirely for the better. But there's a byproduct to that growth, one that's visible – or sometimes less than visible – in the smoggy, smelly skies above cities like Beijing, New Delhi and Jakarta. Thanks to new cars and power plants, air pollution is bad and getting worse in much of the world, and it's taking a major toll on global health.

How big? According to a new analysis published in the *Lancet*, more than 3.2 million people suffered premature deaths from air pollution in 2010, the largest number on record. That's up from 800,000 in 2000. And it's a regional problem: 65% of those deaths occurred in Asia, where the air is choked by diesel soot from cars and trucks, as well as the smog from power plants and the dust from endless urban construction. In East Asia and China, 1.2 million people died, as well as another 712,000 in South Asia, including India. For the first time ever, air pollution is on the world's top-10 list of killers, and it's moving up the ranks faster than any other factor.

David Pettit of the Natural Resources Defense Council explains why air pollution can be so deadly:

> *"So how can air pollution be so damaging? It is the very finest soot – so small that it lodges deep within the lungs and from there enters the bloodstream – that contributes to most of the public-health toll of air pollution including mortality. Diesel soot, which is also a carcinogen, is a major problem because it is concentrated in cities along transportation corridors impacting densely populated areas. It is thought to contribute to half the premature deaths from air pollution in urban centers. For example, 1 in 6 people in the U.S. live near a diesel-pollution hot spot like a rail yard, port terminal or freeway."*

We also know that air pollution may be linked to other nonlethal conditions, including autism. Fortunately in the U.S. and other developed nations, urban air is for the most part cleaner than it was 30 or 40 years ago, thanks to regulations and new technologies like the catalytic converters that reduce automobile emissions. Governments are also pushing to make air cleaner – see the White House's move last week to further tighten soot standards. It's not perfect, but we've had much more success dealing with air pollution than climate change.

A smoggy day in New Delhi, Nov. 2012. *Photo*: TIME

Will developing nations like China and India eventually catch up? Hopefully – though the problem may get worse before it gets better. The good news is that it doesn't take a major technological leap to improve urban air. Switching from diesel fuel to unleaded helps, as do newer and cleaner cars that are less likely to spew pollutants. Power plants – even ones that burn fossil fuels like coal – can be fitted with pollution-control equipment that, at a price, will greatly reduce smog and other contaminants.

But the best solutions may involve urban design. In the *Guardian*, John Vidal notes that Delhi now has 200 cars per 1,000 people, far more than much richer Asian cities like Hong Kong and Singapore. Developing cities will almost certainly see an increase in car ownership as residents become wealthier — and that doesn't have to mean lethal air pollution. (Even ultra-green European cities often have rates of car ownership at or above the level Delhi has now.) Higher incomes should also lead to tougher environmental regulations, which is exactly what happened in the West. We can only hope it happens before the death toll from bad air gets even higher. *Source*: http://science.time.com/2012/12/20/unbreathable-air-pollution-becomes-a-major-global-killer/

China to release real-time air quality data — The Chinese Ministry of Environmental Protection reported in December that the government would issue real-time air quality monitoring data in 74 cities starting Jan. 1, 2013. Notably, the data are to include PM2.5, whereas information on particulate matter available in China used to be limited to PM10. A chief ministry engineer said data on major pollutants in the air, namely sulfur dioxide, nitrogen dioxide, ozone, carbon monoxide and particulate matter will be collected via 496 monitoring sites and released on an hourly basis. *Source*: Xinhua

Turning Israeli roofs into green habitats

Photo: Israel21c

The new ***Green Roofs Ecology Center*** *in Haifa is the first of its kind in the Middle East – and one of the first globally to focus on biodiversity*

December 2012 — Anybody can plunk down some potted trees and pretty planters on a roof, but a rooftop garden does not offer the same environmental and ecological benefits as a "green roof" – a layer of low-maintenance vegetation that insulates the building underneath and reduces flash flooding on paved streets below by acting as a sponge for rainfall.

Prof. **Leon Blaustein**, director of the University of Haifa's new Green Roofs Ecology Center, says the Israeli center is the first of its kind in the Middle East and one of the first worldwide to focus specifically on how to conserve biodiversity in an urban setting.

"When you create a city, you're destroying much of the natural habitat for plants and animals, and we want to mitigate this as much as possible with our rooftop habitats," Blaustein says.

Blaustein and his team have installed 48 experimental modules on top of the university's Student Union, each with a different growing material, drainage configuration and plant grouping.

Ecology researchers around the world will be watching as the Israelis monitor how well each of the modules thrives and attracts insects, birds and other fauna, in the hope of determining the most successful recipe for developing biodiverse green roofs in arid climates.

Eventually, they hope to create experimental green roof plots on additional buildings on the campus and around the city of Haifa, as well as other Israeli cities.

Rooftop 'playground' for ecologists

The Green Roofs Ecology Center will provide an unusual outdoor laboratory for ecology and evolutionary biology researchers from around the world to develop and test ecological theories, says Blaustein, who heads the university's Community Ecology Laboratory.

"We're just getting started. We are looking for collaborators outside the university, such as government and NGO officials," says Blaustein, who has lately been in touch with interested scientists from Switzerland and the United States.

The project got up and running thanks to an overseas donor and input from University of Haifa pollination and plant ecologist Amos Dafni, landscape ecologist Lior Blank, environmental management expert Shay Levy, geography professors Noam Greenbaum and Dan Malkinson, and London green roofs and eco-design expert Gary Grant.

Doctoral candidate Amiel Vasl is in charge of the experiment on the Student Union building, while master's degree candidate Ariel Solodar will be testing the feasibility of using "gray water" coming from the building's sinks to irrigate the plants and purify the water.

Blaustein explains that the growing substrate and foliage on green roofs keep buildings insulated from heat and cold so there is less need to use energy for keeping the interior at a comfortable temperature. And by soaking up rain before it hits the non-absorbent asphalt or concrete below, green roofs can prevent flash flooding in urban environments.

The center was inaugurated in October with the backing of an international advisory board that includes, among others, eco-architect Ayal Ronen from Bezalel Academy of Art and Design in Jerusalem; Rakefet Sinai, an architect affiliated with the Technion-Israel Institute of Technology; and Howard Wenger, California-based president of SunPower and various gardening companies.

Source: http://israel21c.org/environment/turning-israeli-roofs-into-green-habitats/

Heat, Flood or Icy Cold, Extreme Weather Rages Worldwide

January 2013 — Britons may remember 2012 as the year the weather spun off its rails in a chaotic concoction of drought, deluge and flooding, but the unpredictability of it all turns out to have been all too predictable: Around the world, extreme has become the new commonplace.

Especially lately. China is enduring its coldest winter in nearly 30 years. Brazil is in the grip of a dreadful heat spell. Eastern Russia is so freezing — minus 50 degrees Fahrenheit, and counting — that the traffic lights recently stopped working in the city of Yakutsk.

Bush fires are raging across Australia, fueled by a record-shattering heat wave. Pakistan was inundated by unexpected flooding in September. A vicious storm bringing rain, snow and floods just struck the Middle East. And in the United States, scientists confirmed this week what people could have figured out simply by going outside: last year was the hottest since records began.

"Each year we have extreme weather, but it's unusual to have so many extreme events around the world at once," said Omar Baddour, chief of the data management applications division at the World Meteorological Organization, in Geneva. "The heat wave in Australia; the flooding in the U.K., and most recently the flooding and extensive snowstorm in the Middle East — it's already a big year in terms of extreme weather calamity."

Such events are increasing in intensity as well as frequency, Mr. Baddour said, a sign that climate change is not just about rising temperatures, but also about intense, unpleasant, anomalous weather of all kinds.

In Britain, people are used to thinking of rain as the wallpaper on life's computer screen — an omnipresent, almost comforting background presence. But even the hardiest citizen was rattled by the near-biblical fierceness of the rains that bucketed down, and the floods that followed, three different times in 2012.

Rescuers plucked people by boat from their swamped homes in St. Asaph, North Wales. Whole areas of the country were cut off when roads and train tracks were inundated at Christmas. In Mevagissey, Cornwall, a pub owner closed his business for good after it flooded 11 times in two months.

It was no anomaly: the floods of 2012 followed the floods of 2007 and also the floods of 2009, which all told have resulted in nearly $6.5 billion in insurance payouts. The Met Office, Britain's weather service, declared 2012 the wettest year in England, and the second-wettest in Britain as a whole, since records began more than 100 years ago. Four of the five wettest years in the last century have come in the past decade (the fifth was in 1954).

Snow in Jerusalem, January 2013. *Photo:* NYTimes

The biggest change, said Charles Powell, a spokesman for the Met Office, is the frequency in Britain of "extreme weather events" — defined as rainfall reaching the top 1 percent of the average amount for that time of year. Fifty years ago, such episodes used to happen every 100 days; now they happen every 70 days, he said.

The same thing is true in Australia, where bush fires are raging across Tasmania and the current heat wave has come after two of the country's wettest years ever. On Tuesday, Sydney experienced its fifth-hottest day since records began in 1910, with the temperature climbing to 108.1 degrees. The first eight days of 2013 were among the 20 hottest on record.

Every decade since the 1950s has been hotter in Australia than the one before, said Mark Stafford Smith, science director of the Climate Adaptation Flagship at the Commonwealth Scientific and Industrial Research Organization.

To the north, the extremes have swung the other way, with a band of cold settling across Russia and Northern Europe, bringing thick snow and howling winds to Stockholm, Helsinki and Moscow. (Incongruously, there were also severe snowstorms in Sicily and southern Italy for the first time since World War II; in December, tornadoes and waterspouts struck the Italian coast.)

In Siberia, thousands of people were left without heat when natural gas liquefied in its pipes and water mains burst. Officials canceled bus transportation between cities for fear that roadside breakdowns could lead to deaths from exposure, and motorists were advised not to venture far afield except in columns of two or three cars. In Altai, to the east, traffic officials warned drivers not to use poor-quality diesel, saying that it could become viscous in the cold and clog fuel lines.

Meanwhile, China is enduring its worst winter in recent memory, with frigid temperatures recorded in Harbin, in the northeast. In the western region of Xinjiang, more than 1,000 houses collapsed under a relentless onslaught of snow, while in Inner Mongolia, 180,000 livestock froze to death. The cold has wreaked havoc with crops, sending the price of vegetables soaring.

Way down in South America, energy analysts say that Brazil may face electricity rationing for the first time since 2002, as a heat wave and a lack of rain deplete the reservoirs for hydroelectric plants. The summer has been punishingly hot. The temperature in Rio de Janeiro climbed to 109.8 degrees on Dec. 26, the city's highest temperature since official records began in 1915.

At the same time, in the Middle East, Jordan is battling a storm packing torrential rain, snow, hail and floods that are cascading through tunnels, sweeping away cars and spreading misery in Syrian refugee camps. Amman has been virtually paralyzed, with cars abandoned, roads impassable and government offices closed.

Israel and the Palestinian territories are grappling with similar conditions, after a week of intense rain and cold winds ushered in a snowstorm that dumped eight inches in Jerusalem alone.

Amir Givati, head of the surface water department at the Israel Hydrological Service, said the storm was truly unusual because of its duration, its intensity and its breadth. Snow and hail fell not just in the north, but as far south as the desert city of Dimona, best known for its nuclear reactor.

In Beirut on Wednesday night, towering waves crashed against the Corniche, the seaside promenade downtown, flinging water and foam dozens of feet in the air as lightning flickered across the dark sea at multiple points along the horizon. Many roads were flooded as hail pounded the city.

Several people died, including a baby boy in a family of shepherds who was swept out of his mother's arms by floodwaters. The greatest concern was for the 160,000 Syrian refugees who have fled to Lebanon, taking shelter in schools, sheds and, where possible, with local families. Some refugees are living in farm outbuildings, which are particularly vulnerable to cold and rain.

Snow in Jerusalem, January 2013. *Photo:* Flash90

Barry Lynn, who runs a forecasting business and is a lecturer at the Hebrew University's department of earth science, said a striking aspect of the whole thing was the severe and prolonged cold in the upper atmosphere, a big-picture shift that indicated the Atlantic Ocean was no longer having the moderating effect on weather in the Middle East and Europe that it has historically.

"The intensity of the cold is unusual," Mr. Lynn said. "It seems the weather is going to become more intense; there's going to be more extremes."

In Britain, where changes to the positioning of the jet stream — a ribbon of air high up in the atmosphere that helps steer weather systems — may be contributing to the topsy-turvy weather, people are still recovering from the December floods. In Worcester last week, the river Severn remained flooded after three weeks, with playing fields buried under water.

In the shop at the Worcester Cathedral, Julie Smith, 54, was struggling, she said, to adjust to the new uncertainty.

"For the past seven or eight years, there's been a serious incident in a different part of the country," Mrs. Smith said. "We don't expect extremes. We don't expect it to be like this." *Source*: NYTimes.com

When **Hurricane Sandy** approached the east coast of the US in late October 2012, the country's most populous meropolitan area got a close look at extreme weather. The largest preemptive public transportation shutdown in US history may have been a sign to residents of New York, Philadelphia, Baltimore, and Washington, D.C. that such storms could have increasingly urban implications. In a poll of New Yorkers, 69% said they consider Sandy and other recent tropical storms to be associated with global climate change, and officials spoke publicly about their expectations that "extreme" events are likely to become the new norm.

Atlantic City meets Sandy: October 29, 2012.

Classification of Local Climate Zones from multitemporal remote sensing data

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The local climate zone (LCZ) scheme recently introduced by Stewart & Oke yields great potential to standardise the classification of local scale landscapes in urban climatology. To ensure higher comparability of measurement sites and results from various study areas, each LCZ class is defined by a standard set of morphological and land cover properties from the canopy layer. To increase the scheme's objectivity and transferability, the scheme includes fact sheets that contain quantitative metadata for each LCZ class. Since LCZs were not designed for mapping purposes, the classification of a larger domain like an entire city is a demanding task which requires considerable expert knowledge, time, as well as certain modification to the original LCZ concept. Therefore, in this study it was investigated whether LCZ can be automatically classified from multitemporal remote sensing data from different sources, including satellite multispectral and thermal data as well as morphological features from airborne interferometric SAR. The results for Hamburg with different classifiers (among them Support Vector Machines, Multilayer Perceptron Networks and Random Forest) are quite promising. Especially multitemporal thermal infrared data (containing information from different irradiation conditions) yielded high potential for LCZ classification with overall accuracies of up to 96.3 %. Multitemporal multispectral data including NDVI reached 95.1% and automatically selected features from different sensors and pre-processing methods up to 97.4 %. Hence, LCZ can be automatically classified and remote sensing can contribute to a better characterization of urban surfaces with respect to their microclimatic properties. Further, the classified LCZ for Hamburg roughly correspond with the city's heat island pattern as derived from floristic proxy data.

1. Introduction

The urban heat island (UHI) is the most well-known and analysed phenomenon in urban climatology. There are several ways to measure UHI magnitude in the canopy layer, for example through the comparison of upwind-downwind air temperature differences, time trends of differences during urbanisation periods as well as differences between weekdays and weekends (Lowry, 1977). However, the most common method is the difference between measurements within a city and a rural station nearby. This method has several problems, like the assumption that the 'rural' station is free of urban effects and that both stations have identical meso-scale (topoclimatic) settings. An even more fundamental problem is the lack of meaningful definitions for "urban" and "rural" (Stewart & Oke, 2009). In the UHI literature a wide variety of different landscape types have been classified as urban and rural. This is partly a consequence of urban areas not being homogenous with clear borders but rather a continuum of morphologies of different densities with different degrees of imperviousness and various physical material properties. Stewart gave a review of the discrepancies in the portrayal of urban and rural sites and proposed a new approach to space classification using a '*multidimensional, local-scale landscape-classification scheme better suited to the complexity of surface climates characterising UHI in cities and regions worldwide*' (Stewart, 2007).

Two years later Stewart & Oke proposed local (thermal) climate zones (LCZ) as a more purposeful local landscape classification system to quantify UHI magnitudes, and to put 'methodological rigor' behind their computation (Stewart & Oke, 2009). The new typology includes aspects of previous typologies from urban climate literature but is additionally aligned to fulfil clear criteria such as *accessibility* (universal in function and manageable in size), *objectivity* (measurable and testable class properties which are relevant to surface thermal climate), and *inclusiveness* (sufficiently generic in the representa-

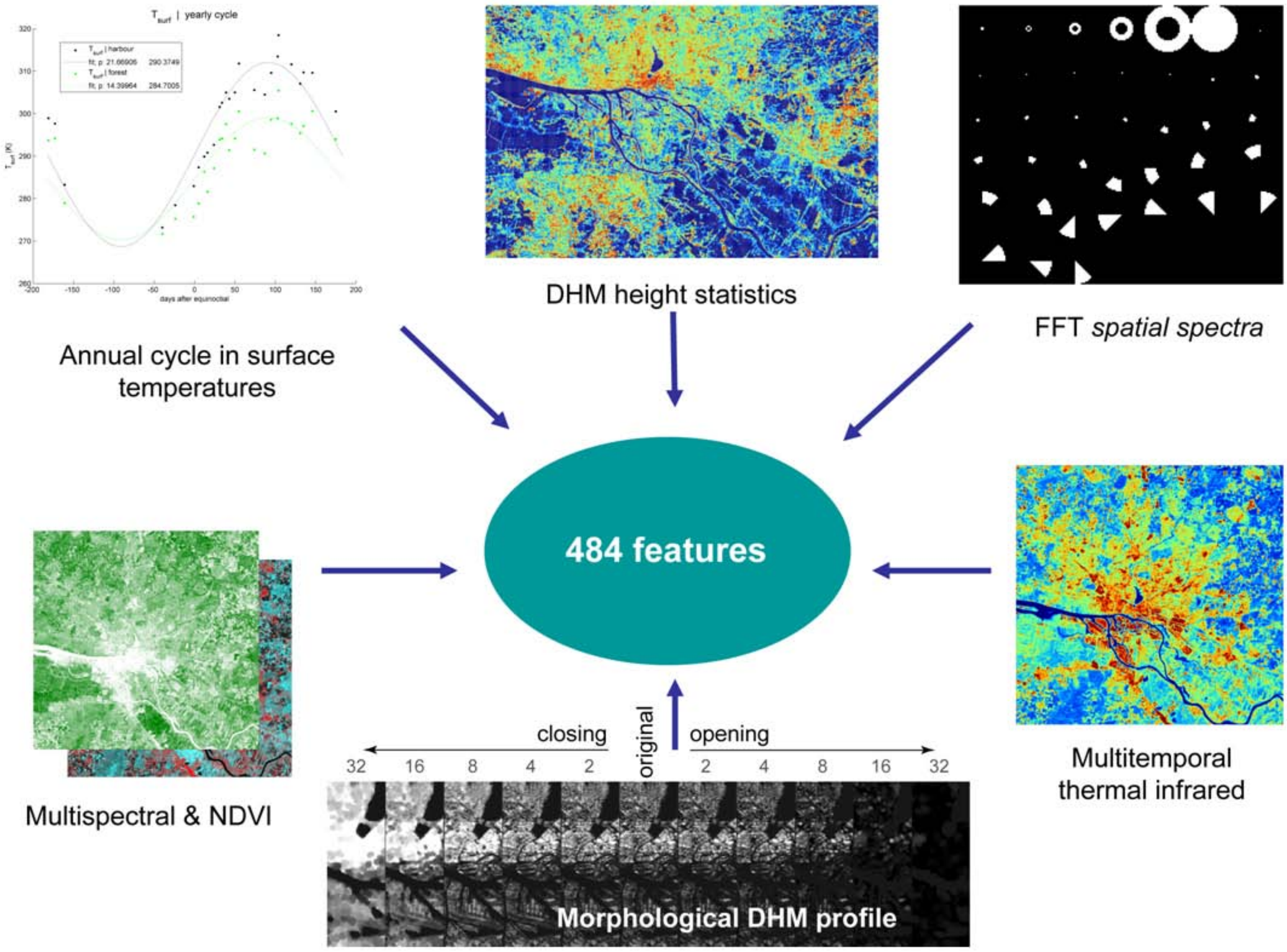

Figure 1. Features from different sources included in the classification.

tion in order not to inherit regional or cultural biases). The final version of the scheme was recently published and comprises ten built and seven land cover types, as well as variable land cover properties (Stewart & Oke, 2012).

The LCZ scheme helps to standardise the classification of local landscapes and urban morphologies in the field of urban climatology. Although the classification system first serves as a framework for improved metadata communication in observational heat island studies, other applications were proposed including climate modelling and weather forecasting with urban canopy parameters derived from LCZ and planning tools based on spatial databases for urban form and cover (Stewart & Oke, 2012). These applications require a spatially extensive classification of LCZs which is not trivial, since it involves considerable expert knowledge and is very time consuming when conducted for a large domain. Therefore, an automated classification of LCZ would be an asset for studies in urban climatology. The most promising data source for such an automated and extensive classification of LCZ is multitemporal remote sensing. In this study it was investigated whether LCZ can be automatically derived from such data and which features and classifiers are most suitable. The idea was introduced in (Bechtel, 2011); the complete study is published in (Bechtel & Daneke, 2012). This paper includes a summary of the most important findings as well as additional results. Further, the derived classes were tested with a UHI pattern derived from floristic proxy data.

2. Data and methods

For the case study, the city of Hamburg in Northern Germany was chosen. It has approximately 1.8 million inhabitants and is a good example of a European metropolis. It has a rather moderate climate and a mean UHI of about 1.1 K (Schlünzen *et al.*, 2010).

Features for classification

For this study, features from different sources were considered. The sensors include airborne Interferometric Synthetic Aperture Radar (IFSAR) and the multispectral and thermal sensors onboard Landsat 4, 5 and 7.

The geometric features were derived from the IFSAR data and contain information about the obstacles, their height, density and orientation. While *heightstat* only contains descriptive statistic measures like maximum, minimum, mean and variance of heights within one grid-cell, *morph* is a morphological opening and closing profile, and *fft* a spatial spectral signature derived by Fourier Transformation and spectral filtering with different band pass and sectoral filters.

The multispectral features (MS) were derived from Landsat multispectral data in visible, near and middle infrared wavelength as well as the Normalized Differenced Vegetation Index (NDVI) from different acquisition times. They contain information about the albedo, the composition of surface materials as well as the vegetation.

The multitemporal thermal infrared features (TIR) were also derived from Landsat and contain information about the surface temperature and differential heating patterns under diverse irradiation conditions. Hence, the annual cycle parameters (ACP) describe the mean annual cycle in the surface temperature with a simple sine function (Bechtel, 2012).

Although many features can be related to the urban energy balance or aerodynamic characteristics, the approach is inductive and machine learning tools were applied to chose the most relevant features. Since LCZ are defined at horizontal scales of 10^2 to 10^4 m, all features were resampled to a common 100 m grid. An overview of the parameters is given in Figure 1; for further information about the features and the processing see Bechtel & Daneke (2012).

Training data

LCZ are defined as "*regions of uniform surface cover, structure, material, and human activity that span hundreds of meters to several kilometers in horizontal scale*" with a "*characteristic screenheight temperature regime*" (Stewart & Oke, 2012). In the time between the first and most recent publications of LCZs (in 2009 and 2012, respectively) the scheme evolved considerably. Since in this study the typology served as an interface to other sub-projects (e.g. an urban system model for land use scenarios) and thus had to be determined in the beginning, a rather early version of the LCZ was applied. However, most of the 2009 classes can be transferred to the 2012 scheme, and it is assumed that the proposed method works as well with this most recent version of LCZs.

In addition, a few further aspects need to be considered from a "pattern recognition" point of view. First, the classification requires a rather low variability within a class not only with respect to canopy layer thermal climate but also the features used for classification. It will fail if the internal heterogeneities of the classes become too big. Since the LCZ typology is 'inherently generic' its partitioning into individual classes does not perfectly suit the existing morphologies in Hamburg. In particular, there is a wide variety of compact morphologies with four to six storeys and very different geometric layouts (mostly with trees) which all would be LCZs 2, 2_5 or 5 in the 2012 scheme. Hence the compact morphologies were split into *urbcore* (LCZ 2), *urbdens* (perimeter block buildings of uniform height with courtyards in the center), and *terrace* (regular pattern aligned in rows) instead. Likewise, the class *Extensive Lowrise* from the 2009 scheme was split into *industr* (LCZ 8) and *port* (LCZ 8_G) since Hamburg comprises large harbour areas which 'look' different for the classifier because of container-arrays and water bodies. The classes *modcore*, *blocks*, and *reghous* are equivalent to the respective 2009 (2012) classes: *Modern Core* (LCZ 1), *Blocks* (LCZ 4) and *Regular Housing* (LCZ 6).

The second issue that needs to be addressed is completeness. Since the classification is extensive (meaning a class is assigned to every pixel), some additional classes had to be introduced to prevent misclassification. Allotment *gardens* are a specific local landscape in Germany with small huts in a natural setting (roughly LCZ B_7) while *rail* is a special case of LCZ 8. Since the split classes can be reaggregated and the additional classes can be removed post-classification, these changes do not severely limit the universality of the method and a 'pure' LCZ map can easily be derived.

For each of the classes, representative reference

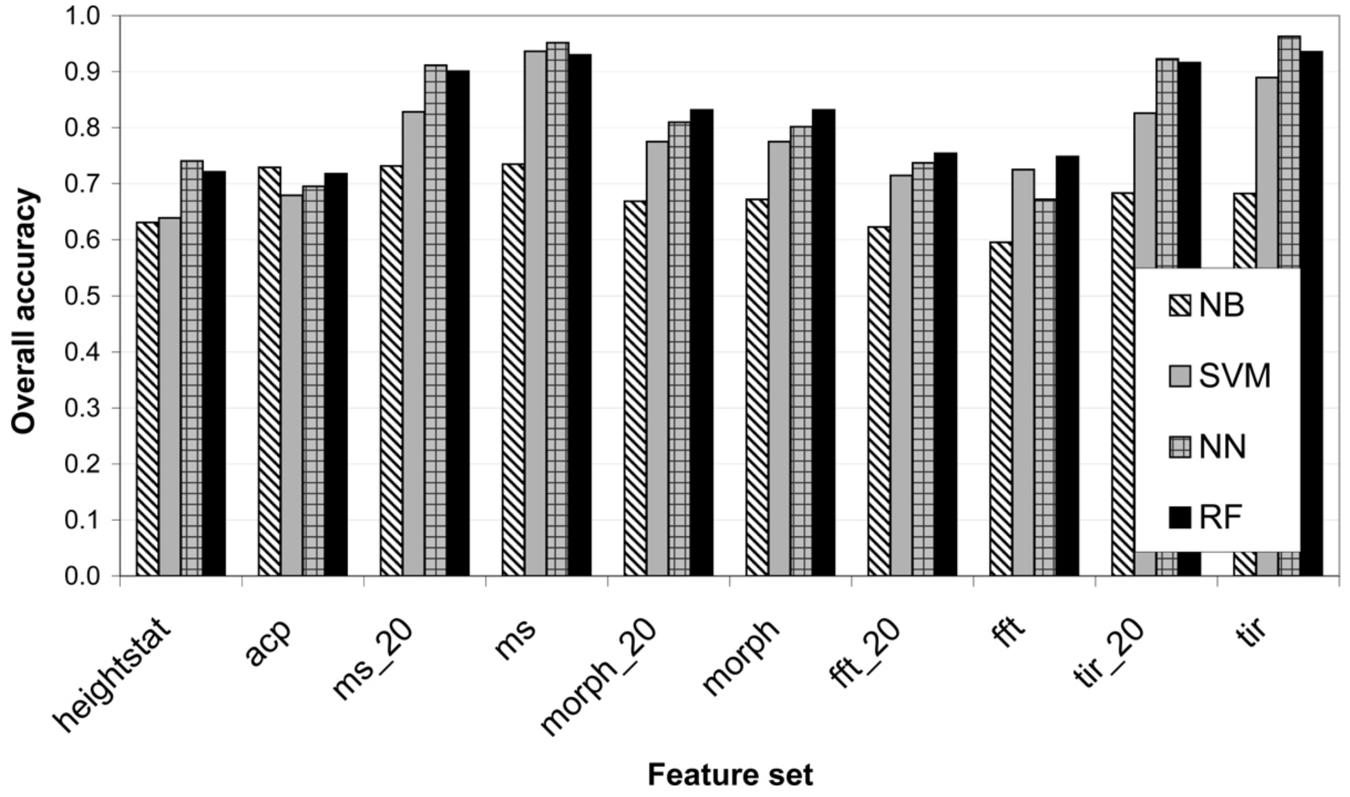

Figure 2. Overall accuracy for predefined feature sets and different classifiers.

areas were manually digitized using maps and very high resolution multispectral data. From these areas, about one fourth of the pixels were reserved for testing while the rest were used to train the classifiers.

Classifiers and feature selection

To test the suitability of the chosen features for LCZ classification, three experiments were conducted. First the single feature sets were used for pixel-based supervised classification with a number of up-to-date classifiers including naïve Bayes (NB), support vector machine (SVM), neuronal networks (NN) and random forest (RF). Since all classifiers are trained, prior calibration of the features (to reflectance and surface temperature instead of radiance) was not considered necessary (Song *et al*., 2001).

In the second experiment, feature sets of different sizes from all sources were selected with the minimum redundancy maximal relevance (MRMR) feature selection (Peng *et al*., 2005). The algorithm selects features with high relevance for classification and low redundancy with the prior chosen features by a mutual information criterion (called MID or MIQ for difference and quotient respectively).

In the third experiment, different configurations of RF and NN classifiers were tested for their performance. RF is an ensemble of tree-structured classifiers which vote for the result. Hence the number of trees and the number of features used for each tree can be varied. For NN, number and size of the hidden layers between the input layer (features) and the output layer (classes) were varied.

Thermal differentiation of LCZ

In addition to the performance evaluation, the surface-air temperature of the derived classes should be evaluated. Unfortunately, in Hamburg no data is available that fulfils the scientific requirements for observational heat island studies formulated by Stewart (2011). However, a mean heat island pattern from floristic proxy data (UHI_{EIT}, EIT = Ellenberg indicator values for temperature) was recently published by Bechtel & Schmidt (2011). The pattern was derived from the distribution of established, spontaneous vascular plant species as recorded in a comprehensive floristic mapping and calibrated with mean daily UHI observations at five stations from

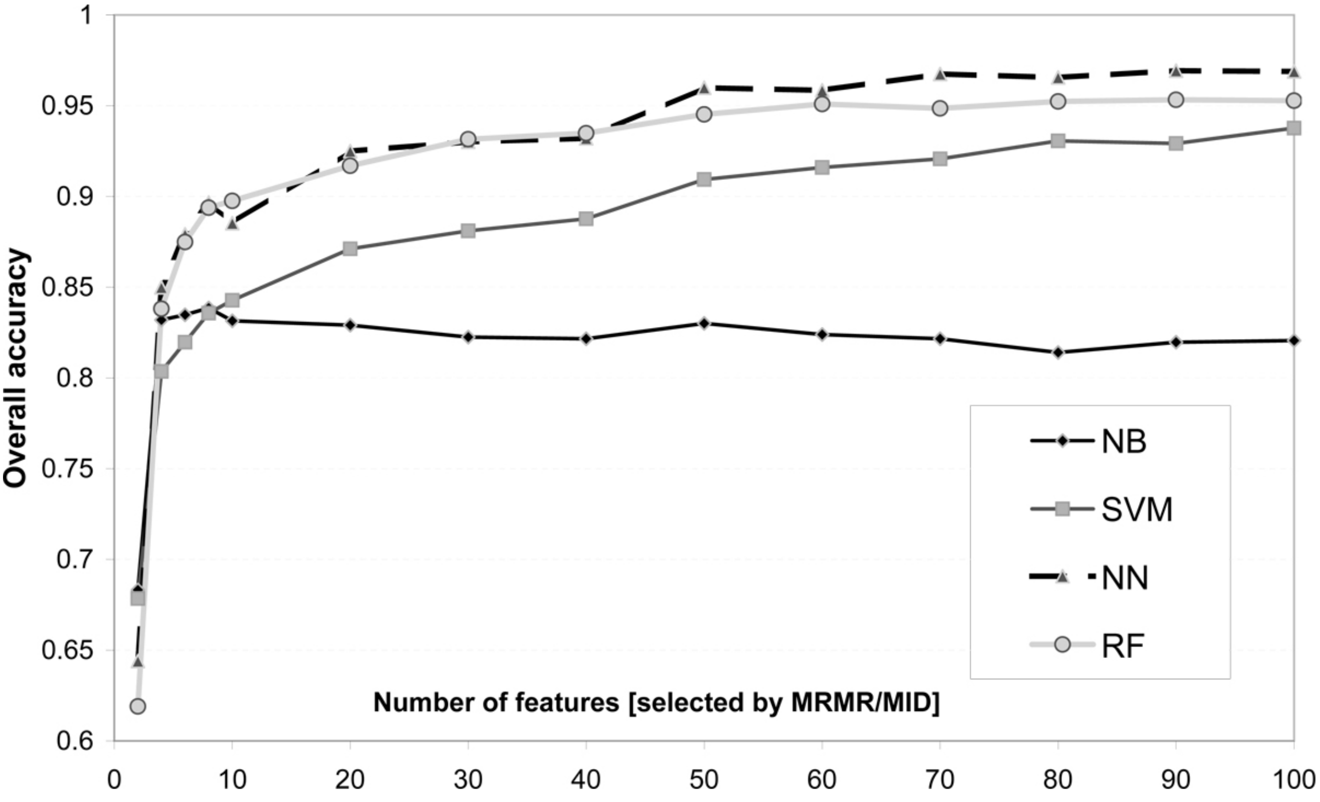

Figure 3. Overall accuracy for selected feature sets with MRMR/MID and different classifiers.

one decade (Schlünzen *et al.*, 2010). Although the pattern is likely to contain further effects (including meso-scale differences inherited from the calibration data), the resulting data set shows a clear heat island pattern that is assumed to be predominantly related to the mean canopy layer air temperature over a longer time. Hence, while the exact numbers of the UHI_{EIT} are not particularly reliable, the dataset has the great advantage of complete 'observations' on a 1 km raster and integration across a longer time (Gödde & Wittig, 1983). In this study the UHI_{EIT} (derived from mean EIT from at least 80 species) of the derived classes were evaluated for the classified LCZ. Since Stewart & Oke (2012) recommend the use of homogenous patches of 200 – 500 m radius, the derived class memberships were first filtered by a morphological opening with a disk-shape structuring element of 400 m radius and only the homogenous patches were assigned to their closest UHI_{EIT} value.

3. Results

Classification of LCZ

The results of the predefined feature sets with different classifiers are shown in Figure 2. The given numbers indicate the overall accuracy (OA, percentage of correctly classified pixels of the testing data).

Naïve Bayes performed less well than the more sophisticated classifiers. SVM is especially useful for very large feature sets (e.g. MS with 198 features) but it was mostly outperformed by NN and RF. Regarding the feature sets, multitemporal MS (95.1 % with NN) and TIR (96.3 % with NN) data showed the best results. This is very convenient, since these data are available worldwide at no charge. *FFT* and especially *morph* showed better results than the simple height statistics, indicating an added value of the incorporated spatial information. However, the morphological features did not reach the performance of TIR and MS. For the larger feature sets, selected subsets of 20 features were tested in addition, which performed slightly worse in all cases.

Figure 3 shows the results for feature sets of different sizes selected by MRMR with the mutual information difference criterion. It can be seen that all classifiers rapidly improved their performance between 2 and 10 features. With more than 10 features the performance of NB decreased (because the assumption of conditional independency is violated) and the performances of the other classifiers

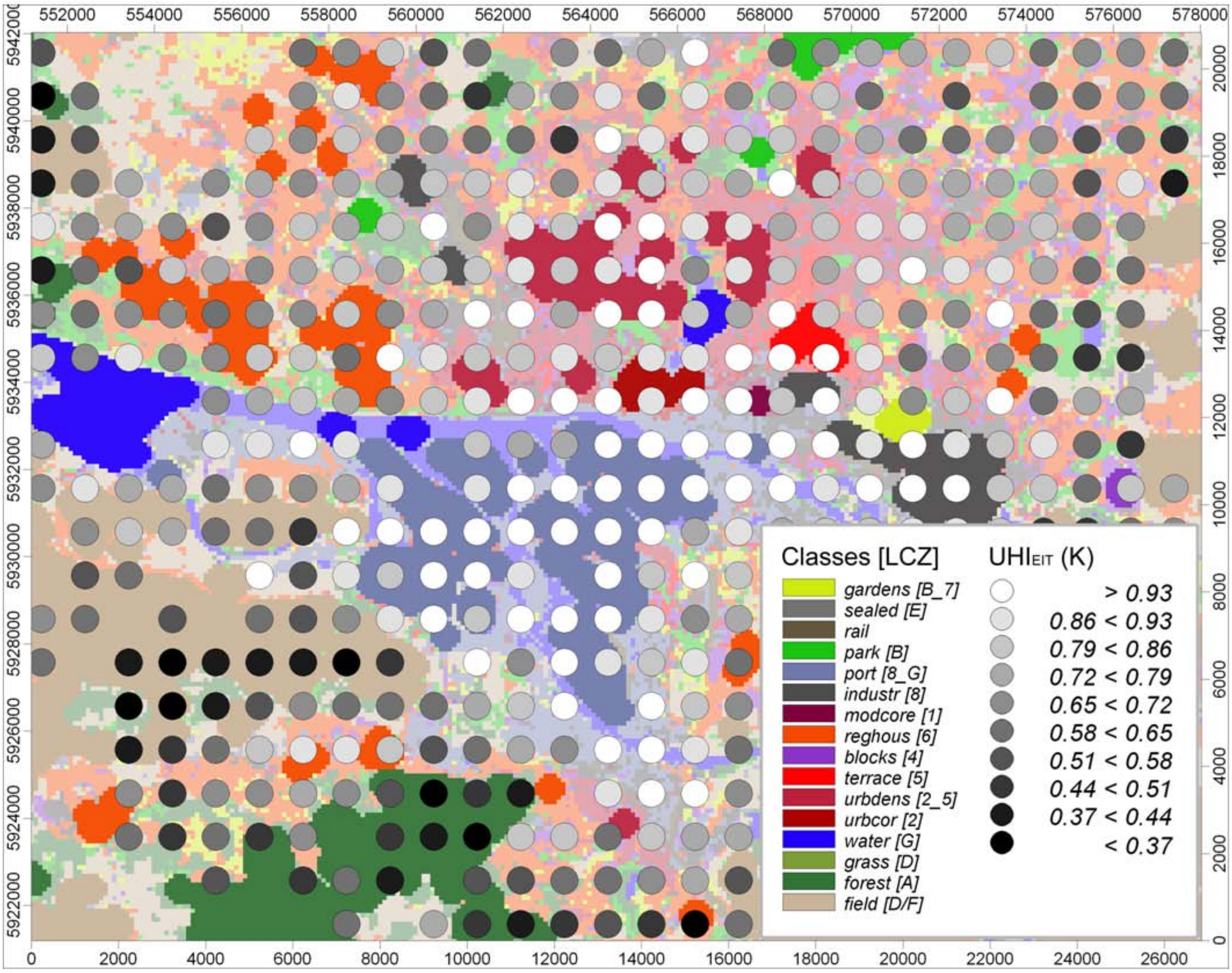

Figure 4. Homogenous LCZ patches from classification and floristic heat island pattern UHI_{EIT}.

improved more slowly (because of the high redundancy in the dataset). RF and NN reached a plateau at about 50 features while SVM performed less well but still improved with larger datasets. Again NN and RF outperformed the other classifiers. All predefined feature sets were represented within the top 20 selected features.

In the third experiment, different configurations of the best classifiers NN and RF were tested with one feature set. TIR as the best predefined set and 50 MRMR features were selected. Table 1 shows that the results were slightly improved with more complex classifiers. However, which classifier performed best depended on the feature set.

Thermal differentiation with floristic UHI pattern

The floristic heat island pattern and the homogenous patches of selected classes from the neuronal network classification with 100 features (MRMR/MIQ) are shown in Fig. 4. Thermal differences be-

Table 1: Results of experiment 3 – different NN and RF classifiers. F: number of features, C: number of classes. Best input parameters for respective classifier and feature set are highlighted in blue colour.

	hidden layers / trees	tir_20	tir	MRMR/ MID 50
Neuronal Network	40,30,20	**0.940**	0.962	0.939
	50,30,15	0.932	**0.967**	0.946
	F	0.934	0.963	**0.960**
	F,C	0.925	0.951	0.952
	F,F,C	0.924	0.966	0.955
Random Forest	10 trees	0.922	0.922	0.924
	30 trees, 20 feat	0.921	**0.938**	0.948
	50 trees, 30 feat	0.920	0.936	0.945
	60 trees, 20 feat	**0.923**	**0.938**	**0.951**

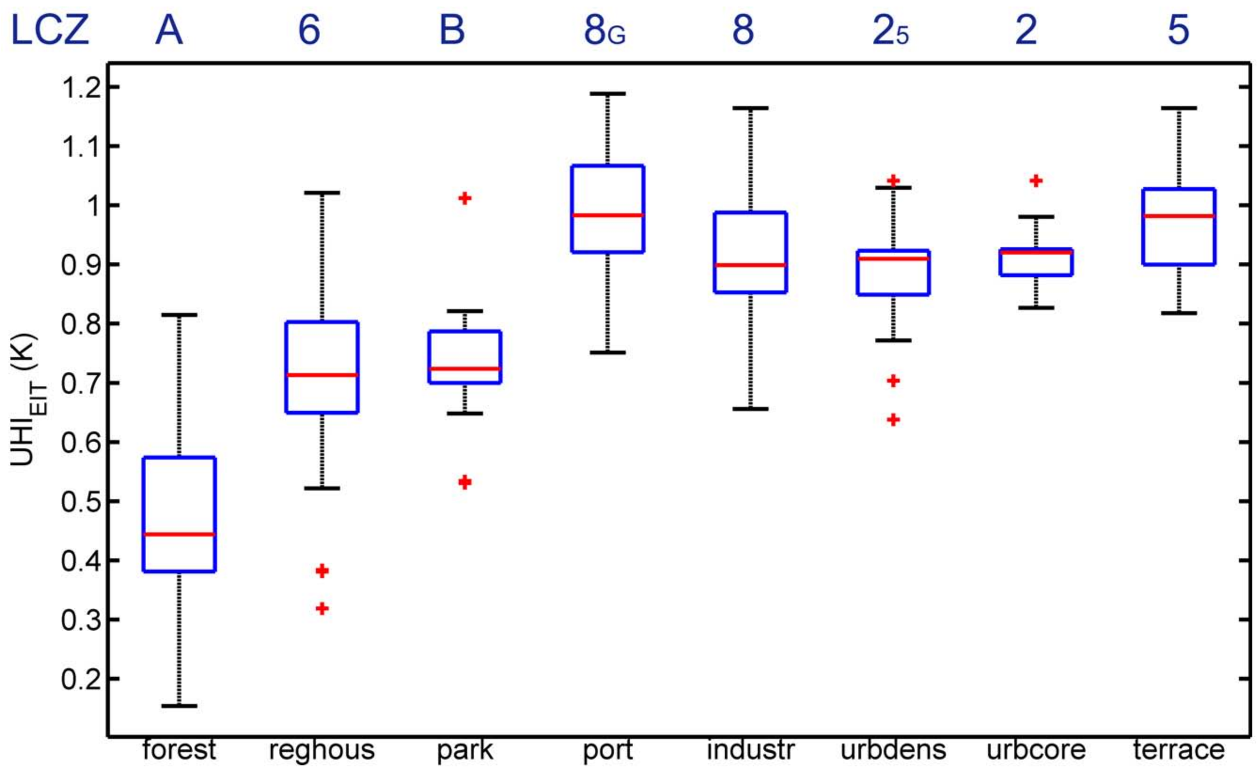

Figure 5. Floristic heat island UHI_{EIT} for classified LCZ.

tween the port areas, the dense inner city and the less compact suburban areas are clearly visible.

Fig. 5 shows the (floristic) heat island for different LCZs. First, it is noticeable that the natural land cover type forest (LCZ A) also shows a certain heat island signal. This indicates a meso-scale bias inherited from the calibration data and as stated before, the absolute numbers should not be taken too seriously. The relative differences however are much more reliable, and show a clear thermal differentiation in UHI_{EIT} between forest (LCZ A), the medium dense class *Regular Housing* (LCZ 6), and the dense urban (LCZs 2, 2_5 and 5) as well as commercial/industrial classes (LCZ 8 and 8_G).

The differentiation matches the expectations quite well except for the large UHI of the terrace (LCZ 5) class. In a one-way analysis of variance combined with a multiple comparison test based on the Tukey's honestly significant difference criterion the differences in the class means were significant for most class pairs (except LCZs [6,B], [8,2], and [8_G,5]). However, this result should be treated carefully for a number of reasons. First, the sample of LCZ estimates is much larger than the number of independent UHI_{EIT} estimates, resulting in an overestimation of the significance. Secondly, the co-occurrence of other LCZs in the 1 km UHI_{EIT} grid was neglected. Besides, the limitation to large homogenous patches resulted in an exclusion of large areas due to the noisy nature of the pixel-based classification. Furthermore, considering the origin of the UHI_{EIT} data, which clearly fails the criteria for observational studies, the validity of this result is certainly somewhat limited. Nevertheless, besides the acknowledged limitations, the UHI pattern based on floristic proxy data is a novel dataset and can still be seen as a small contribution to the validation of LCZs.

4. Conclusion

The central findings of this study are:

- The automated classification of LCZ is possible with very good OA of > 95 %.
- Different features are suitable, especially multitemporal TIR and MS data, which are freely available from Landsat.
- Morphological features can be used to improve the classification but are not sufficient alone.
- NN and RF classifiers are very powerful for the classification and can be optimised.
- Choice of the right classifier is about as impor-

tant as the right input data.

- The classified LCZs show (significantly) different mean thermal characteristics (derived from floristic proxy data).

More case studies shall be conducted to see whether the results can be reproduced for other cities. In the future, the 2012 version of LCZs will be used. However, for the classification it might be necessary to prior define subclasses and additional classes in order to get a more comprehensive representation of the local morphologies and landscapes. Since this partly contradicts the aim of generalisation, it should be evaluated whether these (especially diverse compact morphologies in European cities) only effect the automated classification or also result in different canopy layer climates to find the most appropriate division of the landscape universe. Further, more standardised features shall be developed in order to create transferable classifiers and to investigate the properties of the different LCZ. Eventually, such an improved method will hopefully contribute to building spatial databases of urban form and cover.

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Assessment of urban climate conditions in a hot humid tropical city

Summary

Attendant problems of urbanization on the quality of the thermal environment have been well researched in many temperate countries, but studies are relatively lacking in the low tropics. Urbanisation in developing countries requires scientific approaches that can foster new ways of governance since it brings several management practices and environmental concerns into focus.

The rapid growth of Akure has made it one of the fastest growing metropolitan cities in the Southwestern Nigeria. Within the last three decades, subsequent changes in the land-atmosphere energy balance relationships have occurred alongside traffic-related air quality degradation over the city. With the rapid rate of this expansion, the study of urban climatology and human impacts on the local climate and air quality has become more important. Knowing the extent of change in the transition of various land use types within the city metropolis is very important in this study. Hence, multi-temporal remote sensing data and GIS techniques with field survey were used to detect land-use/land-cover changes (LULCC) at different epochs in the city. The climatological analysis of the differences in air temperature between rural and urban areas (ΔT_{u-r}) corroborates the existence of an urban heat island (UHI) in the city. The nocturnal heat island is observed to be more frequent than the daytime heat island and stronger during the dry season. Values of cooling degree days obtained suggest that elevated temperatures in the central urban areas both day and night will increase the potential for cooling of buildings. Also, intra-urban variations of temperature are shown to be influenced by land use and other site factors. The highlights of the cooling effects of the vigorous evapotranspiration of the city trees during both the dry and wet seasons, and the potential of trees as a cost effective UHI and climate change impact mitigation tool in Akure is presented in this regard.

The Study City

Akure, the capital city of Ondo State, Nigeria is located at latitude 7.25°N and longitude 5.20°E. The rapid growth of the city, particularly within the last 25 years, has made it one of the fastest growing metropolitan cities in the Southwestern Nigeria. Its population has more than tripled from 157,947 in 1990 to ~500,000 in 2006 (Balogun *et al*., 2011). It became an administrative and economic seat to Akure South Local Government Authority, and Ondo State with the latter's creation in 1976 from the old Western State. Since then, the city has witnessed immense growth in the size of built-up areas, number of inhabitants, transportation, and commercial activities.

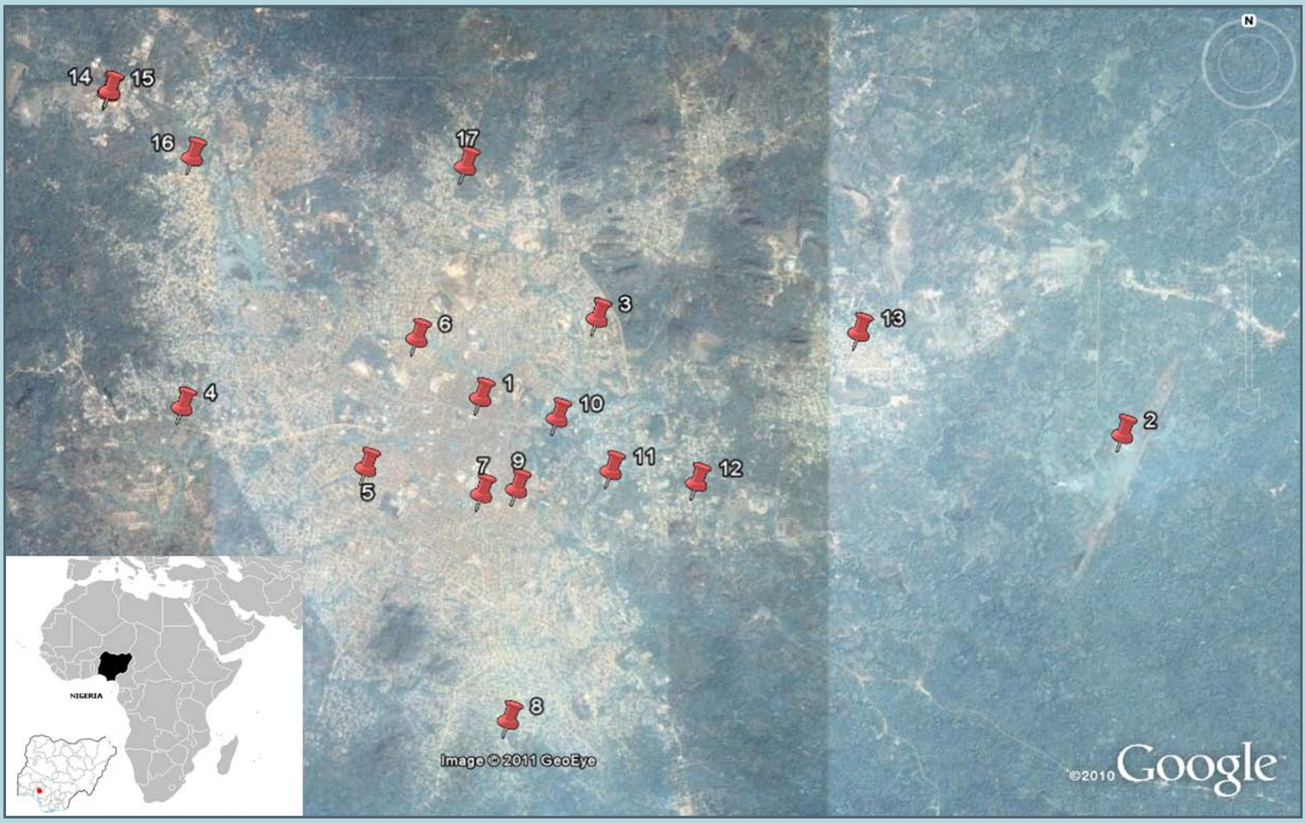

Figure 1. Map of the temperature stations network.

Table 1: Summary of site characteristics.

Station	Site	Lat. (N)	Long. (E)	Elev. (m)	LCZ	Description
1	Oja Oba	07° 15.250′	005° 11.672′	347	2	Compact midrise
2	Airport	07° 14.881′	005° 18.001′	329	10	Sparsely built
3	Ijapo Est	07° 15.983′	005° 12.512′	342	6	Open-set lowrise
4	NTA Ondo Rd	07° 15.030′	005° 07.940′	373	14	Bush/scrub
5	Aratusin	07° 14.546′	005° 10.682′	347	6	Open-set lowrise
6	Ayedun	07° 15.708′	005° 11.149′	351	3	Compact lowrise
7	Oshinle	07° 14.156′	005° 11.442′	361	3	Compact lowrise
8	Ijoka	07° 12.093′	005° 12.030′	359	3	Compact lowrise
9	Ala Qtrs	07° 14.181′	005° 12.480′	369	6	Open-set lowrise
10	Alagbaka Park (Deciduous)	07° 15.018′	005° 12.444′	367	16	Close-set trees
11	Alagbaka GO (Asphalt)	07° 14.479′	005° 12.994′	367	5	Open-set midrise
12	Alagbaka Est	07° 14.252′	005° 13.495′	367	6	Open-set lowrise
13	Oba ile	07° 15.343′	005° 14.841′	367	6	Open-set lowrise
14	FUTA lawn	07° 18.234′	005° 08.181′	367	5	Open-set midrise
15	FUTA tree (Evergreen)	07° 18.222′	005° 08.173′	367	15	Open-set trees
16	FUTA Obk (Concrete)	07° 17.586′	005° 08.975′	367	3	Compact lowrise
17	Shagari Est	07° 17.290′	005° 11.601′	367	6	Open-set lowrise

The climatic condition of Akure follows the pattern of southwestern Nigeria where the climate is influenced mainly by the rain-bearing southwest monsoon winds from the ocean and the dry northwest winds from the Sahara Desert. Akure experiences a warm humid tropical climate, with two distinct seasons, the rainy and dry seasons. The rainy season lasts for about seven months, April to October. It records an average rainfall of about 1500 mm per annum.

Annual average temperatures range between 21.4°C and 31.1°C, and the mean annual relative humidity is about 77% (based on 1980-2010 data from the Nigerian Meteorological Agency). Vegetation is of the tropical rainforest type. Akure lies on a relatively flat plain of about 360 m above sea level within the Western Nigerian plains.

Methodology

The analysis of LULCC is predicated basically on the use of remote sensing and GIS techniques. The study utilizes diverse forms of data. Remotely sensed data – Landsat TM satellite imageries of Akure in 1986, 2002 and 2007 were obtained from the Global Land Cover Facility. A year-long dataset from *in situ* measurements of air temperature and humidity, sampled at 5 minute intervals, was obtained from shielded portable Lascar EL-USB-2 temperature / humidity data loggers that were mounted on lamp posts above head height (3 m) at an-urban site and a rural reference site.

The spatio-temporal variability of the canopy-level urban heat island (UHI) of Akure is examined on the basis of observations using shielded thermochron i-button temperature loggers. Temperature data obtained from the seventeen selected sites, which include different urban areas (Central Business District-CBD, high-density and low-density housing) are compared with 'rural' reference data and analysed with respect to meteorological variables and differences in land use. The land use classification followed the urban climate zone scheme of Stewart and Oke (2010), as shown in Table 1.

Results and Discussions

Landuse Landcover change detection

The older traditional central district of the city has become increasingly congested and the city has expanded outwards, depleting cultivated land and vegetation in the fringe, particularly towards the northwestern part of the city (Figure 2). Within the period under consideration (1986-2007), the built up land has increased by over 28%, consequent upon the various projects that were embarked upon after the city's declaration as state capital and the subsequent discovery that the state falls within a region that is rich in minerals (oil and bitumen, among others). This has, however, led to the physical expansion of the city as evident in the increased land consumption rate from 0.083 to 0.160 and already having a land absorption coefficient of 0.277 between the periods of study (Balogun *et al*., 2011).

Climatic response to urbanisation

The most identified and essential index for assessing urbanisation-induced land-use changes and rapid population growth impacts on climate is the urban-rural difference in air temperature and humidity properties. The results regarding the air temperature differences $\Delta T_{u\text{-}r}$ at both sites are presented in Figure 3. This reveals that the urban area is at all times warmer than the rural area, and this indicates the existence of an urban heat island (UHI) in Akure throughout the day except in November and December when an urban cool island (UCI) is observed for just a few hours in the afternoon. At this time there is a reversed thermal contrast, indicating a cooler city than its rural surroundings. Similar results have been reported for Barcelona (Moreno-Garcia, 1994) and Dallas (Ludwig, 1968). Daytime urban-rural temperature differences (heat islands) may be positive or negative depending on the particular characteristics of the urban area and their surroundings (Runnalls and Oke, 2000). Diurnal differences of humidity content between urban and rural areas are observed to be modified according to the season of the year. The negative value means that the urban area has a lower relative humidity than the rural area. The urban environment has an influence on relative humidity at all hours, causing constant humidity privileging in the rural area throughout the day (Figure 3), and throughout the year. An urban moisture deficits (UMD) exists throughout the day for all months, with the highest differences observed at night. Also the difference was more pronounced in the dry season, from November to January. Thus maximal values of the differences occur during the dry season and at night hours. The time of maximum UHI coincides with the time of maximum UMD.

Spatio-temporal characteristics of the heat island

The diurnal behavioural pattern of the heat island on

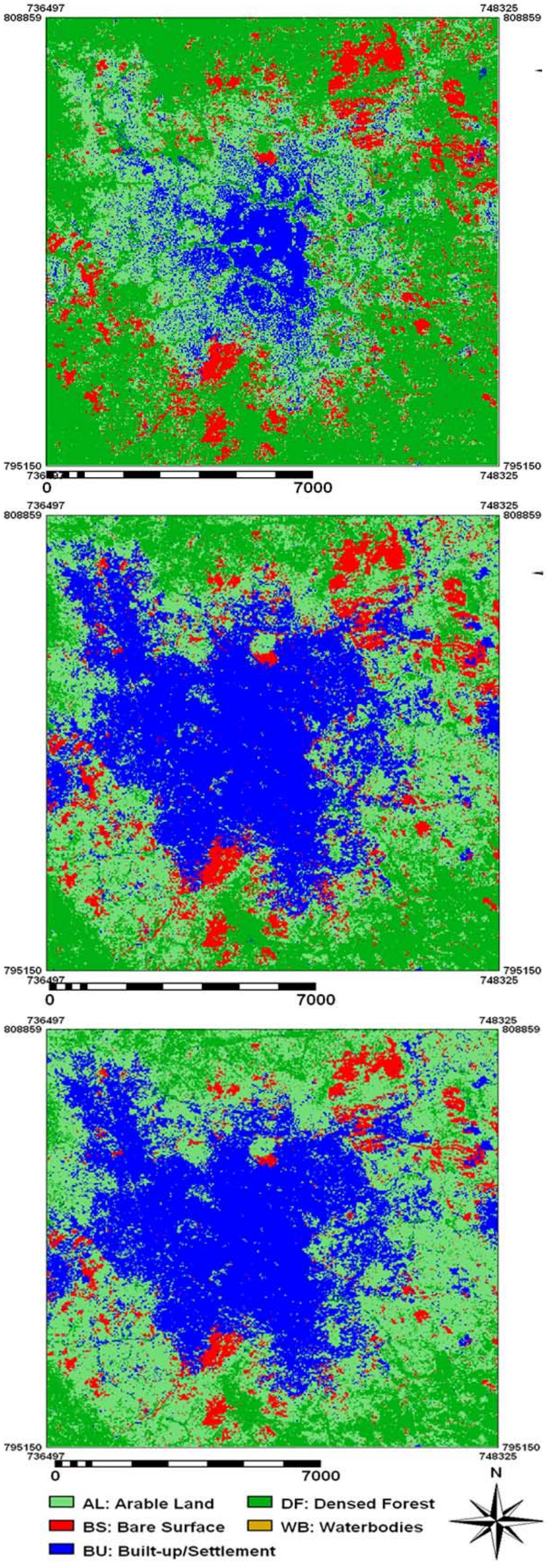

Figure 2. Land-use/land-cover map of Akure, in 1986, 2002 and 2007 (respectively from top to bottom).

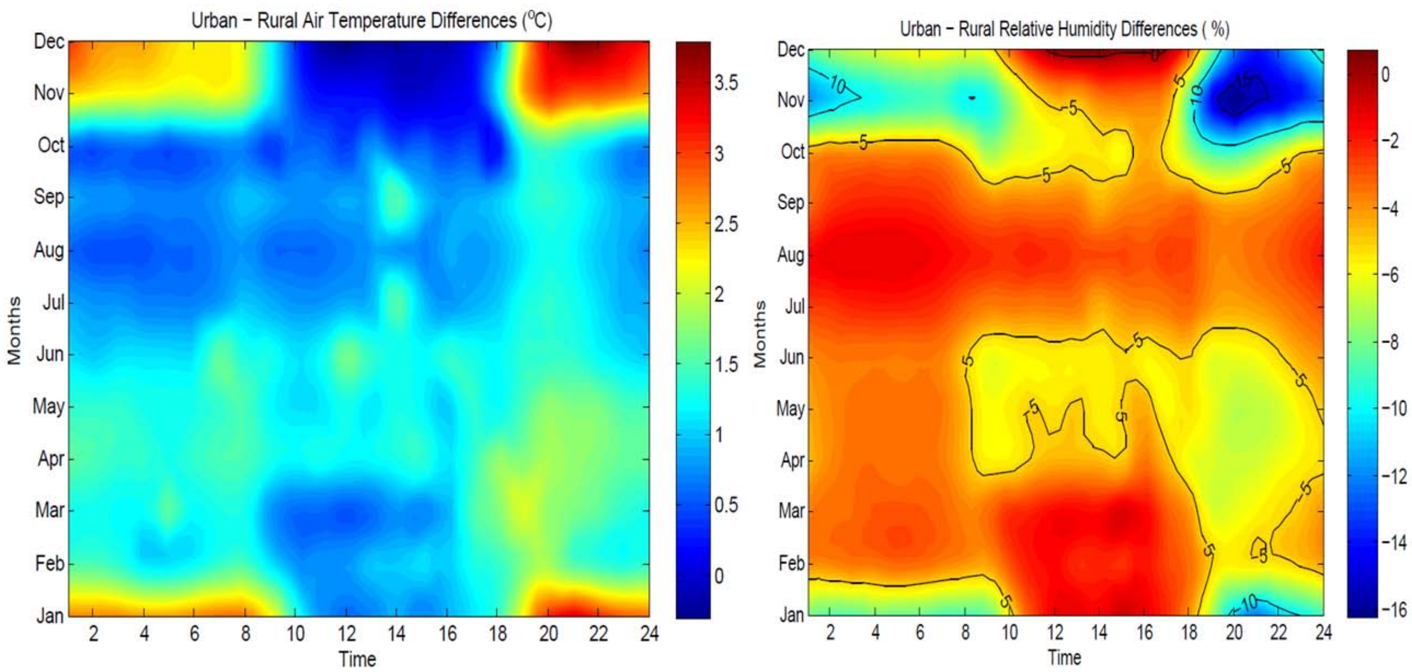

Figure 3. Diurnal variation of mean monthly urban-rural differences in air temperature (left) and relative humidity (right).

a synoptic hour basis is presented in Fig. 4, which shows that the Akure UHI contour patterns differ from the simple idealized concentric structure around the city centre during the dry and wet seasons respectively. Warm regions extend over the city core to the south during the cooler parts of the day (at night), while cooler regions are located in the central vegetated park area and outer fringes. The influence of different LCZs in the evolution of the UHI in Akure is of special interest in this study. The central Alagbaka park, LCZ 16 consisting of close-set 10-15 year old deciduous Teak trees (Tectona grandis) and the evergreen open-set FUTA trees, LCZ 15 (Magnifera indica) create cool island effects of 5-8°C during both dry and wet seasons. The cooling effect is of the same magnitude during the dry season, even though the deciduous trees are devoid of leaves (DJF), but markedly different during the wet season (JJA). This is because both LCZs experience similar radiation regimes during the dry season as the ovate leaf deciduous close-set trees behave similar to the lance leaf evergreen open-set tree.

Relationship between sky view factor & heat island intensity

The value of SVF varies with individual canyons because of subtle differences in the street width from canyon to canyon. Figure 5 shows the relationship between UHI intensity and SVF for all built-up areas during the dry (solid diamonds) and wet (open squares) seasons of 2010, excluding LCZ 3 (concrete), LCZ 5(asphalt), LCZ 5 (grass lawn), LCZ 15 (evergreen trees) and LCZ 16 (deciduous trees) that have extreme thermal regimes as a result of differing surface properties in similar LCZs. The observed relationship is better during the dry ($R^2 = 0.62$) than wet ($R^2 = 0.25$) season. The strong relationship observed in the dry season (time of maximum UHI) is similar to those reported by Svensson (2004) and Yamashita *et al.* (1986) in Göteborg, Sweden and the cities of Tama river basin, Japan respectively. The weak relationship observed during the wet season suggests that the relationship between the UHI and SVF is not only dependent on the LCZs but also on prevailing weather conditions such as clouds and wind speed, as well as varying surface properties.

Conclusion

This study has investigated the impacts of urbanisation on the local climate of Akure, a hot humid tropical city in Nigeria, West Africa. The paper has illustrated that land-use and land-cover changes are closely associated with climatic responses. In this study, the potential use of remote sensing data and GIS techniques in investigating these changes has revealed some interesting findings. Results of the five classes distinctly produced for each study year indicated a rapid change in built-up and arable land as they have increased tremendously and the dense forest terribly depleted. Results further revealed the modifying effect of urbanisation on the city's climate, resulting in the urban heat island phenomenon and urban humidity deficits. A clear linear relationship between the sky view factor and UHI intensity is obtained, which is an indication that street geometry and its regional distribution within the city play a fundamental role in generating differential air temperature patterns. Findings from this research have identified the the potential of trees as a cost effective UHI and climate change impact mitigation tool in Akure.

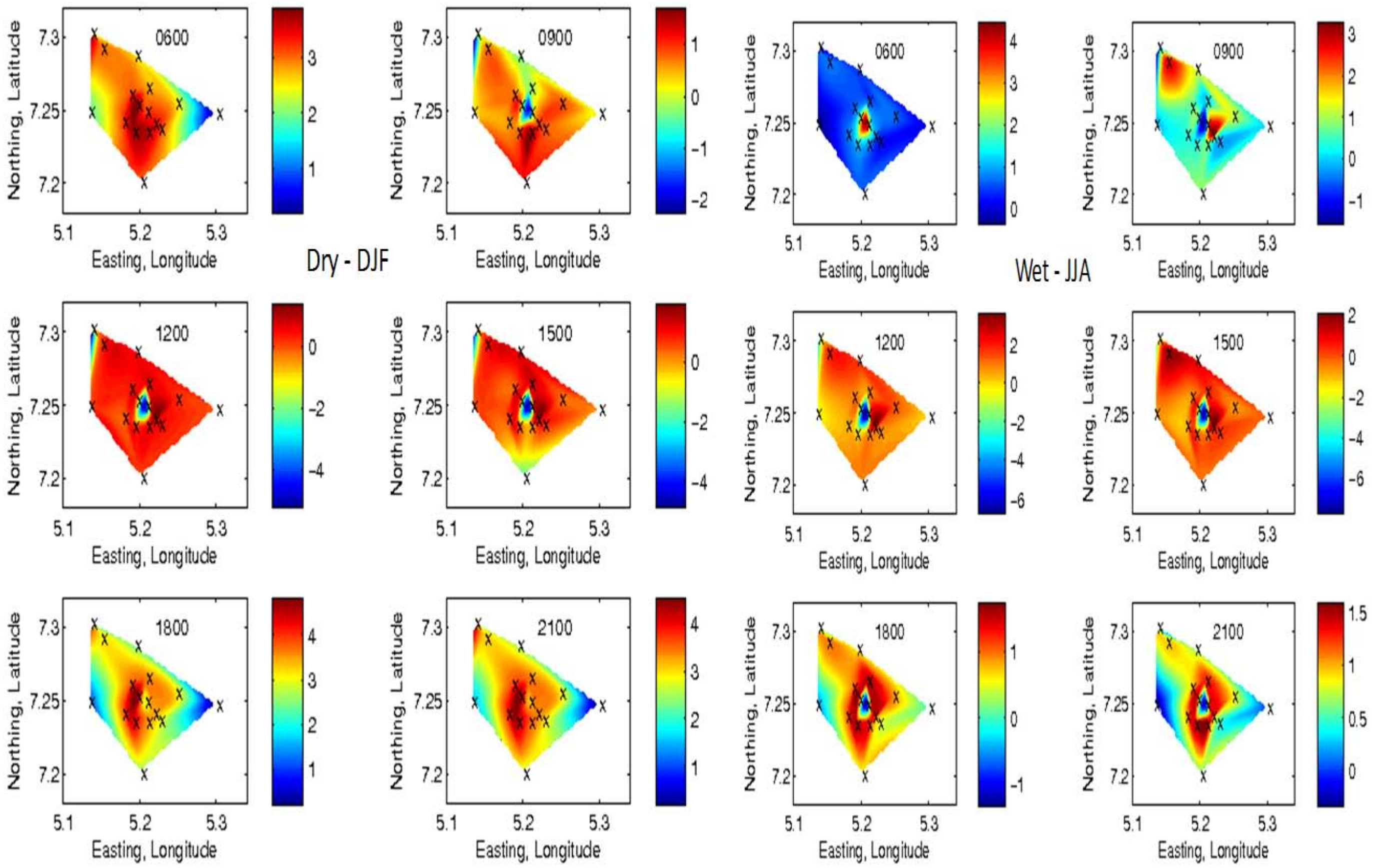

Figure 4. Spatial and temporal variation of Akure UHI during the dry (DJF) and Wet (JJA) seasons.

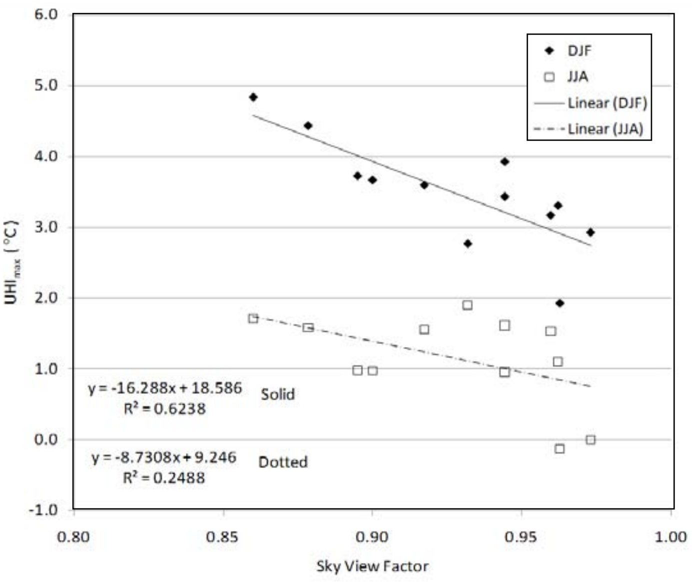

Figure 5. Relationship between UHI intensity and SVF for all built-up areas during the dry (solid diamonds) and wet (open squares) seasons of 2010.

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Transmissivity of solar radiation through the crowns of single urban trees

1. Introduction

One of the most efficient ways to regulate the local climate conditions and to reduce heat stress in cities during periods of extensive heat is to increase the vegetation cover (e.g. Akbari *et al*. 2001; Oke 1989; Shashua-Bar, Hoffman 2000). Cooling effects of vegetation are achieved by evapotranspiration and, in the case of trees and bushes, by their shading. While the air temperature reduction caused by single urban trees is limited, they can strongly influence outdoor thermal comfort by decreasing direct shortwave radiation and thus also the surface and radiant temperatures (Ali-Toudert, Mayer 2005; Mayer *et al*. 2009; Oke 1989; Shashua-Bar *et al*. 2011).

While studies on the transmissivity of solar radiation through the canopies of trees are few, it has been shown that on average about 20% of total solar radiation is transmitted to the forest floor (Gay *et al.* 1971; Hardy *et al*. 2004; Oke 1987; Ni *et al*. 1997; Pomeroy, Dion 1996). The forest canopies were also found to strongly diffuse the solar radiation transmitted to the forest floor (Gay *et al*. 1971; Oke 1987).

In cities, properly chosen and located trees can significantly reduce cooling loads in buildings (Simpson, McPherson 1996) and be beneficial for mitigating outdoor heat stress in the summer. However, the seasonal variability of transmissivity of deciduous trees plays an important role, especially in high latitude cities, where the shading effect of defoliated trees can reduce already limited solar access to the buildings and street canyons (e.g. Cantón *et al*. 1994). Knowledge about the actual values of transmissivity of solar radiation through the crowns of single urban trees and their variations among different species and seasons can provide useful information with regards to climate sensitive planning and modelling of outdoor thermal comfort in cities.

The objective of the study is to measure the transmissivity of total and direct solar radiation through the crowns of single street trees, both foliated and leafless, in a high latitude city.

2. Methods

Four deciduous trees – *Aesculus hippocastanum* (horse chestnut), *Tilia cordata* (small-leaved linden), *Betula pendula* (silver birch) and *Prunus sp.* (cherry), as well as a coniferous *Pinus nigra* (European black pine), were chosen for the study. All five tree species, in particular the deciduous ones, are common in northern European cities including Göteborg. The selected trees are fully grown and in good condition, located at relatively flat and open sites. The dimensions of the trees are listed in Table 1 and their locations are shown in Figure 1.

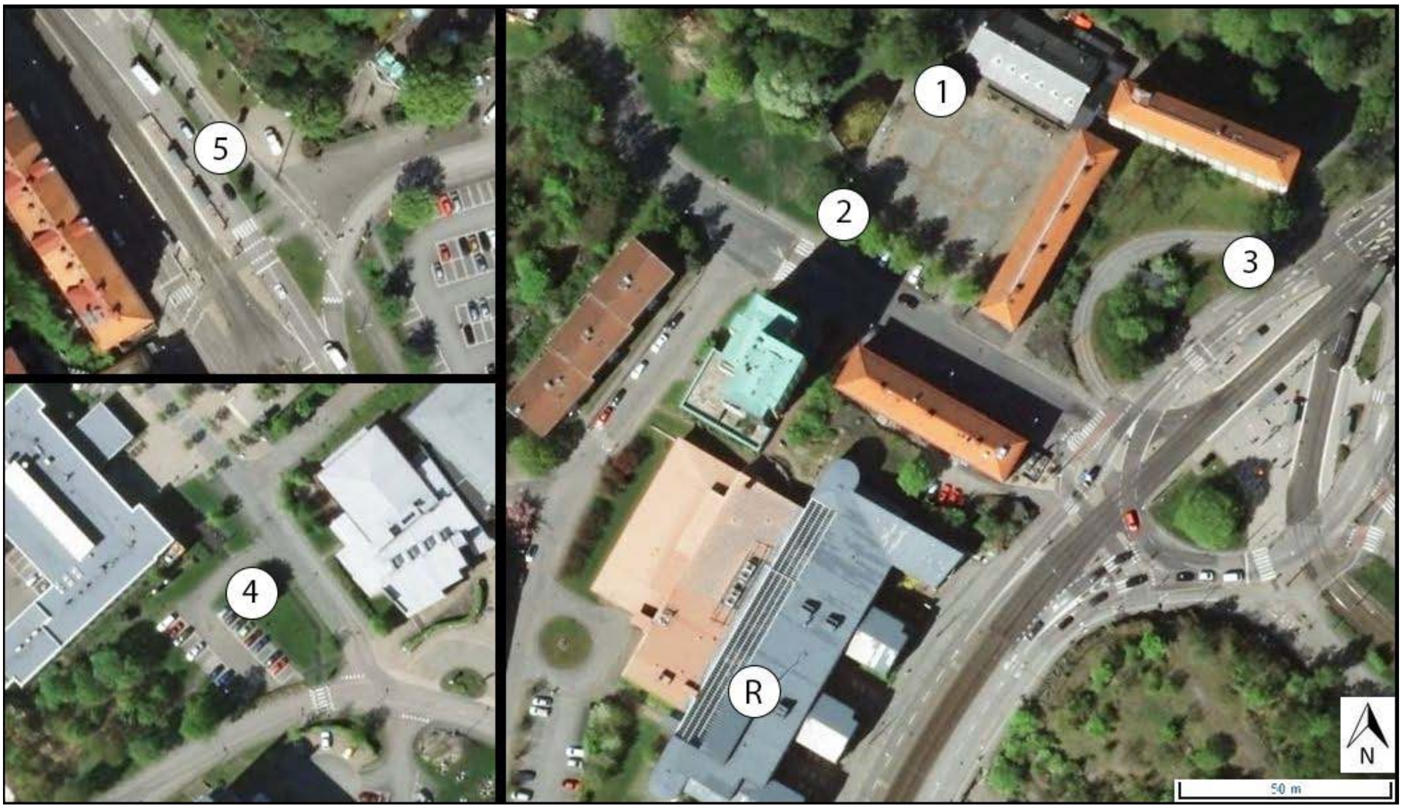

Figure1. Location of the measurement points: 1 – chestnut, 2 – linden, 3 – birch, 4 – cherry, 5 – pine, R – reference point. Photograph source: kartor.eniro.se

Two calibrated DeltaT® SPN1 sunshine pyranometers were used to measure the transmissivity of total and direct shortwave radiation (τ_G and τ_I, respectively) through the selected trees. One of the instruments was located a few meters north of one of the studied trees, at the height of 1.1 m corresponding to the height of the centre of gravity of an average European male (Mayer and Hoppe 1987; Mayer *et al*. 2009), and the other at a reference point located on top of a 4-storey high building. The deciduous trees are located within the radius of 400 meters from the reference point, while the coniferous tree is located about 2 km northeast. The exact position of the sensor located underneath the trees was chosen depending on the tree height and diameter, to provide the longest time of measurements in both summer and winter. Total solar irradiance (*G*) and the diffuse component (*D*) were recorded as 10 min averages, and the direct component on a horizontal surface (I_h) was later calculated by subtracting the diffuse from total radiation.

The measurements were conducted on nine clear days in different seasons of 2011 and 2012. Measurements under each of the deciduous trees were conducted twice, in foliated and leafless conditions. The morning and late afternoon periods, when the instrument was not shaded by the studied tree, were excluded from the analysis. On one of the measurement days the sky became partly cloudy in the afternoon, which sharply decreased the direct component of the shortwave radiation. Data from this period has not been analysed.

τ_G and τ_I were calculated as the ratio of irradiance measured under the crown of the tree to that incident upon it, at the reference point (Cantón *et al*. 1994; Hardy *et al*. 2004):

$$\tau_G = G'/G \qquad [1]$$

and

$$\tau_I = I_h'/I_h \qquad [2]$$

where the apostrophe accounts for the radiation measured in the shadow of the studied tree.

Table 1. Dimensions of the studied trees. H – height, h – trunk height, Φ – diameter

Tree	H (m)	h (m)	Φ (m)
Aesculus hippocastanum (horse chestnut)	13.5	2.0	11.0
Tilia cordata (small-leaved linden)	16.6	1.5	12.0
Betula pendula (silver birch)	18.5	3.0	14.0
Prunus sp. (cherry)	8.5	1.0	13.0
Pinus nigra (European black pine)	8.0	2.4	4.0

Table 2. Mean and standard deviation (σ) of transmissivity of direct (τ_I) and total (τ_G) shortwave radiation through the crowns of studied trees.

Tree		Defoliated		Foliated	
		τ (%)	σ	τ (%)	σ
Chestnut	τ_I	51.9	0.27	1.7	0.03
	τ_G	57.4	0.24	9.8	0.04
Linden	τ_I	50.8	0.23	1.3	0.03
	τ_G	54.2	0.21	8.4	0.04
Birch	τ_I	51.1	0.31	3.6	0.06
	τ_G	59.0	0.28	14.5	0.05
Cherry	τ_I	40.2	0.21	5.3	0.07
	τ_G	48.0	0.19	13.9	0.07
Pine	τ_I	N/A	N/A	5.1	0.06
	τ_G	N/A	N/A	12.2	0.07

3. Results and discussion

Diurnal courses of total and direct solar radiation at the reference point (G and I_h) and below the canopy of studied trees (G′ and I_h′) are shown in Figure 2. Mean values of τ_G and τ_I as well as standard deviation (σ) are listed in Table 2.

In summer the dense, foliated crowns of studied trees were almost impermeable for the direct component of shortwave radiation. τ_I was found to be very weak, particularly in the cases of linden and chestnut (1.3% and 1.7%, respectively). Even the birch, which in comparison to other trees has a relatively sparse and heterogeneous crown, had a mean transmissivity of only 3.6% in the summer. Such low values of transmissivity indicate that the canopy of single trees can strongly influence the radiation balance and thermal comfort in urban areas.

In winter the diurnal variability of transmissivity of direct radiation through the leafless deciduous trees was high (with σ of 0.25), as there were no leaves giving constant shade (Fig. 2, Table 2). Values of τ_I ranged from 0%, when the radiometers were shaded by the trunk of the tree (e.g. Fig. 2b, hours 12-13), to 100%, when the radiation beam could find an unobstructed way through the canopy. The mean τ_I, however, was similar for all trees and amounted to 50.8-51.9% except for the cherry tree

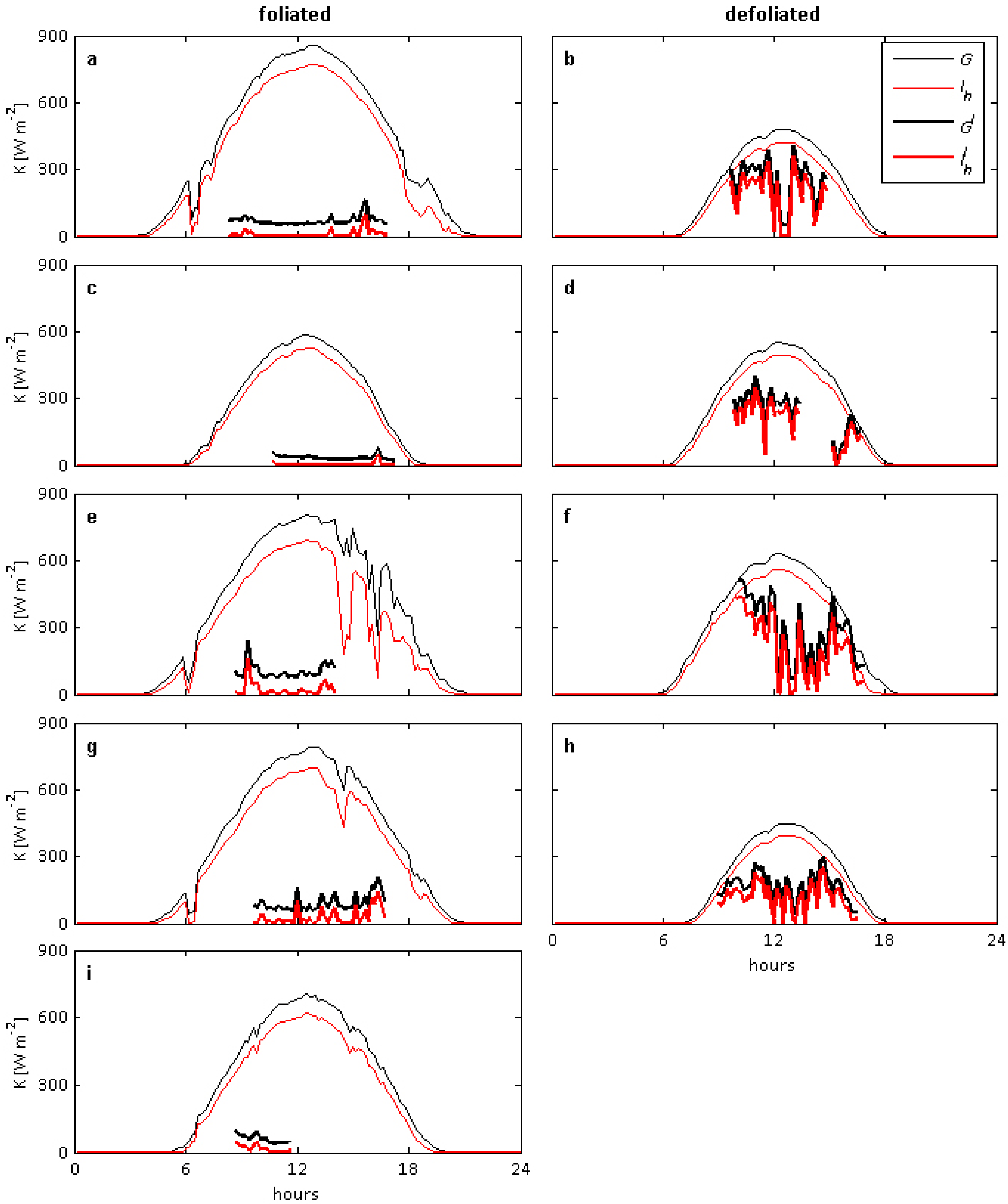

Figure 2 (a-i). Diurnal course of the total (G) and direct (I_h) solar radiation above and below the canopies of the studied trees: chestnut (a, b), linden (c, d), birch (e, f), cherry (g, h) and pine (i), both foliated (left) and leafless (right). Data recorded by the radiometers located under the tree of interest (G' and I_h') is limited to the time when the radiometer was shaded by its crown. Data from period when the instrument located under the linden tree was shaded by an adjacent building (Fig. 2d) and when clouds appeared during the measurements under the birch (Fig. 2e) are not shown. Temporary drops in irradiance at the reference point, visible around 6 a.m. and 11 a.m., are caused by shading by an adjacent building and anemometer mast.

(Table 2). Even though the cherry is the shortest of all four trees, it has a relatively wide, dense crown with thick branches. In winter it had the lowest transmissivity of all trees (40.2%).

In cities, the diffuse and reflected radiation is not only transmitted through the crown of a tree, but can reach the trunk zone from the surroundings – open areas, adjacent buildings etc. At the same time, the direct component is strongly diminished in the tree shadow. For this reason, the proportion of diffuse radiation under the tree is significantly higher than above its canopy. While on a sunny day the direct component amounts to about 85% of the total incident solar radiation, under the crowns of studied urban trees this ratio was transformed to 67.8 % in winter and only 17.6 % in summer, on average (Table 3).

This diffusing effect of the tree canopies results in higher values of transmissivity of total radiation (τ_G) than of τ_I, particularly in the case of foliated trees (Table 2). Average τ_G through the studied trees ranged between 8.4% and 14.5% for trees in leaf and from 48.0% to 59.0% in leafless conditions. These values are in good agreement with those reported in other studies conducted on single trees (de Abreu, Labaki 2008; Heisler 1986; Youngberg 1983). However, several studies reported higher values of τ_G in forests (about 20%), caused by the existence of gaps between trees and smaller canopy density in forests than in the case of single trees (Gay *et al*. 1971; Hardy *et al*. 2004; Oke 1987).

Due to the heterogeneity of canopies, especially those of forests, representative measurement sampling is essential (e.g. Ni *et al*. 1997). Measurements presented here were conducted at one point under the canopy of each tree. However, since the measurements were continued for several hours, the direct solar beam was penetrating the crown at different angles. The relationship between sun altitude and the transmissivity of shortwave radiation through both foliated and defoliated canopies of all studied trees was found to be very weak (not shown). The foliated crowns of studied trees were found to be dense enough to block almost all direct radiation regardless of the length of the sun path through the tree. These results confirm that constant values of transmissivity can be used for modelling thermal comfort in areas shaded by vegetation at different solar zenith angles.

The most favourable urban tree in temperate climates would be the one with the lowest transmissivity in summer, when the heat stress occurs, but highest in winter, when the sunshine is limited due to low sun altitude (Cantón *et al*. 1994). However, the dimensions and location of a tree also play a major role. At high latitudes the sun altitude in winter is low and trees located in street canyons or in courtyards can be shaded by adjacent buildings for the whole day. In such cases their low transmissivity does not contribute to the limitation of solar access, while in summer their shading effect can improve thermal comfort and decrease energy consumption for cooling.

Table 3. Mean ratio of direct (I_h) to total (G) radiation above and below the canopies of trees.

Tree	Defoliated		Foliated	
	Ref. (%)	Tree (%)	Ref. (%)	Tree (%)
Chestnut	86.5	68.4	89.9	11.3
Linden	88.0	77.4	87.8	8.8
Birch	82.8	61.6	75.8	16.2
Cherry	84.6	64.0	86.1	24.0
Pine	N/A	N/A	87.0	27.5

4. Conclusions

Transmissivity of total and direct shortwave radiation through the crowns of single urban trees was measured on clear summer and winter days in the high latitude city of Göteborg, Sweden. Even though the studied trees differ in species, height and diameter, their crowns are characterised by a similar transmissivity of shortwave radiation. Dense, foliated crowns of single trees were almost impermeable for the solar radiation and only 1-5% of the incident direct beam reached the ground in their shadow. Transmissivity of total radiation was higher (average of 8-15% for different foliated trees) than of the direct component due to a high proportion of diffuse radiation in the tree shadow.

In winter the transmissivity was also low – the leafless deciduous trees were found to block on average 40 to 52% of the direct component and 48 to 59% of the total solar radiation. Such a low transmissivity of leafless trees is a disadvantage in high latitude cities, where the access to sunlight in winter is limited. Therefore, transmissivity of direct radiation and its seasonal variability should be taken into account in choosing the location and species of urban trees.

The results of this study will be used for parameterization of SOLWEIG (Lindberg *et al*. 2008), a model simulating spatial distribution of shadow patterns, 3D radiation fluxes and the mean radiant temperature in complex urban settings.

Acknowledgments

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Characteristics of the UHI in a high-altitude metropolitan city, Ulaanbaatar, Mongolia

Introduction

The urban heat island (UHI) is known as the higher near-surface air temperature in an urban area than in its surrounding rural area. Its causative factors are well known. These include anthropogenic heat, impervious surfaces, and three-dimensional urban geometry (Ryu and Baik 2012). Anthropogenic heat is an important causative factor, especially in the nighttime (Fan and Sailor 2005). The sensible heat flux is larger and the latent heat flux is smaller in urban areas than in rural areas owing to the high heat storage capacity of urban surfaces and the low surface moisture availability of less vegetated urban surfaces. Relationships between meteorological parameters/weather conditions and UHI intensity are investigated in a number of studies (e.g., Unger 1996; Kim and Baik 2002). An ideal meteorological condition for UHI development is a stable, calm, and clear sky condition (Oke 1982). The UHI intensity depends on the time of day and the season. Strong UHI intensity more frequently appears in winter than in summer in many cities around the world (e.g., Figuerola and Mazzeo 1998; Liu *et al*. 2007). In this study, the characteristics of the UHI in Ulaanbaatar, the capital of Mongolia, are for the first time investigated.

Study area and data

Mongolia is situated in an area between permafrost to the north and desert lands to the south. Ulaanbaatar is the economic, social, political, cultural, and educational center of Mongolia. The city is located at an altitude of about 1350 m and in a valley. The area belongs to a cold semi-arid climate. Ulaanbaatar is known as the coldest capital city in the world because of its geographic features such as high altitude and landlocked location and the effects of the wintertime Siberian high. The monthly average temperature for each month from October to March is below 0°C, and the average temperature in winter is −19°C. The annual precipitation total is about 270 mm, and most precipitation occurs in summer. The population of Ulaanbaatar reached 1.1 million (at the end of 2009), constituting 41% of the total population of Mongolia. The city area has almost doubled since 1974 (Amarsaikhan *et al*. 2009).

The UHI intensity is defined as the difference in air temperature at a height of 2 m between urban and rural stations. Ulaanbaatar station, located in a residential area that consists of ger-houses (traditional living houses known as yurts) and apartment buildings, represents an urban station. Buyant-Ukhaa airport station, located to the southwest of the city, represents a rural station. The altitudes of Ulaanbaatar and Buyant-Ukhaa stations are 1306 and 1286 m, respectively. Data recorded at 3-h intervals from 1980 to 2010 are used in this study. Data are obtained from the State Archive and Database Center of the National Agency for Meteorology and Environmental Monitoring (NAMEM), Mongolia.

Analysis of results

The difference in annually averaged daily mean temperature between the two stations is 1.6°C for the period of 1980–2010. Figures 1a and 1b show the monthly and daily variation of the UHI intensity. The UHI intensity is strongest in winter (3.3°C) and weakest in summer (0.3°C). According to Ryu and Baik (2012), in the nighttime anthropogenic heat contributes greatly to the UHI intensity. In the nighttime, coal and wood burning in the traditional ger-houses for heating and cooking purposes

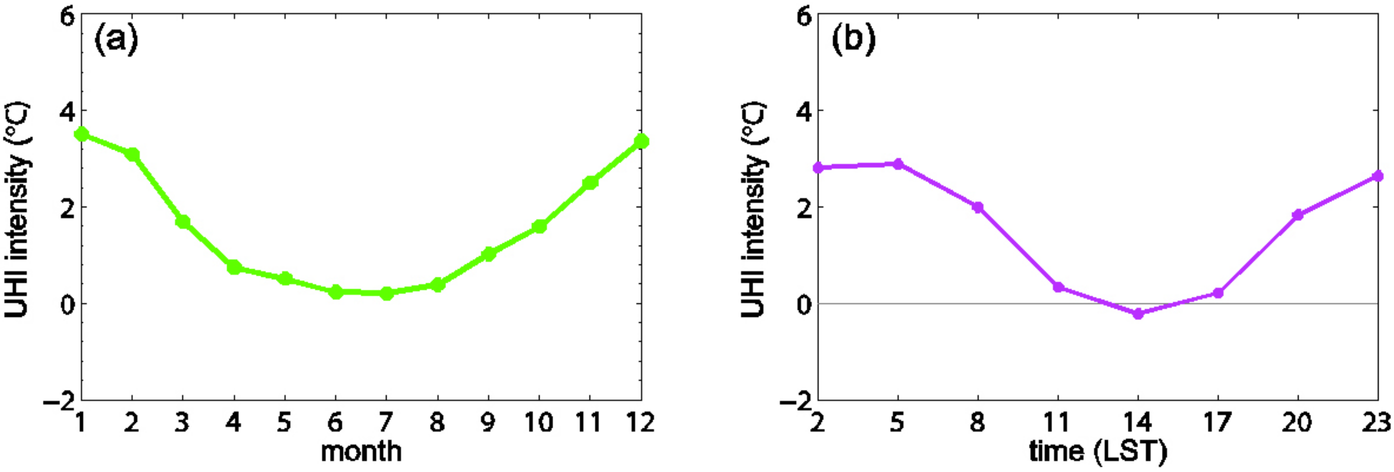

Figure 1. (a) Monthly and (b) daily variation of the UHI intensity.

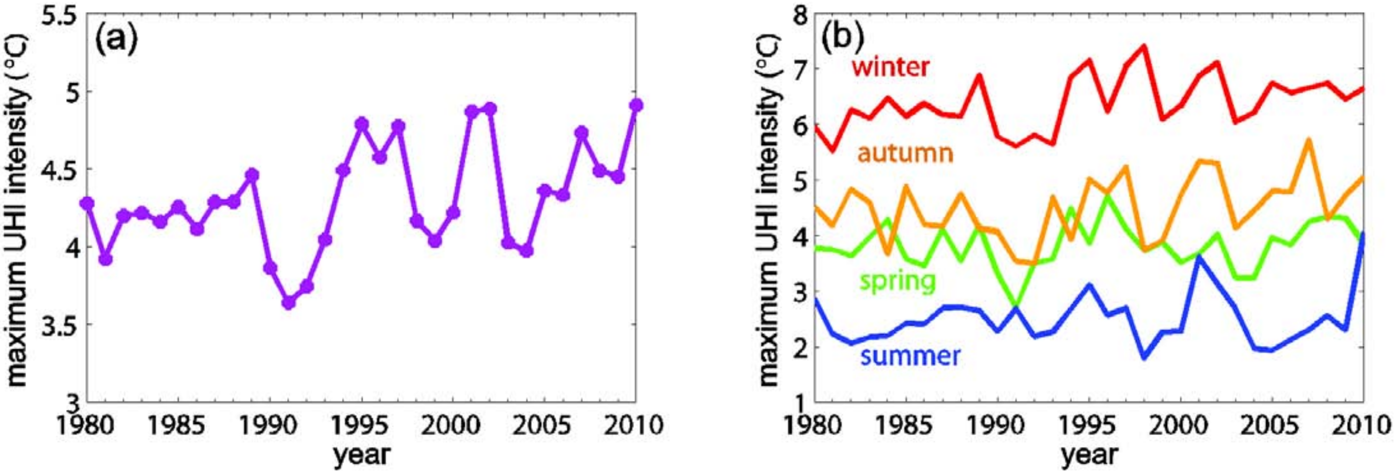

Figure 2. (a) Annually and (b) seasonally averaged daily maximum UHI intensities.

likely contributes to increasing temperature in the urban area, especially in cold months. As pointed out by Goldreich (1984), a stronger UHI intensity is expected in high-altitude cities associated with inevitable space heating demand under cold conditions. The UHI intensity is seen to be strongest at 0500 LST (2.9°C) and weakest at 1400 LST (–0.2°C). In each season, the UHI is stronger in the nighttime than in the daytime (not shown).

The average daily maximum UHI intensity for the period of 1980–2010 is 4.3°C. The annually averaged daily maximum UHI intensity exhibits an increasing trend (Fig. 2a). The strongest daily maximum UHI intensity occurs in winter with an average intensity of 6.4°C, and the weakest daily maximum UHI intensity occurs in summer with an average intensity of 2.5°C (Fig. 2b). The average daily maximum UHI intensity is 3.8°C in spring and 4.5°C in autumn.

Figure 3a shows the histogram of frequency distribution of the maximum UHI intensity. About 84% of the total frequency of the maximum UHI intensity exists in the range of 1–8°C. The most frequently observed maximum UHI intensity is 6°C. The occurrence frequency of the daily maximum UHI intensity in the nighttime is 5.6 times larger than that in the daytime (Fig. 3b). This value is larger than the value for Seoul (3.3) (Kim and Baik 2002).

Following Kim and Baik (2002), a multiple linear regression analysis is performed to examine the relative importance of meteorological parameters that affect the daily maximum UHI intensity. Four meteorological parameters are considered: the maximum UHI intensity for the previous day (PER), wind speed (WS), cloudiness (CL), and relative humidity (RH). For all data, the multiple linear regression model explains half of the variance (49.8%). The stronger daily maximum UHI intensity is mostly led by stronger PER (Table 1). The second and third most important parameters are CL and WS, respectively, and are negatively correlated with the daily maximum UHI intensity. Magee *et al.* (1999) found that the increase in wind speed reduces the UHI intensity in Fairbanks and noted that the reason for the stronger UHI intensity under weak winds is because weak winds allow heat to accumulate near the surface without extensive mixing. In spring and summer, the most important parameter is CL and the second most important parameter is PER. In autumn and winter, PER is the most important parameter and CL is the second most important parameter.

Table 1. Normalized regression coefficients of the four meteorological parameters (PER, maximum UHI intensity for the previous day; WS, wind speed; CL, cloudiness; RH, relative humidity). r^2 is the percentage of the total variance explained by the regression model, and *n* is the sample size.

	All	Spring	Summer	Autumn	Winter
PER	0.48	0.30	0.20	0.41	0.32
WS	–0.14	–0.22	–0.14	–0.15	–0.05
CL	–0.34	–0.36	–0.44	–0.34	–0.26
RH	0.03	–0.06	–0.18	–0.02	0.02
r^2	49.8	33.4	33.4	38.1	18.5
n	11272	2845	2847	2818	2762

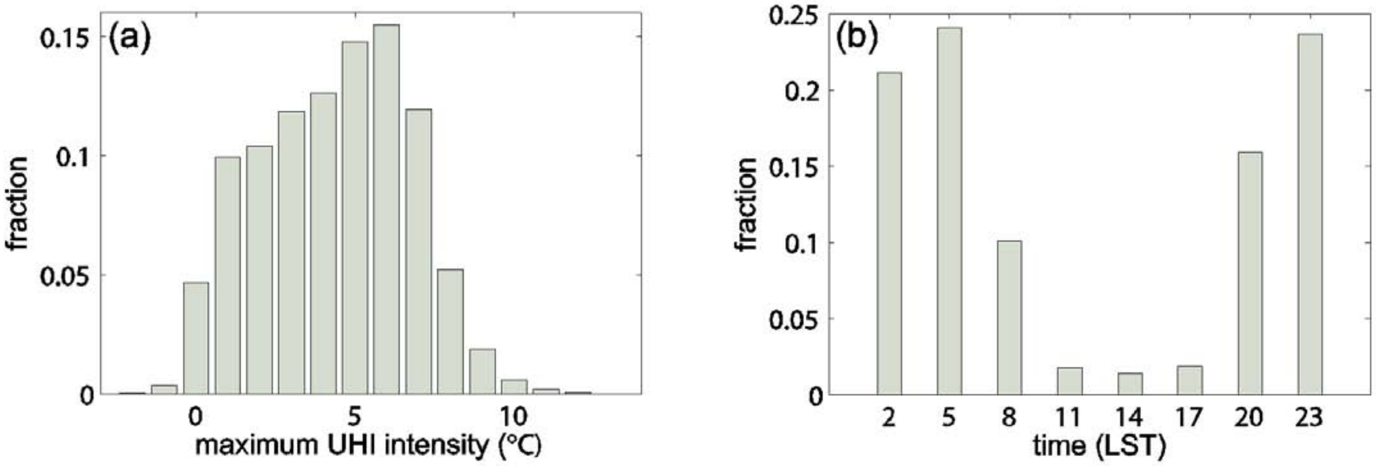

Figure 3. (a) Histogram of the frequency distribution (in fraction) of the daily maximum UHI intensity and (b) same as (a) except as a function of the time of day.

Summary

In this study, the characteristics of the Ulaanbaatar UHI were for the first time documented using surface meteorological data for the 31-year period of 1980–2010. The UHI features for Ulaanbaatar are qualitatively similar to UHI characteristics in many other cities around the world. The Ulaanbaatar UHI in winter, however, appears to be strong compared to the UHI in other cities (e.g., Seoul). We attribute this to the peculiar geographical features of Ulaanbaatar, wintertime weather that is strongly influenced by the Siberian high, and anthropogenic heat resulting from the burning of coal and wood.

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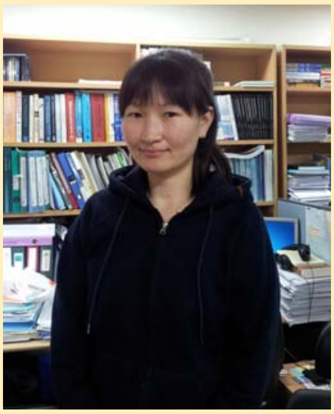

Flux observations in London – Energy, water and carbon dioxide exchange in a dense European city centre

The micrometeorology research group at King's College London (KCL) is monitoring surface energy and carbon dioxide exchange in London, UK, since October 2008. Greater London, a metropolitan area with over 8.2 million inhabitants (2011 census, Office for National Statistics, 2012), is situated in the southeast of the country (Figure 1). The climate of this region is temperate marine, with mid-latitude cyclones that cross the UK from East to West: the prevailing wind direction is from the southwest. Mean annual rainfall observed at a central London Met Office station (St James's Park , Figure 1) accumulates to 570 mm and mean daily (24 h) temperatures range between 5-19°C, in January and July, respectively.

Measurement sites are located in a dense urban setting, on top of buildings at the KCL Strand campus (51°30′ N, 0°7′ W), just north of River Thames (Figure 1). Loridan et al. (2013) classified the surrounding area as High Density UZE (Urban Zone for Energy partitioning, Loridan and Grimmond 2012). With 43% impervious

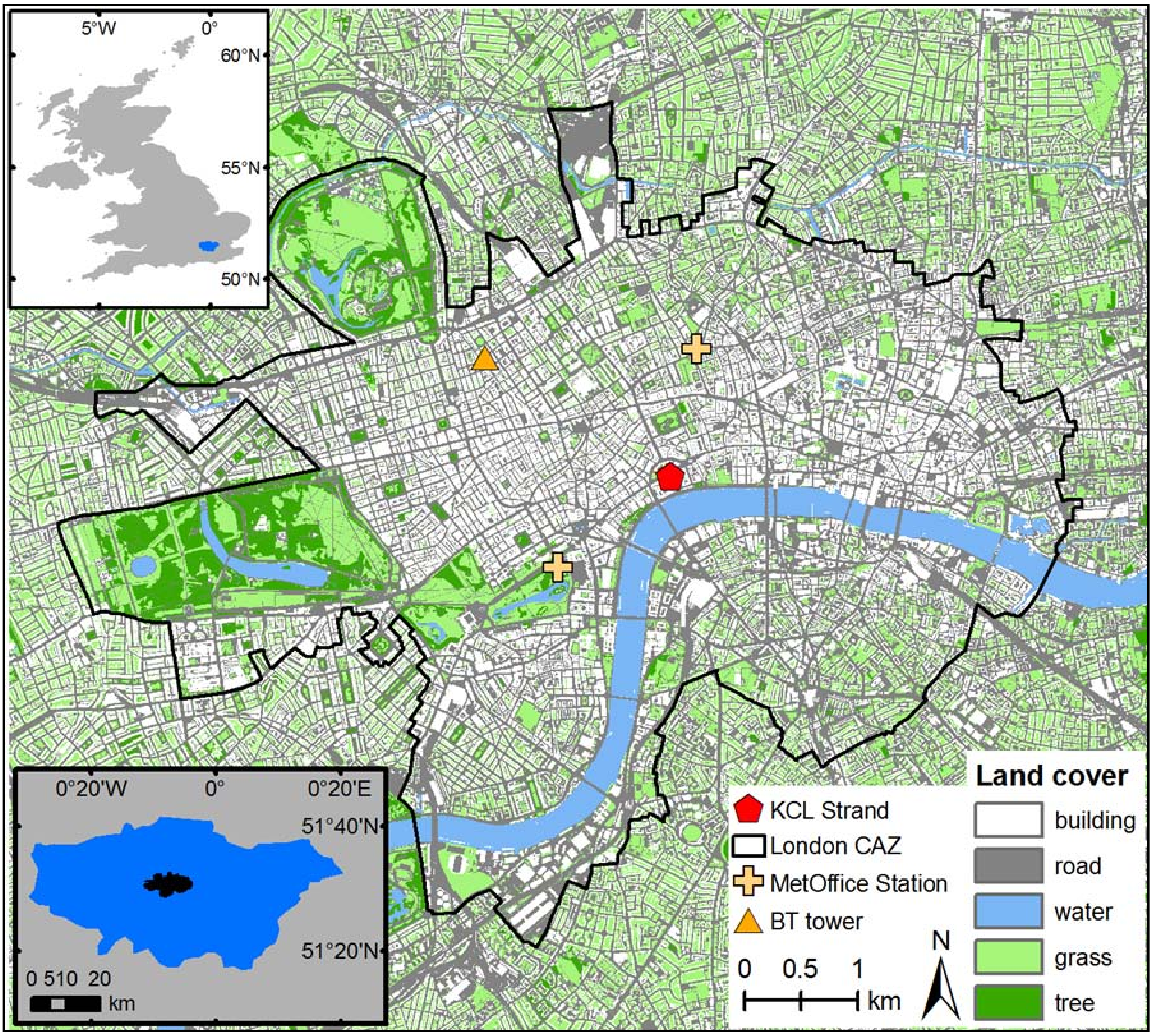

Figure 1. Land cover map (based on OS MasterMap) with site locations of KCL Strand, Met Office stations and BT tower within the London Central Activity Zone (CAZ). Inlets show geographic location of CAZ within Greater London (bottom) and this within the UK (top). Figure based on Figure 1 in Kotthaus and Grimmond (in preparation).

ground and 38% buildings, the surrounding surface cover is clearly dominated by anthropogenic materials. Due to the proximity to the River Thames, 14% of the surface is open water, leaving only about 5% to vegetation (grass and street trees). According to the image-based classification approach by Stewart and Oke (2012), the study area can be described as compact midrise LCZ 2 (Local Climate Zone) with water (LCZ G).

Two measurement towers are installed with a distance of about 60 m (Figure 2): observations at the KSK site (measurement height z_m=39 m above ground or 1.9 x mean building height z_H) started in October 2008, while the KSS site (z_m=49 m or 2.2 x z_H) became operational in November 2009. The latter has been moved to the western end of the building in March 2012, here termed KSSW (z_m=50.3 m or 2.3 x z_H). At all three sites, radiation balance components are monitored (CNR1 and CNR4, Kipp & Zonen) alongside the turbulent surface fluxes of sensible and latent heat so that processes governing the surface energy balance can be investigated (Kotthaus and Grimmond, in preparation).

The eddy covariance setup deployed here consists of a sonic anemometer (CSAT3, Campbell Sci.) and an infrared gas analyser (Li7500/Li7500A, LiCor Biosciences), which also enables monitoring of the turbulent flux of carbon dioxide. Besides the flux observations, a series of auxiliary data are collected including standard meteorological variables but also more specialised observations, e.g. cloud and aerosol conditions in the atmospheric boundary layer are monitored with a CL31 Ceilometer, Vaisala. The KCL London sites are part of the Urban Flux Network (www.geog.ubc.ca/urbanflux) and have been presented in an article of the FLUXNET Newsletter dealing with eddy covariance measurements in the urban environment (Kotthaus *et al*. 2012). Kotthaus *et al.* (2012) put the KCL observations, collected at the dense urban KSS site, in context to surface fluxes observed in the town of Swindon, a typical South England suburban area located 120 km west of London. A detailed study of surface exchange mechanisms in Swindon is presented by Ward *et al*. (2012).

Within the last decade, eddy covariance observations have become more established in the urban environment to measure surface fluxes (Grimmond 2006). However, the heterogeneous, three-dimensional surface structure and the occurrence of emission sources at various heights within the urban canopy create a profoundly complex subject of study. Kotthaus and Grimmond (2012) address the impact of anthropogenic emissions on eddy covariance observations by developing a new procedure for the Identification of Micro-scale Anthropogenic Sources (IMAS). At the KSS site, several sources for heat, moisture and carbon dioxide are located above the mean building height and in close vicinity of the tower. Under certain conditions, these are found to significantly influence the observations, usually leading to an increase of the respective turbulent flux. The detected micro-scale signals are too extreme to be associated with blended emissions from the site's local scale source area but rather originate from chimneys and exhaust pipes in the immediate surroundings of the tower.

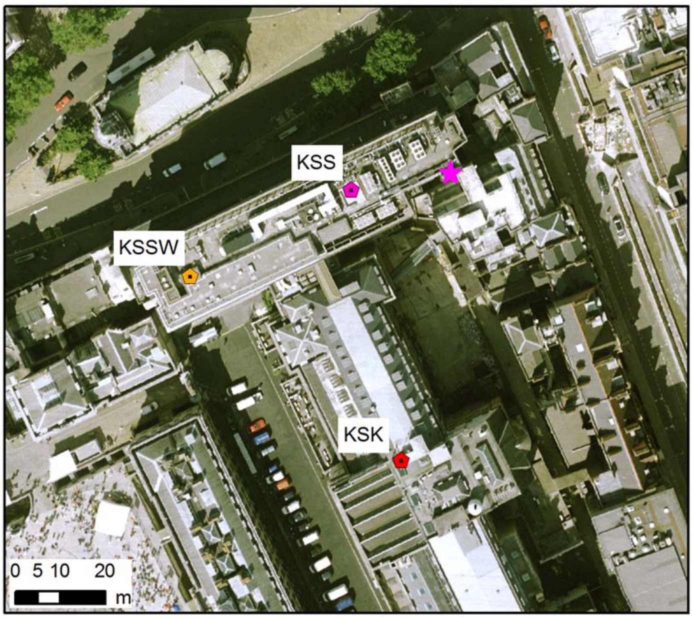

Figure 2. Aerial photo (NERC ARSF) of KCL Strand campus with eddy covariance flux tower locations. The star marks the location of a chimney near KSS, a significant source of anthropogenic emissions of heat, water and carbon dioxide. (See text and Figure 1 for details).

An automatic filtering techniques is presented (Kotthaus and Grimmond 2012) to identify micro-scale anthropogenic emissions in the high-frequency (10 Hz) time series of sonic temperature, water vapour and carbon dioxide. All variables are filtered together, based on a series of tailored criteria (developed by Kotthaus and Grimmond 2012, and updated by Kotthaus and Grimmond, in preparation). It is used to extract the micro-scale effects so that turbulent fluxes can be estimated which are representative at the local scale. Kotthaus and Grimmond (2012) present a detailed evaluation of the method. Amongst others, independent measurements are incorporated which confirm the strong impact of micro-scale emission sources, also fluxes are analysed by wind direction in order to put the observations into context to the locations of the emission sources. A chimney in the East of KSS (star in Figure 2) represents the strongest source so that fluxes calculated using common eddy covariance processing are significantly affected under easterly wind conditions. The flux of carbon dioxide for example shows a strong increase of its high quantiles in the easterly sector (Figure 3a).

The new IMAS procedure automatically identifies time

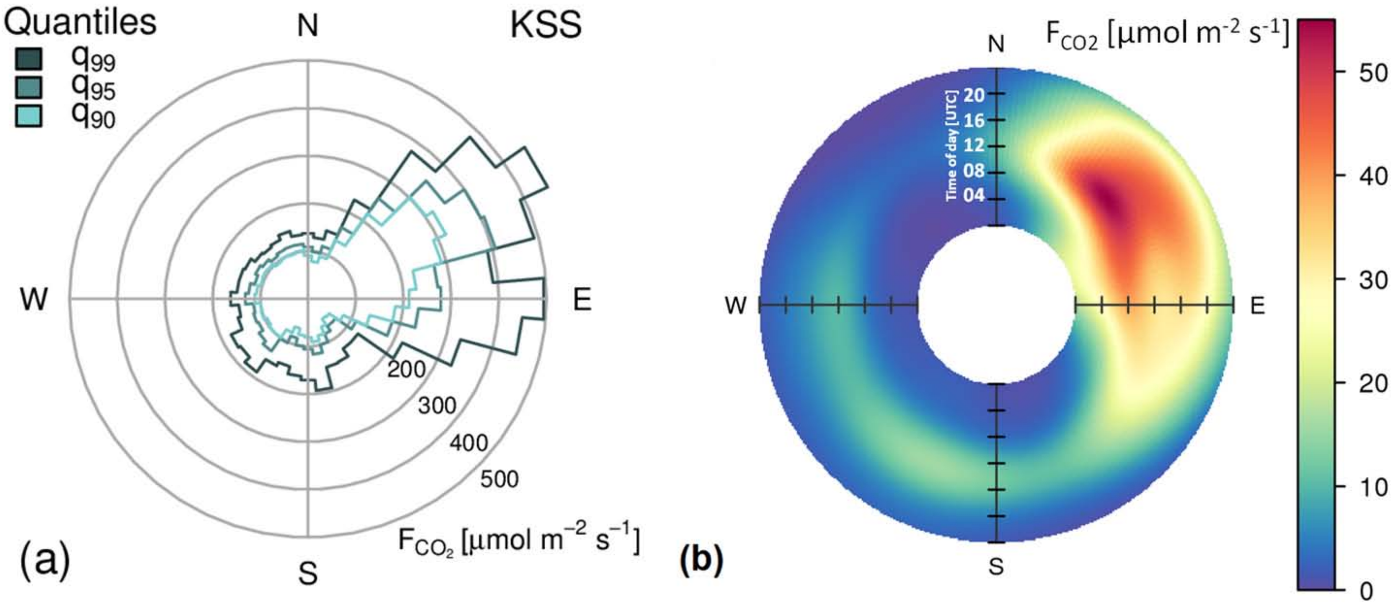

Figure 3. Observations at KSS (11/2009-03/2012): (a) quantiles of carbon dioxide flux F_{CO_2} by wind direction in 10° intervals; (b) micro-scale anthropogenic carbon dioxide flux representative of the building scale, by wind direction and time of day, calculated as the difference between commonly processed turbulent flux (*L1*) and results incorporating the IMAS filter (*L2*). See Kotthaus and Grimmond (2012) for further details: plots are based on their Figure 8 and Figure 11; eddy covariance flux processing and IMAS filter as outlined by Kotthaus and Grimmond (in preparation).

periods affected by the close-by anthropogenic sources based exclusively on the raw time series, i.e. not taking into account aspects such as wind direction. However, the filter mainly picks up events under easterly flow conditions which suggests it to be suitable for its purpose. The filter is incorporated into the flux processing procedure so that results can be obtained which are representative of the respective local scale source area. In order to investigate the impact of the micro-scale effects, the fluxes are calculated as usual (*L1* processing, see Kotthaus and Grimmond 2012 for details) and including the IMAS procedure (*L2* processing). The difference between these results provides a first order estimate of the anthropogenic (heat or carbon dioxide) flux at the building scale. The distribution by wind direction of this micro-scale turbulent flux estimate (*L1-L2*, e.g. for carbon dioxide flux F_{CO_2}, Figure 3b), again emphasizes the directional dependence of the flux estimates on the locations of the main emission source at KSS (to the East). Figure 3b further shows variations of micro-scale fluxes by time of day (radial axis), with generally larger values recorded during daytime. This is in agreement with the time of usage of the building generating the emissions, which is located in the central business district where the daytime population far exceeds the one at night. With respect to the order of magnitude, building scale fluxes of sensible and latent heat or carbon dioxide observed at KSS show reasonable agreement with modelling approaches. These are usually employed to estimates anthropogenic contributions to the surface energy balance (e.g. Iamarino et al. 2012) and the carbon dioxide budget. The presented filtering technique depicts the first attempt to directly measure these fluxes, which are especially important in high density urban environments.

Flux processing at KCL incorporates an updated version of the IMAS procedure, so that turbulent surface exchange can be interpreted based on the local scale source area (Kotthaus and Grimmond, in preparation). Given the dense urban setting of the KCL Strand campus (Figure 1), anthropogenic effects are also clearly evident at this larger scale (as opposed to the building scale flux shown in Figure 3b). Median diurnal patterns of energy fluxes observed at KSS in summer (JJA) and winter (DJF) reveal how energy exchange is affected in central London (Figure 4). Naturally, energy input from the net all-wave radiation Q^* is significantly higher in summer, while its contribution to the surface energy balance is rather small during times of low sun elevation. Turbulent sensible heat flux Q_H is also weaker during winter, however its median diurnal maximum of about 100 W m^{-2} distinctly exceeds the radiation flux (~65 W m^{-2}). And even more notably, night time sensible heat flux accounts for strong upward energy transport of over 50 W m^{-2} with even higher median values during summer. Significant storage heat flux is characteristic for dense urban environments and provides energy for the turbulent fluxes in times of no radiative input. A few other measurement studies with sites locates in the city centre (e.g. Basel, Christen and Vogt 2004) have reported conditions maintaining positive Q_H during the whole night. Additionally to the heat storage of the urban surface, further anthropogenic contributions to this strong nocturnal sensible heat flux can be expected from direct building and vehicle emissions. Despite the vicinity to the River Thames (Figure 1), moisture availability in the dense urban environment is restricted under many flow conditions so that Q_H dominates over the turbulent latent heat flux Q_E. The long-term operation of the central London sites allows for the analysis of temporal and spatial variations of surface energy exchange in a dense European city centre which will be presented shortly by Kotthaus and Grimmond (in preparation).

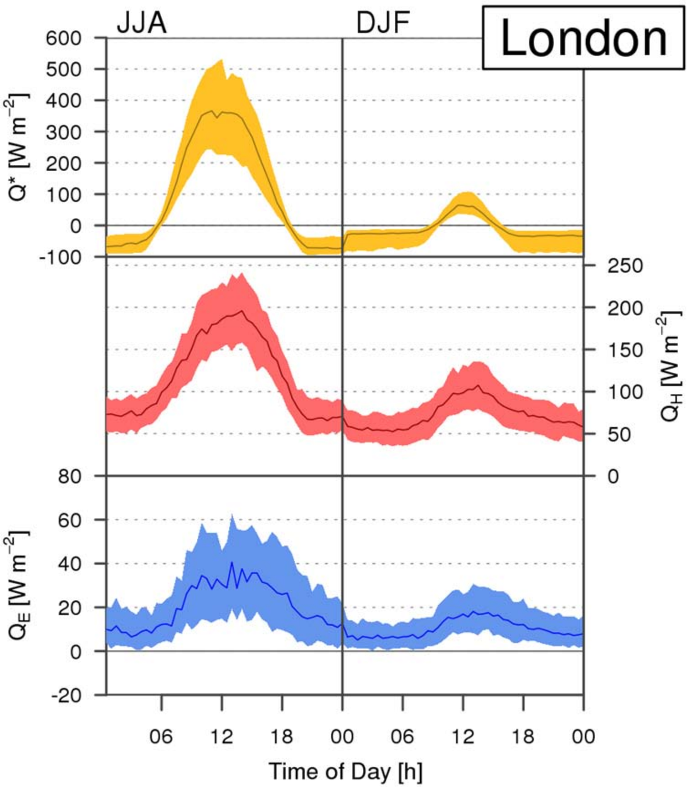

Figure 4. Median diurnal patterns (shading marks interquartile range) observed at KSS (11/2009-03/2012) in summer (JJA) and winter (DJF): net all-wave radiation Q*, turbulent flux of sensible heat Q_H and turbulent flux of latent heat Q_E. Figure is based on Figure 5 in Kotthaus *et al*. (2012), however data presented here cover a longer time period and are calculated using an updated version of the IMAS processing (Kotthaus and Grimmond, in preparation).

Acknowledgements

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On the road to a universal equation for the UHI

Within the urban climate community, the urban heat island (UHI) effect, here defined as the difference in temperature between the urban and rural environment at the pedestrian level, is a longstanding research topic. The UHI causes adverse effects for human thermal comfort, urban energy consumption, and urban air quality. While the UHI has been regarded of significant importance, simple models for estimating the UHI intensity within urban areas are still lacking (Arnfield, 2003). In addition, computer power to run global weather prediction models is increasing. Yet this is not enough to couple the global models to relatively complex urban energy balance parameterizations. In order to produce accurate temperature predictions for urban areas it can be beneficial to have a simple method to forecast the UHI as an operational tool.

Despite several attempts to derive a uniform formula for the UHI, the complexity of the system so far has inhibited this. Considering the amount of factors that govern the UHI, this is no wonder. In general, we can distinguish between urban and rural governing factors. The UHI magnitude depends not only on urban properties such as areal green and water cover, street geometry (aspect ratio) and thermal properties of building materials, but also on wind speed and direction, incoming radiation, cloud cover, urban soil moisture, season and the location of the city itself (e.g. elevation, latitude, etc.). The geographical location of the city also includes properties of its rural surroundings, i.e. whether it is a forest, grassland, desert, or any other land use type. Of course, many more factors affect the UHI magnitude. Possibly too many factors are involved to capture the UHI in one model and the dependencies are unique for each city or town. Hence, combining all these variables poses a great challenge. Oke (1998) made a first attempt to combine known relations between the UHI and some of these variables (street geometry, cloud cover and wind). This resulted in a simple model for the diurnal cycle of the UHI.

We will attempt to approach this problem from a different angle. Within atmospheric boundary-layer research, dimensional analysis (e.g. Langhaar, 1951) is a widely used method to tackle these kinds of complex systems. A well-known example of this approach is Monin-Obukhov similarity theory (Monin and Obukhov, 1954). This theory relates the shape of the vertical profiles of wind speed and temperature to the turbulent fluxes of momentum and heat within the atmospheric surface layer. In this study we use dimensional analysis in search of a uniform equation for the UHI. However, due to the amount of variables influencing the UHI, the problem would be mathematically too complex to solve. Therefore, selecting the most important variables is the first step of our approach. The variables will be selected using the statistical principle component analysis method, a way of identifying patterns and data reduction. Using this analysis we are able to find the variables which are most important in influencing the UHI magnitude. On this compressed dataset the dimensional analysis will be performed.

About dimensional analysis

Dimensional analysis is a method to estimate the dependence of one variable, in this case the UHI, on other variables, e.g. clouds, wind speed, vegetation in the city, soil moisture, etc. The analysis can be carried out using three steps.

1. Selecting variables

First, all quantities that affect the studied variable need to be selected. As mentioned before, the amount of variables influencing the key variable can make for a complicated mathematical problem. Therefore, we use a principle component analysis and limit the amount of variables.

2. Define dimensionless groups

Once the right quantities have been selected, one can derive dimensionless groups. Depending on the amount of selected variables (m) and their basic S.I. dimensions (n), the number of dimensionless groups (r) to be made is m-n=r. For example, if we consider six variables with a total of 3 basic dimensions, such as temperature (K), length (m), time (s), etc., 3 dimensionless groups can be made (6-3 = 3). The dimensionless groups should be unique.

3. Use data to determine a universal function between dimensionless groups

Once the dimensionless groups have been defined, the mutual dependencies between the dimensionless groups have to be quantified. In order to do so, an experimental dataset is needed, either from observations, or model output. With this dataset, the dimensionless groups are plotted as a function of each other. Consequently, we derive an equation describing the functional relation between the dimensionless groups, i.e. by a suitable regression analysis method. Finally, rewriting this equation will provide an expression for the studied variable, i.e. UHI. As the number of variables increases, the number of dimensionless groups increases as well, and it becomes more complex to fit an equation through all the groups.

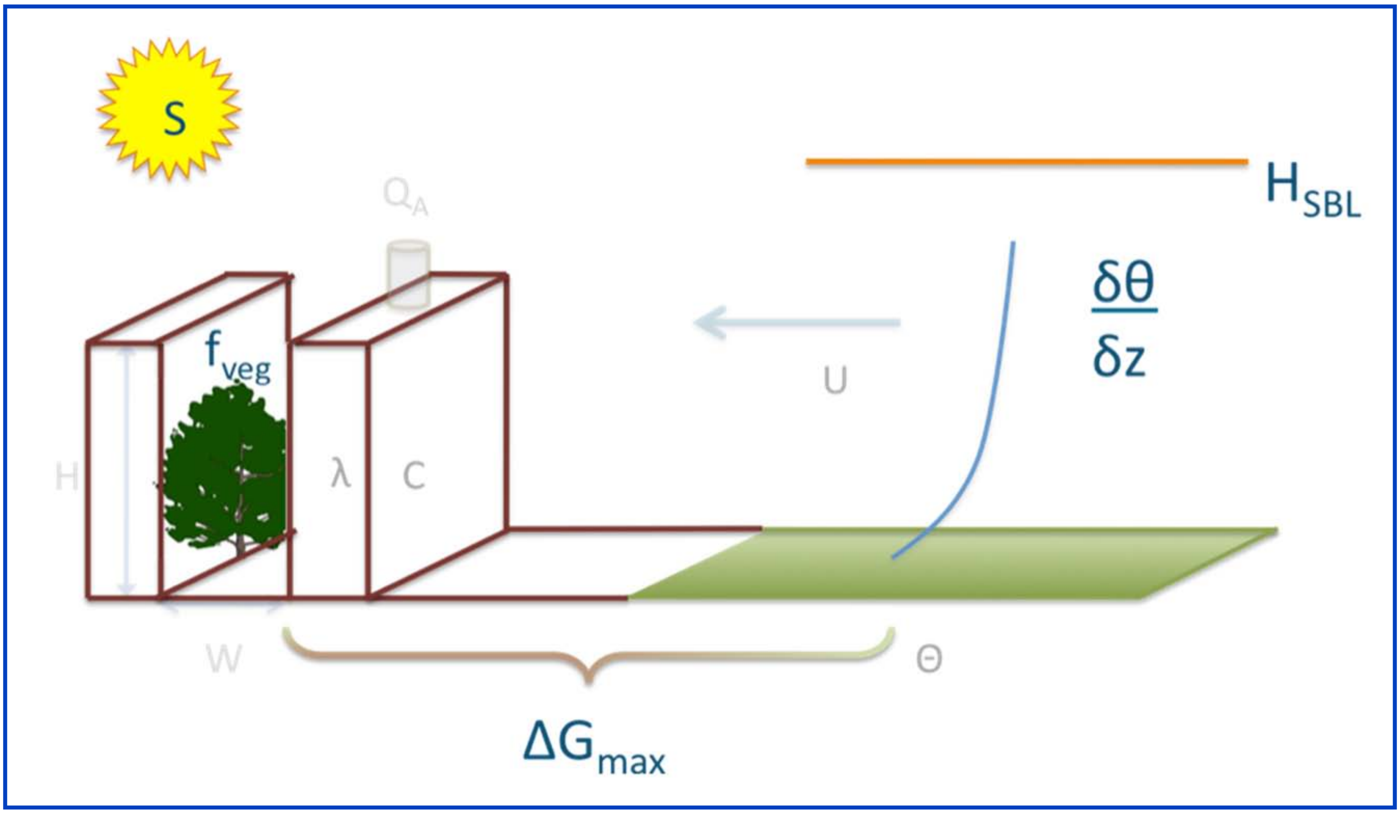

Figure 1. A schematic overview of the variables taken into account with the dimensional analysis.

Application to the UHI

We illustrate the described procedure for the UHI, using preliminary results obtained from output of the Weather Research and Forecasting (WRF) model (Skamarock *et al*., 2008) in single column mode, version 3.2.1. The model is coupled to the single-layer urban canopy model (Kusaka *et al*., 2001). As a reference for the UHI, a second column was run separately with surface properties of grassland. This column represents the rural environment. The MYJ planetary boundary-layer scheme was used.

The analyzed case has an academic setup, initialized with idealized profiles and large-scale forcings, i.e. with a uniform mixed layer temperature and specific humidity, a logarithmic wind speed profile, a temperature and humidity jump at the boundary-layer top, and a constant lapse rate above the boundary layer. This case was run while varying soil moisture content, geostrophic wind speed, vegetation fraction, anthropogenic heat flux, building heat capacity and thermal conductivity, season and latitude.

For example, six variables were selected from the WRF simulations to enter the dimensional analysis. These were the UHI [K] (in this case the difference in the *minimum* two meter air temperature between the urban and rural simulation), vegetation fraction (f_{veg}[-]), the maximum downwelling shortwave radiation (S_{max} [W m^{-2}]), the maximum difference in ground heat/storage flux between the urban and rural simulations (ΔG_{max} [W m^{-2}]), the lapse rate in the rural environment during the night ($d\theta/dz$ [K m^{-1}]) and the stable boundary-layer height (H_{SBL}[m]) (Fig. 1). Using these variables we are able create three dimensionless groups. The first group (Π_1) is a function of the vegetation fraction, which has often shown to be a strong governing parameter of the UHI (e.g. Steeneveld *et al*., 2011).

$$\Pi_1 = 1/(1+ f_{veg}) \qquad (1)$$

The physical rationale behind applying a transformed version of f_{veg} rather than f_{veg} itself, is to ensure well behaved limiting behavior of Π_1 for f_{veg}-> 0.

The second group (2) is the ratio of the absolute maxima of the two fluxes (shortwave and storage fluxes) and relates to the amount of energy stored within the buildings and pavement.

$$\Pi_2 = \Delta G_{max}/S_{max} \qquad (2)$$

The rationale behind this group is based on the idea that that the difference in heat storage capacity of the offered solar radiation by the land surface will be reflected in different cooling and cooling rates at night, and thus in the UHI.

The third group (3) includes the remaining variables, (UHI, stable boundary-layer height and lapse rate) and gives an indication of the stability of the atmospheric boundary layer.

$$\Pi_3 = \frac{\mathrm{UHI}}{(\partial\theta/\partial z)H_{SBL}} \qquad (3)$$

This group is introduced in order to represent the state of the boundary layer in the rural surroundings. A stronger stability will limit the turbulent transport of relatively warm air from aloft to the surface, and thus maximizing the UHI. Note that the two variables in the denominator are connected, since a stronger stability will reduce H_{SBL} due to the suppressed turbulence.

Plotting these dimensionless groups as a function of each other, an approximately linear relation appears and an equation for the UHI can be formulated. This equation for the UHI is compared to the UHI calculated by the WRF model in Figure 2. Half of the dataset was used to derive the equation and the other half for validation. The derived model has a correlation coefficient to the one to one line of about 0.78.

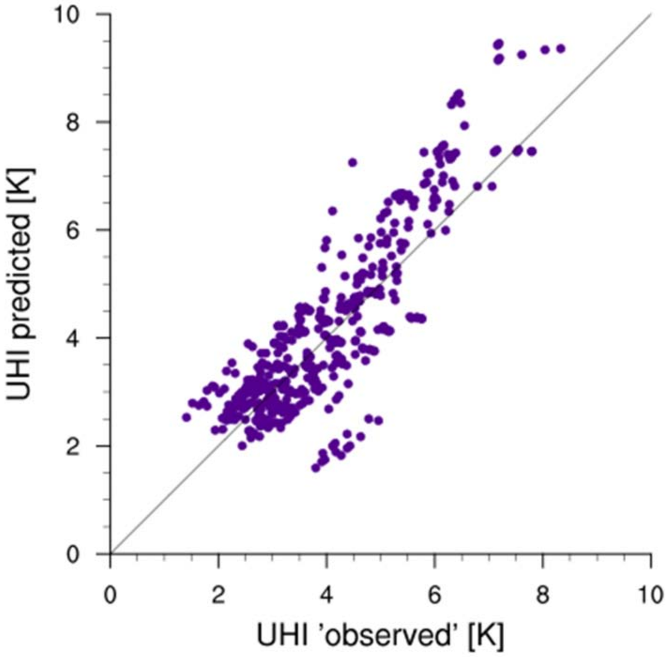

Figure 2. A scatter plot of the predicted UHI by the equation calculated using dimensional analysis and the UHI calculated by the WRF model. ($r^2 = 0.78$)

The simple dimensional analysis described above gives a promising, preliminary result. However, these findings are only based on WRF model results, which has its own limitations. Furthermore, this is only one example with a limited dataset. In order to find whether or not there is a uniform equation for the UHI, a much larger dataset is needed, including field observations from different cities around the globe. Therefore, possible cooperation and contributions from field campaigns from the audience of *Urban Climate News* are highly welcomed and appreciated.

Acknowledgements

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Announcing the Student Award Winners from the 8th International Conference on Urban Climate (ICUC8) in Dublin

The IAUC has announced the names of 13 student award winners who were recognized for work they presented in August 2012 at the **Eighth International Conference on Urban Climate (ICUC8)** in Dublin, Ireland.

Each of these PhD students has been awarded a $200 prize, with funding coming from the Board of the Urban Environment of the American Meteorological Society, the WMO, the EPA and SFI in Ireland, and the family of William P. Lowry, who was an important contributor to the field of urban climatology.

This edition of *Urban Climate News* includes articles by recipients of the IAUC and Lowry awards (see pages 7-34), and the work of AMS award winners will appear in the March2013 issue.

Jonas Alegrini

Empa Dübendorf,
Switzerland

AMS Student Award

The urban microclimate has a significant influence on the energy demand for space cooling and heating in buildings. The radiative heat gains are increased due to multiple reflections of longwave and solar radiation between the buildings. The convective heat transfer at the building façades is decreased, because the wind speeds are decreased in urban areas. Further, the air temperatures are, due to the urban heat island effect, increased in urban compared to rural areas. All three effects lead to a higher space cooling demand for buildings in urban areas. This study shows the importance of accounting for the local urban microclimate, when predicting the energy demands for buildings in urban areas.

Ifeoluwa Adebowale Balogun

Federal University Of Technology,
Akure, Nigeria

Lowry Student Award for Africa

I am a lecturer at the Department of Meteorology, School of Earth and Mineral Sciences, Federal University of Technology, Akure, Nigeria. I am an applied meteorologist with expertise in micrometeorology, urban climate, biometeorology, and climate change. I have specific interest in monitoring, assessing and quantifying urban impacts and associated landuse landcover changes on local climate, air quality and inhabitants' comfort. I have participated in several micrometeorology and urban climate field experiments in Nigeria. My current research involves understanding the role of cities in modifying the weather, climate and air quality, and also suggesting how such research may be usefully employed at various scales of urban management by architects, environmentalists, urban planners, and decision and policy makers. The research also involves mitigation measures that can be applied to combat climate change impacts.

I have authored or co-authored several publications on these issues in reputable journals. Several more manuscripts are currently in preparation.

Research Summary - Urbanisation with its attendant landuse and landcover changes (LULCC) has been affirmed to produce significant changes in surface and atmospheric properties that can result in inadvertent local weather and climate changes. In view of this, Akure (Lat: 7.25 °N; Lon: 5.20 °E), a medium sized rapidly developing tropical city in south-western Nigeria, has been investigated. Incidentally, the city ranks among the Millennium Cities initiative project of the Columbia University and Columbia national investment working with the Millennium Developmental Goals (MDG) support team of the United Nations Development Program (UNDP). A network of in situ measuring stations were set up for two years (January, 2009 - December, 2010) at seventeen different locations within the city with each landuse type fairly represented.

Understanding the extent of change in the transition of various land use types within the city metropolis is very important. Multi-temporal remote sensing data and GIS techniques were used to detect landuse landcover changes and analyse the urban expansion through different classification schemes, and the associated climatic responses were further investigated. Results shows the consequential modifications of the city growth on the local climate as the relationship between the urban and rural parameters indicates the significance of local effects. Urbanization effects on local temperature and humidity have been shown to be significant in the city.

Values of cooling degree days obtained to estimate how much cooling energy may be needed for inhabitants' comfort revealed that elevated temperatures in the central urban areas at both day and night will increase the potential for cooling of buildings. Existing bioclimatic indices were used to derive the bioclimatic conditions of the urban city centre and a rural reference site. Results showed that higher frequencies of urban induced high temperatures observed in the city centre suggest a significant heat stress and health risk in this hot humid environment.

The aspects of heat islands and their relation to urban geometry functions such as the sky view factor (SVF) were further investigated. A clear linear relationship between the sky view factor and UHI intensity is obtained, which is an indication that street geometry and its regional distribution within the city play a fundamental role in generating differential air temperature patterns. Also, intra-urban variations of temperature are also shown to be influenced by land use and other site factors. The highlights of the cooling effects of the vigorous evapotranspiration of the city trees during both the dry and wet seasons, and the potential of trees as a cost effective UHI and climate change impact mitigation tool in Akure have been established in the study.

The project has provided a better scientific understanding of urban climate characteristics arising from anthropogenic activities in Akure. Results obtained can help facilitate measures that can be applied to mitigate climatological degradation, and to design alternate measures to sustain or improve the overall Akure urban environment in the future. The proceeds from the work will be a good toolkit for urban and town planners, architects, environmental managers and other decision/policy makers.

Benjamin Bechtel

KlimaCampus, University of Hamburg, Germany

IAUC Student Award

Benjamin Bechtel was born in Heidelberg, Germany. He studied geography, physics, computer science and urban planning at the University of Hamburg, the Hamburg University of Applied Sciences, and the Hamburg University of Technology. He is currently finalising his PhD and working as a research associate in the Cluster of Excellence CliSAP at the KlimaCampus in Hamburg.

His research interests are in the fields of urban climatology and urban remote sensing, in particular the characterization of urban surfaces for applications in urban climatology and the provision and integration of urban surface parameters. For his PhD thesis with the title "Remote sensing of urban canopy parameters for enhanced modelling and climate related classification of urban structures" he developed and tested new surface parameters and methods to classify local climate zones from remotely sensed data. Further, he used floristic proxy data to derive a long-term urban heat island pattern and compare a large number of surface parameters as empirical predictors. In a subsequent study he showed that the novel parameters are also beneficial for downscaling of coarse resolution land surface temperatures from geostationary satellites in urban areas. His overall aim is to strengthen the bridge between urban remote sensing and urban climatology by finding new applications and interfaces.

Mr. Bechtel is a member of the International Association for Urban Climate, the European Geosciences Union, and the German Society for Photogrammetry, Remote Sensing and Geoinformation. He acts as a reviewer for several international journals including Meteorologische Zeitschrift, IEEE Transactions on Geoscience and Remote Sensing, and Landscape and Urban Planning.

Cécile de Munck

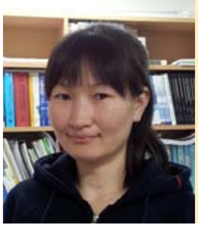
Meteo France - CNRS, France

AMS Student Award

"Green roofs for cities: modelling within TEB" – The need to prepare cities for climate change adaptation requests the urban modeller community to implement within their models sustainable adaptation strategies to be tested against specific city morphologies and scenarios. Greening city roofs is part of these strategies.

In this context, a GREENROOF module for the Town Energy Balance (TEB) model has been developed to model the interactions between buildings and green roof systems at the scale of the city. This module, consisting in the coupling of the TEB and the ISBA-DF (Diffusive version of the Interaction between Soil Biosphere and Atmosphere) models, allows to describe an extensive green roof composed of four functional compartments (vegetation - grasses or sedums, substrate, hydrological control layer, and artificial layers) and to model fluxes of heat, water and momentum between the vegetation and the atmosphere, as well as water and thermal fluxes throughout the natural layers of the green roof and the thermal coupling with the structural building envelope. A calibration exercise of GREENROOF, focusing on hydrological characteristics, has been carried out at building-scale for an extensive sedum green roof, which is the most frequently type of green roof implemented in cities.

The methodology consisted in running 864 versions of GREENROOF calibrated with different sets of realistic hydrological characteristics in order to identify on the basis of statistical scores the calibration set providing the best match with observations. GREENROOF proved capable of well reproducing the dynamics and amplitude of the substrate moisture status while performing well in simulating the temperatures of all the layers. Consequently, the hydrological calibration identified for the standard green roof of the case study will be retained as the default calibration to model green roofs at city-scale.



Gantuya Ganbat

Seoul National University,
South Korea

IAUC Student Award

"Characteristics of the UHI in a high-altitude metropolitan city, Ulaanbaatar, Mongolia" – Ulaanbaatar is the capital city of Mongolia with a population of 1.1 million and is located at about 1350 m above sea level. This study documents for the first time the characteristics of the urban heat island (UHI) in Ulaanbaatar. Data at two meteorological stations, an urban site and a rural site, for a 31-year period of 1980–2010 are used for UHI analysis. The average UHI intensity is 1.6°C. The UHI intensity is strongest in winter (3.3°C) and weakest in summer (0.3°C). The occurrence frequency of the daily maximum UHI intensity in the nighttime is 5.6 times larger than that in the daytime. A multiple linear regression analysis is undertaken to examine the relative importance of meteorological parameters (previous-day maximum UHI intensity, wind speed, cloudiness, and relative humidity) that affect the daily maximum UHI intensity. The previous-day maximum UHI intensity is the most important parameter and is positively correlated with the daily maximum UHI intensity. The cloudiness is the second most important parameter and is negatively correlated with the daily maximum UHI intensity. When all data are stratified into daytime/nighttime and season, the relative importance of the meteorological parameters is changed.

Janina Konarska

University of Gothenburg,
Sweden

Lowry Student Award for Biometeorology

Janina Konarska is a second year PhD student within the Göteborg Urban Climate Group at University of Gothenburg, Sweden. Her current research focuses on the influence of various types of vegetation on different aspects of the urban climate. She has been measuring transmissivity of solar radiation through the crowns of trees, mean radiant temperature, nocturnal cooling rates and tree transpiration.

Simone Kotthaus

Kings College London,
UK

IAUC Student Award

Since 2009 I have been part of the Micrometeorological research group of Prof. Sue Grimmond at King's College London (KCL), UK. Currently, I am in the final stages of my PhD. My work combines both modelling and measurement approaches to observe the exchange of sensible heat in urban areas.

While the main focus of my research lies on the application of the eddy covariance (EC) method in dense urban settings, I am also working with (surface and atmospheric) remote sensing techniques.

Scott Krayenhoff

University Of British Columbia,
Canada

AMS Student Award

My research seeks to better understand the processes responsible for the unique surface climates that result from urban development. To date I have studied surface-atmosphere exchange and urban canopy layer processes via the development, evaluation and application of numerical models. In the present work a new multi-layer urban canopy model of shortwave and longwave radiation exchange is developed that explicitly includes the radiative effects of tall vegetation (trees).

Tree foliage is permitted both between and above buildings, and mutual shading and reflection between buildings and trees are included. The model is designed to be portable to any neighbourhood-scale urban canopy model based on the urban canyon. The new radiation model will help extend the applicability of neighbourhood-scale urban climate models and permit more robust assessment of trees as a tool to improve urban microclimates.

Kevin Lau

The Chinese University Of Hong Kong, China

AMS Student Award

Due to the limited history of district-scale meteorological stations, the study of the effect of urbanization on local climate has been restricted to territory-scale (i.e. taking Hong Kong as a whole). It results in a lack of understanding of district-scale climatic variability as sufficient observational records are limited. The study aims to supplement the understanding of the effect of urbanization on district-scale variations in air temperature by using an extended record of air temperature between 1971 and 2010. Warming trends are generally observed and the rate of warming is particularly observed in rural stations. Such a trend is associated with land conversion into concrete surface in surrounding areas and reduction in vegetation cover. Findings of the present study contribute to the understanding of the effect of climate change on areas with various land use and provide baseline conditions for temperature projection of future climate change scenarios. Such information will be useful to the incorporation of microclimatic conditions into the planning and design of potential development in country areas and redevelopment of inner urban areas in the future.

Natalie E. Theeuwes

Wageningen University, Netherlands

Lowry Student Award for Methodology

"Towards a new formula for the urban heat island using dimensional analysis" – This research aims to study the urban heat island intensity and its causes. Many variables affect the urban heat island, such as incoming solar radiation, wind speed, clouds, available vegetation, building thermal properties, anthropogenic heat production, etc. First a statistical analysis is performed to identify the most important variables governing the urban heat island using observational data from different cities in the world and idealised WRF model results. By applying the dimensional analysis technique, a well-known tool in boundary-layer meteorology, on the key parameters identified, we aim to reveal a universal equation for the urban heat island.

Patrick Wagner

University of Duisburg-Essen, Germany

AMS Student Award

To form ozone in the troposphere two types of precursor substances are needed: NOx (nitrogen oxides) and VOCs (volatile organic compounds). Whereas NOx are mainly emitted by anthropogenic sources, for VOCs there are considerable biogenic emissions. It is well-known that in rural areas BVOCs (biogenic VOCs) are the dominant VOC type, but there is still little knowledge about their importance in urban areas and only a few studies were performed to investigate this issue worldwide. Because there are high anthropogenic VOC (AVOC) emissions and vegetation density is much lower in comparison to rural areas, the importance of BVOCs might be underestimated in urban environments. However, BVOCs are more reactive than AVOCs and BVOC emissions reach their maximum during hot and sunny summer days which are also favorable for ozone formation. Moreover, some popular urban tree species are so-called high-emitters for BVOCs, especially isoprene which is the most abundant BVOC.

To investigate the aforementioned issue, concentrations of isoprene, benzene and toluene were measured with a GC-PID system in Essen, Germany. Spatial and temporal variations of VOC concentrations were investigated and isoprene concentration was compared to concentration of benzene and toluene (which are popular proxys for AVOCs), especially in the summer. It was found that isoprene concentration exceeds the concentration of benzene and toluene during daylight hours on hot summer days. Isoprene/benzene concentration ratio can reach values above ten in vicinity of isoprene emitting trees (e.g. *Platanus acerifolia*, *Quercus robur*, *Quercus rubra*, *Robinia pseudoacacia* and *Populus nigra*). These measurement results indicate that BVOCs have to be considered with regard to ozone formation not only in rural, but also in urban areas.

Jaime Young

Tel Aviv University, Israel / MIT, US

AMS Student Award

My presentation, entitled "Climatic planning according to Vitruvius and its application in the Holy Land" came out of a collaboration between MIT and Tel Aviv University, supported by MIT's International Science and Technology Initiative. I worked with Oded Potchter in the Lab for Climate and Environment at Tel Aviv University, researching and preparing an article that we hope soon to publish. Our research delved into the theory and practice of design and planning according to climatic conditions in ancient times. We looked at ancient texts regarding architecture, urban design, and city planning, then compared these with the physical remains of city plans and public buildings. We chose to focus for this project specifically on Vitruvius' writings and cities that were built during the Roman Empire.

Abstract: Roman civilization is known for its plethora of large-scale planning projects and monumental architecture. Architects and planners used the resources available to them to create pleasant thermal conditions in public places without the use of high-tech climate control systems. Passive techniques were employed for lighting, shading, and ventilation based on the wisdom of generations and knowledge of local conditions. The Roman architect Vitruvius produced the first recorded guidelines for climatic planning of cities and design of public buildings. This study examines the application of these principles in the Holy Land as it is rich in architectural remains from the Roman and Byzantine era and has great variety in its climatic zones. The research was carried out using archaeological evidence of town plans and floor plans of monumental structures, specifically theaters, baths, and basilicas. Each plan was evaluated based on geographic location and adherence to Vitruvian principles. The research yields findings in the way design followed the recommendations, but was altered when local environmental and climatic considerations necessitated a different model. Patterns were found that provide understanding of the climatic design theory. In analyzing the designs' response to climate, inspiration can be drawn from the attitude of the ancients that harmonized the constructed with the natural.

Yuan Chao

The Chinese University of Hong Kong, China

AMS Student Award

High-density living makes cities more efficient in the use of natural resources. However, it also causes serious urban environmental problems. To efficiently mitigate the negative effects of compact living, apart from modeling the environment, it is also important to relate the modeling with planning and design issues. My work aims to allow urban planners and architects practical scientific understandings to improve the high-density urban living environment.

January 9, 2013

Dear Colleagues,

It is with great sadness that we inform you that our friend and colleague, **Henrique Andrade**, passed away yesterday at the age of 52. Henrique's passing is a great loss for the University of Lisbon and especially for the Institute of Geography and Spatial Planning, where he was Assistant Professor, and the Centre of Geographical Studies, where he was member of the board and researcher at the research group on climate and environmental changes.

Henrique's academic career developed at the University of Lisbon. He graduated in Geography in 1990. His master's degree in Physical Geography was obtained in 1994, focusing on atmospheric pollutants in Lisbon and his PhD was obtained in 2004 on human bioclimatology and air temperatures, a topic where he was a pioneer in Portugal. His recent research targeted the societal impacts of climate in cities, including climate change: a) urban green areas and well-being, b) climate and health (mainly on the effects of heat and cold waves), c) climate change and tourism. He was supervising PhD students on these topics and currently was working on mortality and cold events in Central Portugal and also on the effects of lightning on the number of asthma cases in children, through a collaboration with the D. Estefânia Hospital. He was responsible for the mesoscale urban climate network of Lisbon. He has recently published in journals such as the *International Journal of Biometeorology*, *Building and Environment*, *Landscape and Urban Planning*, *Theoretical and Applied Climatology*, *International Journal of Biometeorology* and *Finisterra*. He was author or co-author of several papers in international books. Henrique was low profile but very active and continuously searched for new research lines and funding sources. He will be greatly missed by friends and colleagues. His research legacy is very significant and will be continued by colleagues and students at IGOT/CEG-UL.

Colleagues from teams CliMA and ANTECC at CEG-UL
Centre for Geographical Studies, Institute of Geography and Spatial Planning, University of Lisbon (http://clima.ul.pt)

Recent publications in Urban Climatology

Since the last newsletter, not only the co-ordinator of the Bibliographic Committee has changed, but also some new members volunteered to strengthen the Bib-Com. Team. In this IAUC Newsletter I would like to introduce our 6 new motivated members: **Hendrik Wouters** (KU Leuven/VITO, Belgium), **Kathrin Haeb** (University of Kaiserslautern, Germany), **Rafiq Hamdi** (RMI, Belgium), **Ashley Broadbent** (Monash University, Melbourne, Australia), **Julien Le Bras** (Meteo France, France) and **Bharathi Boppana** (University of Southampton, U.K.). Welcome! At the same time I would warmly like to thank **Grégoire Pigeon**, **Erell Evyatar** and **Anurag Kandya** for their contribution to this Committee over the last few years!

In this edition a list of publications are presented that have come out until the end of November 2012. As usual, papers published since this date are welcome for inclusion in the next newsletter and IAUC online database. Please send your references to the email address below with a header "IAUC publications" and the following format: Author, Title, Journal, Volume, Pages, Dates, Keywords, Language, URL, and Abstract.

Enjoy!

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Upcoming Conferences...

INTERNATIONAL CONFERENCE ON URBAN CLIMATE AND HISTORY OF METEOROLOGY
Florence, Italy • February 25-26, 2013
http://web.fi.ibimet.cnr.it/urbanclimate

2013 AAG ANNUAL MEETING: SPECIAL SESSION ON URBAN WEATHER AND CLIMATES
Los Angeles, CA • April 9-13, 2013
http://www.aag.org/annualmeeting

HARMONISATION WITHIN ATMOSPHERIC DISPERSION MODELLING FOR REGULATORY PURPOSES
Madrid, Spain • May 6-9, 2013
http://www.harmo.org/harmo15

6TH INTERNATIONAL CONFERENCE ON FOG, FOG COLLECTION AND DEW
Yokohama, Japan • May 19-24, 2013
http://www.fogconference.org/

Luke Howard Award Nominations

I am pleased to announce the call for nominations to the 'Luke Howard Award for Outstanding Contributions to the Field of Urban Climatology.' The Luke Howard Award may be given annually to an individual who has made outstanding contributions to the field of urban climatology in a combination of research, teaching, and/or service to the international community of urban climatologists.

IAUC members are requested to nominate suitable candidates for the Luke Howard Award. The person making the nomination will act as the coordinator to put together a nomination package (including a CV of the nominee and three letters of recommendation). Self nominations are not permitted and current Awards Committee members cannot be evaluated. Complete nomination packets (single electronic submission) are to be submitted to the Awards Committee Chair. Dr Jason Ching (jasonching@embarqmail.com) or (jksching@gmail.com) is the Chair of the Awards Committee.

Luke Howard Award Nomination Process

1. Nomination materials should be collected by a nomination coordinator (i.e. the first person to notify the Chair of the IAUC Awards Committee that a particular person will be nominated);
2. Self nominations are NOT permitted.
3. The coordinator should collect the following documentation:
   a) a five page candidate CV
   b) three letters of recommendation from IAUC members from at least two different countries which are two pages in length.
4. Complete packages should reach the Chair by the announced deadline. Please advise the Chair of the committee early in the nomination process of the candidate you have selected to avoid duplication of effort.

Please note that nominations which were not successful may be reconsidered in subsequent years at the discretion of the committee. The IAUC Awards committee will recommend the name of a recipient for consideration and approval by the IAUC Board.

Previous winners include:

2010 John Arnfield, The Ohio State University, USA
2009 Sue Grimmond, King's College, UK
2008 Bob Bornstein, San José State University, USA
2007 Masatoshi Yoshino, University of Tsukuba, Japan
2006 Arieh Bitan, Tel Aviv University, Israel
2005 Ernesto Jauregui, UNAM, Mexico
2004 Tim Oke, UBC, Canada

Nominations should reach the Chair of the Awards Committee (Dr Jason Ching, email above) before **15 February 2013**.

Thank you,
Rohinton Emmanuel
Secretary, IAUC

Board Members & Terms

- Tim Oke (University of British Columbia, Canada): President, 2000-2003; Past President, 2003-2006; Emeritus President 2007-2009*
- Sue Grimmond (King's College London, UK): 2000-2003; President, 2003-2007; Past President, 2007-2009*
- Matthias Roth (National University of Singapore, Singapore): 2000-2003; Secretary, 2003-2007; Acting-Treasurer 2006; President, 2007-2009; Past-President 2009-2011*
- Gerald Mills (UCD, Dublin, Ireland): 2007-2011; President, 2009-2011
- Jennifer Salmond (University of Auckland, NZ): 2005-2009; Secretary, 2007-2009
- James Voogt (University of Western Ontario, Canada), 2000-2006; Webmaster 2007-*; 2009-2013
- Manabu Kanda (Tokyo Institute of Technology, Japan): 2005-2009, ICUC-7 Local Organizer, 2007-2009.*
- Andreas Christen (University of British Columbia, Canada): 2012-2016
- Rohinton Emmanuel (Glasgow Caledonian University, UK): 2006-2010; Secretary, 2009-2011
- Jason Ching (EPA Atmospheric Modelling & Analysis Division, USA): 2009-2013
- David Pearlmutter (Ben-Gurion University of the Negev, Israel): Newsletter Editor, 2009-*
- Alberto Martilli (CIEMAT, Spain), 2010-2014
- Aude Lemonsu (CNRS/Meteo France), 2010-2014
- Silvana di Sabatino (Univ. of Salento, Italy), 2010-2014
- Hiroyuki Kusaka (University of Tsukuba, Japan): 2011-2015
- David Sailor (Portland State University, USA): 2011-2015

* *appointed members*

IAUC Committee Chairs

Editor, IAUC Newsletter: David Pearlmutter
Bibliography Committee: Matthias Demuzere
Nominating Committee: Tim Oke
Chair Teaching Resources: Gerald Mills
Interim-Chair Awards Committee: Jennifer Salmond
WebMaster: James Voogt

Newsletter Contributions

The next edition of ***Urban Climate News*** will appear in late March. Items to be considered for the upcoming issue should be received by **February 28, 2013** and may be sent to Editor David Pearlmutter (davidp@bgu.ac.il) or to the relevant section editor:

News: Winston Chow (wtchow@asu.edu)
Conferences: Jamie Voogt (javoogt@uwo.ca)
Bibliography: Matthias Demuzere (matthias.demuzere@ees.kuleuven.be)
Projects: Sue Grimmond (Sue.Grimmond@kcl.ac.uk)

Submissions should be concise and accessible to a wide audience. The articles in this Newsletter are unrefereed, and their appearance does not constitute formal publication; they should not be used or cited otherwise.