A Breath of Fresh Air in Urban Heat Island Studies

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The urban heat island effect is a well-known phenomenon, i.e. cities are usually several degrees warmer at night than the surrounding country side. Surprisingly, a significant amount of studies have observed a cooler city than their surroundings in the morning or during the entire day, i.e. the urban cool island. However, an explanation for the phenomenon so far has been lacking. In this research we use a conceptual boundary-layer model to explain the physical mechanism behind the urban cool island. In the morning the rural boundary-layer is shallower than the urban boundary layer, because the urban boundary layer often remains unstable or neutral during the night. Hence, the provided solar heating in the morning is distributed in a shallower layer in the countryside, resulting in a rapid heating. The urban boundary layer takes longer to warm up because the volume of air to be heated is much larger. Whereas, the rural boundary layer has less air heat, and warms faster. This causes the rural mixed layer to be warmer than the urban environment at the start of the day. The intensity of the formed urban cool island depends on many parameters, including the difference in stability of the urban and rural boundary layer, the stability of the free troposphere and surface heat flux dependent on the local climate zone. The conceptual model is initialised and validated with observations from the BUBBLE campaign in Basel, Switzerland.

Observed Spatial Characteristics of Beijing Urban-Climate Impacts on Summer

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This study investigates interactive effects from the Beijing urban area on tem- perature, humidity, wind speed and direction, and precipitation by use of hourly automatic weather station data from June to August 2008-12. Results show the Beijing summer urban heat island (UHI) as a multi-center distribution (corresponding to underlying land-use features), with stronger nighttime than daytime values (aver- ages of 1.7 vs. 0.8°C, respectively). Specific humidity was lower in urban Beijing than in surrounding non-urban areas, and this urban dry island is stronger during day than night (maximum of -2.4 vs. -1.9 g kg-1). Wind direction is affected by both a mountain- valley breeze circulation and by urbanization. Morning low-level flows converged into the strong UHI, but afternoon and evening southerly winds were bifurcated by an urban building-barrier induced divergence. Summer thunderstorms also thus bifurcated and bypassed the urban center, due to the building-barrier effect during both daytime and nighttime weak-UHI (<1.25°C) periods. This produced a regional- normalized rainfall (NR) minimum in the urban-center and directly-down- wind of the urban area (of up to -35%), with max values along its downwind lateral edges (of >15%). Strong-UHIs (>1.25°C), however, induced or enhanced thunder- storm-formation (again day and night) which produced an NR maximum in the most urbanized area of up 75%.

An investigation of the dynamic and thermodynamic impacts of urbanization via WRF-LES

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Understanding the dynamic and the thermal impacts of urbanization is essential for improving our parameterization of urban flow and urban fluxes. This study investigates the urban-rural contrast in terms of surface temperature (TSK) and roughness length (z0) using Large Eddy Simulations (LES) with the Weather Research and Forecast (WRF). In addition, the impacts of small-scale urban heterogeneities in terms of surface temperature and roughness length are also examined. The WRF-LES is first modified in order to use prescribed TSK, in addition to prescribed sensible heat flux, as the surface boundary conditions. Numerical simulations are then conducted to examine turbulence characteristics and mesoscale circulations resulting from the urban-rural contrasts in TSK and z0 as well as their small-scale heterogeneities in urban areas. The results indicate that: (1) the urban-rural contrasts in TSK and z0 have significant but different effects on the vertical distribution of potential temperature and winds, and they interact synergistically to modify the urban boundary layer. As a result, using sensible heat flux as the surface boundary conditions cannot separate the dynamic and thermal impacts of urbanization. (2) the impacts of small-scale urban heterogeneities can be important but significantly depend on their characteristics length scales.

Observation and Simulation on the Characteristics of Summer Urban Heat Island in Nanjing, China

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Urban heat island (UHI) effect acts as a hot topic in urban climate research. Meanwhile, it is an important issue related to urban environment, urban development planning and climate change. Based on the data of 2010 'Nanjing Summer UHI Observation' and numerical simulation results, the temporal and spatial distribution characteristics of UHI in Nanjing were showed as the following

(1) The daily UHI intensity on typical sunny day was above 1°C in the summer of 2010 in Nanjing. UHI was stronger and more stable in the nighttime than it was in the daytime. The average UHI intensity was 1.63°C at night, and its distribution corresponded well to urban landuse status. The strong heat island existed under sunny, windless weather conditions and UHI intensity was weakened with wind speed increasing. In addition, wind direction can significantly influence on the spatial distribution of UHI. The leeward of a city can be warmed by the tail flow of the city, resulting in the extension of the thermal region to down wind direction.

(2) During the daytime, the mixed layer in urban developed faster and higher than that in suburb. Due to the strong heat island and the strong convective mixing at night, mixed layer can still exist in this period and led to a uplifting night inversion layer. Urban mixed layer height was estimated as 300m in the nighttime and 1300m in the daytime in this observation. Owing to high heat storage and strong turbulent transport of urban underlying surface, heat island took shape in urban boundary layer, with UHI intensity decreasing with height. Heat island in boundary layer extended up to 900m in the daytime and maintained at 300m in the nighttime.

(3) Simulation results showed that, in the summer when the weather was fine, heat island took shape in boundary layer all day in Nanjing. At 02:00 p.m., sensible heat flux reached 350W/m2 in city, twice as that in suburbs. In comparison, the soil heat flux reached 200W/m2 in city as four times that of the suburbs. Urban underlying surface stored a large mount of heat, providing the heat source of UHI. At the same time, TKE in city reached the higher value of 1.2m2/s2 in 200-700m, twice as that in suburbs. Strong turbulent motion in the daytime promoted the development of urban mixed layer, and UHI in boundary layer formed within the height 700m, which was higher than that at night. At 02:00 a.m., sensible heat flux and TKE decreased significantly both in urban and suburban, when urban soil heat flux was up to 30-35W/m2, twice as that in suburbs. Urban surface continuously released heat storage, to maintain UHI in the nighttime.

Keywords: urban heat island; urban boundary layer; urban underlying surface; Nanjing summer; WRF mode

Urban heat island in the metropolitan area of São Paulo and the influence of warm and dry air masses during summer

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Urban heat island (UHI) is a phenomenon created by changes in the surface characteristics caused by the urbanization process: waterproof soil, high buildings, channelization of rivers, deforestation, anthropogenic heat, etc. These changes cause different values for albedo, heat conductivity and capacity, surface roughness, hydraulic conductivity and capacity and atmospheric transmissivity and emissivity when compared to the surrounding non-urbanized areas. Therefore, higher air temperatures may be found over the city, creating UHI, and the intensity of this phenomenon is evaluated by the difference in temperature between the city and the non-urban surrounding areas. In high altitudes, the anthropogenic heat plays an important role in generating and sustaining the UHI at night and during the winter, however, in tropical latitudes, the UHI is less intense and its maximum is during summer daytime. These difference occurs because at lower latitudes the heat island is strongly modulated by the solar radiation and the difference in the water content in the soil between urban and rural areas. Also the influence of the anthropogenic heat is smaller. The Metropolitan Region of São Paulo (MRSP) is formed by 39 cities, including São Paulo (23° 32′ 56″ S, 46° 38′ 20″ W), the largest city in the South Hemisphere, and has a population of nearly 21 millions of inhabitants in an area of 7,946.84 km2. It has a complex topography, including the Cantareira Mountains at the northern part of the city, three large river valleys (Tietê, Pinheiros and Tamanduateí) and the Serra do Mar Mountains at the southern part. The climate is usually dry and cool during winter and humid and warm during summer. It is located at an average altitude of 760 meters above sea level and is approximately 70 km distant from the ocean, however it is influenced by sea-breeze circulation 50 % of the days of the year, in average. The surface is very complex, presenting parks, water bodies, and familiar agriculture, residences, industries, highways, high buildings, and three airports. The UHI intensity in the city of São Paulo was estimated based on observations in 2004 and resulted between 2.6 (July) to 5.5 °C (September), with maximum intensity between 14 and 16h. Like in other low latitude cities, the UHI presented strong correlation to the net solar radiation at the surface. The summer of the last year (Dec/2013 to Jan/2014) presented an unusual synoptic condition, with a warm and dry air mass over the MRSP. Therefore, cloud cover and precipitation were lower than the climatological averages and temperature and net solar radiation at the surface were higher. The present work aimed to better understand the air temperature field and verify the influence of this particular phenomenon on the UHI of the MRSP using the available observations. The analysis was based on the datasets of three meteorological stations, Mirante de Santana (urban), USP (suburban) and EACH (suburban), 13 air quality monitoring stations (urban sites), and three micrometeorological stations IAG (suburban), Secretaria da Fazenda (urban) and Itutinga (rural). The preliminary results showed that the summer of 2014 presented a more intense UHI and reinforced the influence of the net solar radiation. However, the air temperature in the MRSP presented a complex field, that can produce complexes UHI phenomenon and atmospheric circulation.

About the relation between urban topsoil moisture and local air temperature

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The climate in cities differs from that in the surrounding area due to modified surfaces. As surface sealing ratio, vegetation and building material are known to be relevant for the intensity of the microclimatic modification – what about topsoil moisture content and availability?

Soil acts as a storage and transmitter for water. According to water availability at the surface - dependant from soil physical properties and water refill from above or below - it may have different impact intensities on local climate through distinct evaporation. To find out to which extend soil hydrological characteristics and water replenishment limit the local cooling effect of soils in the urban environment is a main issue of the project HUSCO (Hamburg Urban Soil Climate Observatory). Hereby, focus lies on the impact of soil properties, urban land-use and groundwater table depth on the climate relevance of soils.

Four years record of ongoing measurements in the city of Hamburg, Germany, is evaluated. The data is provided by atmospheric and pedologic measurement sites, located within six urban districts: the city core, four suburban districts, featuring different mean groundwater table depths (> 5 m below surface / < 2.5 m below surface), and one industrial area.

It is found that groundwater table depth, soil substrate and vegetation types influence the temporal evolution of volumetric water content and water tension within the upper horizons of suburban soils. Soil hydrological processes show characteristic patterns at each measurement site, including topsoil moisture variability. Yet, differences between distinct urban land use types are visible only according to differences in the prevailing soil texture.

Air temperature (Ta) anomalies of the suburban sites from the inner city site are analysed for several periods and seasons. During daytime a significant annual mean deviation is found above unsealed, vegetated surfaces from a sealed site during days with a turbulent mixing induced by wind speed ≥ 2 m/s and partly cloudy sky. For days matching these criteria, differences in the Ta span, i.e. increase of Ta during the day, is observed. About a fifth of the variance of the diurnal Ta span is found to be explained by topsoil water content for selected relevant days.

In this contribution the observed relation between topsoil moisture and air temperature increase during daytime at suburban sites will be presented after describing the local conditions. Case studies complement the statistical analyses.

Investigating the impact of anthropogenic heat on urban climate using a top-down methodology

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Since urbanization will continue in the future and the temperatures and also the heat stress are projected to increase, the anthropogenic influence on the urban climate was investigated more intensively during the last years. Having in mind the indirect and direct effects caused by buildings and sealed surfaces, we are focusing on the anthropogenic heat emissions and its contribution to the urban climate.

One way to estimate the anthropogenic heat are the so-called inventory approaches following Sailor (2011). Sailor (2004) developed an inventory-based generic methodology for US cities. Our contribution is a generic methodology, which aims for the determination of the anthropogenic heat releases over the German region based on energy budget reports, i.e. reports provided by the State authorities with a yearly update cycle. Spatial and temporal distributions of anthropogenic heat release are determined by mapping energy consumption in different SNAP classes on high-resolution landuse data and SNAP-based emission inventory (Kuenen et al., 2010). The resulting anthropogenic fluxes are compared and evaluated with the well-established LUCY data base. It is demonstrated that our approach offers some more details about the sources of anthropogenic heat which cannot be resolved by the existing, coarse LUCY data base (e.g. the heat releases at some large industrial sites).
In order to quantify the direct impact of such anthropogenic emissions on the urban climate, mesoscale simulations were performed for the Hamburg Metropolitan region using a nonhydrostatic model and a realistic atmospheric forcing. The anthropogenic heat sources were incorporated on a computational grid with 250 m horizontal resolution. Focusing on the seasonal effect of anthropogenic heat, urban climate was investigated by performing not only one specific weather situation with calm winds, but simulating 19 different weather situations characterizing the typical weather patterns for the Hamburg city in summer (using a dynamical downscaling of ERA analyses).
Results show that the anthropogenic heat emissions have a direct impact on the temperature in urban areas: Taking a mean over the whole summer season the night-time temperature at 10 meter height is increased by about half a degree at specific hot spots in the city. For specific weather types the increase in temperature due to anthropogenic heat can be much higher. This result highlights the importance of anthropogenic heat for the urban heat island but also for future adaptation and urban planning measures.

Effects of Urban Form and Atmospheric Stability on Local Microclimate

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Although proper urban planning options could help minimize the effects of UHI, studies to adapt the built environment to climate changes in urban areas are rare, particularly in the context of cool climate cities where urban warming is typically not seen as a current problem. This will change as the background climate continues to warm. While the exploration of the influence of urban form on local microclimate is helpful, it is necessary to untangle this effect from background atmospheric conditions that lead to such effects. The present paper evaluates the effect of urban morphology (as measured by the Sky View Factor – SVF) on local climate according to atmospheric conditions exemplified by atmospheric stability (modified Pasquill-Gifford-Turner [PGT] classification system) in a cold climate city. The aim is to highlight their combined importance and to make preliminary investigations on the local warming effect of urban morphology under specific atmospheric stability classes. Forty-nine locations were selected in the city centre, on the basis of SVF to represent a wide variety of urban forms (narrow streets, neighbourhood green spaces, urban parks, typical street canyons and public squares) and seven of these were assigned as locations for fixed weather stations. Thirty one temperature measurement campaigns were made during spring and summer 2013, using a 'traverse' method on a 'Meteobike' and on foot. The locations were chosen to represent a variety of urban formation (narrow streets, neighborhood greenspaces, urban parks, uniform and non-uniform street canyons and public squares). The visualization of local temperature variations was accomplished using Arc-Map tool from Arc-GIS package. The present work indicates that the maximum intra-urban temperature differences (i.e. temperature difference between the coolest and the warmest spots in a given urban region) is strongly correlated with atmospheric stability. It appears that atmospheric stability has larger effect on intra-urban temperature variations than urban morphology in a cold climate city. The combined effect of the two provides interesting variations in local temperatures that may have urban planning implications, especially as the background climate continues to warm.

Urban Heat Island of Arctic cities

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Actual progress in Urban climatology in XXI century covers new regions and new cities. New studies shows us a big amount of Urban Heat Island varieties all around the world. This effect is well-known in modern climatology due to its influence on different economic features and urban air quality (Oke, 1987). Also UHI characteristics differs in different climate zones, for example in summer in Mediterranean and subtropical monsoon climate types it leads to growing energy consumption due to AC systems using (Ohashi et al, 2007). But there is only a few papers about UHI (Magee et al, 1999) in high latitudes, for the cities over the Polar Circle and especially about behavior of the heat islands during the polar night, while anthropogenic heat is the main source of thermal energy. The main goal of this study is to mitigate this lack of information about climatology of UHI formation in big cities (with population exceeding 50 000) of Arctic zone.

In this work, we consider the results of experimental research of the UHI of 4 biggest Arctic Cities (Murmansk, Norilsk, Apatity and Vorkuta), which were obtained during the expedition of Russian Geographic Society in 2013-2014. During the project we used a different measurements techniques:

1. Installation of two automatic weather stations (AWS) in rural zone and city center
2. Installation of small temperature sensors (iButton) network in the city and suburbs
3. Regular car-based temperature sounding of the city with AWS.
4. Using MTP-5 microwave temperature profiler.

This investigations allowed to collect unique data about UHI in high latitudes. Analysis of the collected data showed the existence of UHI with the difference between city center and surrounding landscape up to few degrees Celcius.

The most interesting results we received in Norilsk and Apatity. Tha last one can be determined now as the ideal city for Arctic Urban climate issues. Its topography and building density allow UHI to reach about 5-7 degrees during nighttime in January with well observed warm city core. In Norilsk the negative correlation of the UHI power with air temperature was determined and its intensity can vary in different sinoptic conditions.

In Murmansk - the largest city north of the Arctic Circle (about 300 000 inhabitants), UHI is neutralized by Kola Bay influence.

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Vertical range of urban ‘heat island’ in Moscow

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The urban ‘heat island’ vertical range in Moscow region has been studied using collected data of in situ measurements of air temperature T by sensors on TV tower, high meteorological mast and radiosondes. The tower is situated at Ostankino district inside Moscow close to the city centre and has a height of 540 m; mast of 310 m height is located in Obninsk on a distance about 100 km to the South from Moscow; radiosondes are launched in Dolgoprudny on 5 km to the North from the city margin twice a day and measure T with a spatial resolution of 100 m up to the height of 1 km.

As one knows the ‘cross-over’ effect is an intersection between nocturnal profiles of T above the city centre and suburbs as a result of higher intensity of the surface inversion outside a city than inside it. Hence, from some level at night the air temperature above city, especially its central part, is less than at rural zone at the same height. Vice versa, in the afternoon the air temperature above a city is higher due to more super-adiabatic vertical gradient of T in the urban ground air layer. Evidently the vertical range of the ‘heat island’ is equal to the lowest level at which T becomes the same inside and outside a city both at night and at midday. Our data represent conditions of nearly the centre of Moscow (TV tower), city margin (radiosondes) and rural zone (mast). All measurements of the air temperature which were made simultaneously at three locations have been collected for the period from 2000 to 2013 at four heights: the ground, 100-128 m, 300-305 m and 500-503 m. Preliminary results demonstrate that on the ground level (2 m) the air temperature is maximal in Ostankino and minimal in Obninsk both in the afternoon (9.2 and 8.2 ˚C correspondingly) and at night (5.0 and 3.1 ˚C). In Dolgoprudny (close to city margin) average values of T are intermediate between city centre and rural zone: 8.6 ˚C at midday and 3.4 ˚C at night. On the level of 500 m the air temperature in Ostankino is in average 0.1 ˚C less at night and 0.2-0.3 ˚C more at midday than in Dolgoprudny. Thus, vertical range of the urban ‘heat island’ seems to be close to 500 m at night and is a bit more than 500 m (the highest level which is available for comparison) in the midday.

Besides, a dynamics of the air temperature in the lower troposphere above Moscow region (in the air layer up to 4 km height) during last two decades (since 1991 till 2013) was studied in details by the data of radiosondes and high mast. A tendency to some deceleration of current climate warming has been detected at the recent time.

Vertical structure and spatial distribution of Moscow city urban heat island

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Vertical structure of urban heat island (UHI) is one of atmospheric phenomena which requires further study. Continues and simultaneous measurements (2004-2014) of atmospheric boundary layer (ABL) temperature profiles were carried out at several points of Moscow megalopolis by microwave temperature profilers (at the city center, outskirts, suburbs). As was indicated the value and spatial distributions of UHI parameters had a wide range of seasonal and interdaily variations. Maximum of UHI intensity (140 C) was observed in winter season in specific atmospheric conditions. In summer season maximum of UHI intensity was about 4 0 C. Spatial distribution of UHI parameters was also changing from winter to summer. At winter maximum altitude of UHI was indicated as 100-150 m above surface layer, and in summer it was 300-500 m. In the central part of the city UHI was accompanied by atmosphere thermal instability in all seasons, vertical temperature gradient at the layer 0-100 m was more then 0.980 C/100 m, and reiteration of thermal stability was 1-2 % at the surface layer.

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Urban Heat Island in the Lyon metropolitan areas.

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Lyon metropolitan area is located in the centre-east of France, in the Rhone-Alps region. Two rivers flow through and converge at the southern side of the city. In the lower part its altitude is only 170 m, but three hills with altitudes around 250-300 meters surround the city. Lyon metropolitan area is the second in France with 1 300 000 citizens and an important urban growth (for 2030 1 450 000 citizens are predicted). The last study of Lyon Urban Agency shows that, between 2000 and 2010, the city lost 4 percent of its non-urban surface, due to the extension of infrastructures and economic activity areas into the peri-urban area.

Since 2009 Greater Lyon takes part in climate protection strategy and the Urban Heat Island (UHI) is one of the key issues of its climate change adaptation policies. The heat wave in 2003 proved that extreme climate events provoke an increase of mortality in urban area. One essential question for the Greater Lyon is how land cover impacts urban climate and population comfort and health. Urban climate modeling is essential to enhance the knowledge of this local phenomenon as there are very few measurements and no previous studies available to describe the Greater Lyon UHI.

The aim of the present study is to estimate the Urban Heat Island event.

It also presents the impact of data land cover resolution on temperature distribution in Lyon metropolitan area obtained from climate modeling.

Due to the lack of meteorological measurements in the urban area in this study simulation results issued from Meso NH model are used in order to characterize the UHI in Lyon metropolitan area. Meso NH is coupled with a surface model, Surfex, that integrates an urban component TEB.

For the high resolution modeling, the son grid is based on an accurate surface database that includes a description of the urban fraction at a 250m resolution. Outside this grid, ECOCLIMAP is used as land surface reference.

To obtain the Greater Lyon land cover characteristics a new database is created. Three land cover bases are combined: the Greater Lyon local urban plan, SPOT Thema and an urban historical database (N. Ferrand, 2010). The urban historical database gives information for each parcel of Lyon metropolitan area for 5 periods: 1950, 1975, 1990, 2000 and 2010. The basic design principles are the same that are used in Spot Thema with the 3 levels of typology to identify the process of urbanization. Land cover changes and dating of the buildings in the Greater Lyon can be obtained from this historical database. The study in Greater Paris MUSCADE (A. Lemonsu et al., 2012) provides information about the materials of each building regarding its date of construction and its use. A local adaptation of this material typology is completed with architects to take into account the main architectural differences between Lyon and Paris.

Urban heat island study between different size of towns and cities

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Due to rapid development of urbanization, Urban Heat Island Effects have become serious problems in Taiwan's urban environment, which generate higher urban temperature, consume enormous amount of electricity on air conditioning, and devastate urban climate quality. Therefore, this study combines climatic theories and investigation data on site, proposes some effective principles in mitigating urban heat island effects, which could be useful in urban planning, zoning, and land use policies.

On site investigation utilized automobiles as moving vehicles to measure urban heat island effects in 15 counties in Tainan area, in the south of Taiwan. After comparing with previous research databases, the results reveal as below:

(1). According to the climatic theories, urban heat island effects are more obvious when temperature is low. Maximum urban heat island intensity (ΔT) appears in Autumn (3.63℃), is indeed higher than that in Summer (2.33℃). Average heat island intensity (ΔT) in Autumn (1.90℃), is also higher than others. Second is 1.59℃, appeared in winter, then 1.44℃ in spring and 1.17℃ in summer.
(2). Urban heat island intensity is also more obvious in the counties with lower population (under 30000) and lower density of population (3-4 person per hectare), as in Luchia County and Kuantien County.
(3). Urban heat island intensity is closely related to population, urban density, and proportion of non-agricultural population.
(4). Through regression analysis on SPSS program, two predicting formulas are devised: Simple Predicting Formula and Accurate Predicting Formula. In the analyzing process, important variables include log of population, temperature, proportion of agricultural land ratio, and non-agricultural population ratio.

A Simple Statistical Model for Predicting Fine Scale Spatial Temperature Variability in Urban Settings

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Given that mortality rates during a heat wave are a sensitive function of temperature, forecast maps of temperature anomalies within cities should be useful to the health community. An empirically based approach for predicting daily spatial variations in the Urban Heat Island has been developed for New York City. Our technique is derived from two data sets: high spatial resolution temperature data collected by multiple synchronized traverses of Manhattan by foot; and several months of high temporal resolution data collected at 10 fixed locations by instruments mounted on lamp posts. The high spatial resolution data is regressed against local characteristics such as vegetation, albedo and building height to produce a statistical model of relative temperature anomalies. The fixed instruments show local temporal variability attributed to convection, and spatial variability between instruments attributed to local surface characteristics. The magnitudes of both types of variability are regressed against weather conditions such as cloud cover, wind speed, lapse rate and humidity. When applied to the average spatial anomaly map, the amplitude of the temperature variations within the city each day can be predicted based on a weather forecast. A working model should be online by late fall of 2014, predicting temperature variations within the city 24 hours in advance. The technique should be easily portable to other cities.

Mapping of micro-meteorological conditions using statistical approaches - The example of Stuttgart

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The implementation of adaptation measures in cities is important to counteract the estimated increase in heat stress in the 21st century. Before establishing adaptation measures counteracting the urban heat island, city planners and officials need to know about the spatial and temporal dimensions of the meteorological conditions in a city. As city dwellers are the main target of city planners, the integral effect of air temperature, air humidity, wind speed and radiation fluxes on humans in a city has to be quantified and assessed. Hence, modern human-biometeorological methods have to be applied for the quantification of the spatial and temporal distribution of the UHI as well as to assess mitigation and adaptation measures for improving outdoor meteorological conditions.

Four urban measurement station and one rural measurement stations are used to quantify the temporal and spatial climatic characteristics in Stuttgart. Furthermore, a measurement campaign on 3rd – 4th August 2014 in Stuttgart was used as a basic data set. The state capital city Stuttgart is located in the southwestern part of Germany in complex topography. The air temperature UHI between city center and rural reference station at the airport is in average 2 °C but ranges to 12 °C.

The Physiologically Equivalent Temperature (PET) is applied in this study to quantify the integral effect of air temperature, air humidity, wind speed and radiation fluxes (expressed as mean radiant temperature) on the human energy balance.

Different statistical approaches as artificial neural network and stepwise multiple linear regression are applied and compared for mapping thermal conditions in Stuttgart in day- and nighttime. The generated maps of air temperature, urban heat island and PET have a resolution of 10 m.

The spatial distribution of air temperature and urban heat island shows a maximum in the city center and along the low-lying areas of the Neckar river at 21:00 as well as on 14:00 CET. The decrease in PET as well as in air temperature goes along with an increase in altitude, green areas and number of trees as well as a decrease in built-up ratio and sealed areas.

Artificial Neural Network allows a good estimation of the spatial distribution of PET due to its nonlinearity with an R-squared of 0.94 and a root mean square error of 2.0 K, allowing the adherence of comfort class limits.

Cross-analysis between variability of the urban climate and the landscape heterogeneity at the scale of a neighbourhood for a subgrid parametrization in TEB model

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The temperature variations in urban environment are partly related to landscape characteristics. Following the recommendation of Stewart and Oke (2012), these landscapes or climate zones are defined at the scale of few hundreds of meters. Such a spatial resolution is also relevant for urban climate models, such as the Town Energy Balance (TEB) model that simulates pretty realistic temperature maps over a given city, including a spatial variability depending on urban landscapes arrangement. Nonetheless, TEB is not able to run some finer scale simulations, because of the street canyon hypothesis on which it is based. This is a limitation for urban climate studies because temperature variability at a very local scale may be of the same order of magnitude than at city scale. Thus, the aim of the study is to determine experimentally the variability of the temperature in a neighbourhood, to deduce a statistical model based on a set of explicative variables, and then to implement in the TEB model a parametrization able to quantify the subgrid temperature variability.

With this aim, three field experiments were carried out in a neighbourhood of three French cities: Paris, Marseille and Toulouse. For each city, the area covered about 1 km x 0.5 km and was composed of different urban fabrics. Five intensive observational periods were conducted in June 2013 in Marseille, in October 2013 in Paris and in January, April and June 2014 in Toulouse. For three successive days, every three hours, mobile pedestrian measurements of temperature, humidity and wind were continuously recorded along a predefined itinerary through the neighbourhood, with a GPS recording associated. A permanent network was also set up, composed of ten weather stations recording near-surface temperature, humidity, wind speed and direction, and completed by a roof-level reference station in order to document larger scale atmospheric variables including the incoming short- and long-wave radiation.

For each city, high-resolution geospatial databases have been produced in order to obtain geographical indicators relevant for the study. Thus fifteen indicators related to land-cover fractions and morphological parameters have been calculated. Each of them is calculated around each point of measurement of each city, in buffers of different sizes. The first step of the work is to determine which size is the most relevant for each indicator. Then, statistical relationships are found in order to express the temperature variability as a function of geographical indicators and larger-scale meteorological variables. Then, these relationships are implemented in the TEB model and compared with the temperature observed in each city.

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Multilevel Analysis of Spatiotemporal Regime of Air Temperature in Urban and Suburban Landscape (Case study: The Town of Olomouc, Czech Republic

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The identification of spatiotemporal air temperature differences between urban and suburban landscape represents a complex problem. The reason is that a sufficiently dense network of meteorological stations, which represents a distinct heterogeneity of an active surface and which at the same time considers the influences of geographical environment on the urban climate, is missing. It seems necessary to acquire relevant multilevel data, or possibly to use different methods of data collection. The presented multilevel analysis of spatiotemporal regime of air temperature is based on processing stationary, mobile and surface thermal monitoring data. Olomouc represents medium-sized central European town.

First level presents stationary data measured by the special-purpose Metropolitan Station System Olomouc (MESSO) that included up to 23 measuring points in the inner city and its surrounding. The analysis proved that the mentioned relatively dense station network cannot provide satisfying detailed information on causes of spatiotemporal temperature differences. On the other hand we have obtained basic information about the air temperature field at the local scale.

Therefore the series of mobile measurements of air temperature for selected profiles (second level) namely in night time of days with radiative weather regime and in all seasons of year was carried out. The routes of mobile measuring covered both suburban and inner city areas. The results demonstrate principal differences of temperature courses between urban and suburban landscape and simultaneously enabled identification of hot/cold spots. The profile measurement also granted knowledge about the thermal stratification of urban/rural canopy layer.

Third data level presents thermal images based on surface monitoring by the use of handheld IR camera. Thermal records provided detailed values of surface temperature. Localities with various active surfaces in the time with positive/negative radiative balance and also during individual seasons of year were monitored. The results have proved extreme differences in surface temperatures for both surface type and day/year time.

It can be concluded that multilevel air temperature monitoring together with precise knowledge of local geographical conditions can yield representative findings about the character of air temperature field of middle-sized central European city.

The heterogeneity of urban thermal environment during summertime as observed by in situ and remotely sensed measurements

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The well known phenomenon associated with urban thermal environment is urban heat island (UHI), which urban areas are generally warmer than its surrounding rural areas. Currently, many studies have been conducted with focus on the general UHI intensity. However, the landscape complexities over urban areas may result in the non-uniformity of thermal environment. It is a critical question that whether the heterogeneity is inclined to highlight under heat extreme events. Because, as projected, global warming resulted from the raise of anthropogenic greenhouse gases will possibly increase the incidence, intensity, and duration of summertime heat wave events. Urban area, which holds large amounts of wealth and population, with large energy consumption is potentially sensitive to these related changes.

According to our previous investigation, thermal heterogeneity over urban areas was generally obvious under the condition of heat wave event, as measured by remotely sensed land surface temperature (LST), suggesting that proper and effective counter measures for heat wave events are location-dependent. However, due mainly to the uncertainties both in the quality and quantity of remotely sensed LST records, further investigation is necessary to be done more than the preliminary findings. For fully understanding the thermal heterogeneity over urban areas at summertime, especially during heat wave event, hourly records of meteorology stations were primarily collected, in addition to the MODIS remotely sensed LST products, and CRU TS and GHCN CAMS gridded land air surface temperature data. In this paper, specific attention is given to the case study of Shenzhen City in summer 2007, which located in the South China and is characterized by rapid urbanization and developed economy. Totally 140 meteorology stations were primarily included.

Findings according to monthly records show the general thermal anomalies in the whole summer 2007 over Shenzhen City, both observed by remotely sensed LST and gridded air surface temperature. However, monthly variation is significant, specifically, anomalies are more positive in July in which heat wave events occurred, compared with the anomalies in June and August. The monthly differences give a chance for detailed investigation on urban thermal heterogeneity under different conditions, to get insights into the characteristics of thermal response resulted from urban complexity during heat extreme events. The urban thermal heterogeneities over Shenzhen City were compared and discussed in view of the anomalies of LST and air temperature. Furthermore, the relationship between thermal heterogeneity and urban landscape complexity was also investigated.

UCP4: Observations of Surface Energy and Water Balances

The daytime energy budget of small parks in Mexico City and Lisbon, Portugal, as derived by tree sap-flow measurements and transpiration modeling

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A series of sap flow (transpiration, TRPSF) and energy balance components measurements were carried out in small urban parks in Mexico City. Measurements of sap flow in the trunks of the trees was selected as an alternative tool instead of eddy covariance or Bowen ratio-energy balance methods in order to determine the energy balance components of the tree canopy. These measurements were made in the rainy season (July 2009), from 8:00 to 17:00 LST. With these data, a simple model to estimate transpiration (TRPE) was generated and applied to urban parks in Lisbon, Portugal. Both TRPSF and TRPE showed a unimodal pattern during the day. Mean daily transpiration was higher at urban parks in Lisbon (536 g m-2 d-1) than in Mexico City (411.5 g m-2 d-1), with maxima rates of 0.027 and 0.030 g m−2 s−1, respectively. Net radiation (QN) was mainly dissipated by latent (QE) and sensible (QH) heat around 76 and 17%, respectively in Mexico City and 78 and 13%, respectively, in Lisbon. These differences in QE and QH in the two cities were probably due to differences of water availability since urban parks are irrigated more frequently in Lisbon than in Mexico City. Heat storage of the urban parks was found to be a negligible component of the energy balance in both cities. It is demonstrated that small urban vegetated areas can play an important role in the urban microclimate and therefore, in the mitigation of the urban heat island. Presumably, the constructed model presented a good performance.

Surface Energy Balance at an Urban Residential Area in Seoul, Korea

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CO_2 concentration and flux, and surface energy balance observed at urban residential area, Jungnang site, in Seoul from January to December in 2014 are analyzed. The results for the period from 16 to 23 May 2014 show that (1) westerly winds are dominant in the afternoon, (2) vertical gradients of temperature and humidity are negative, (3) vertical gradients of wind speed and friction velocity are positive throughout the day, (4) wind speed shows a maximum in the late afternoon, (5) CO_2 concentration and flux show maxima at the morning rush hour, (6) albedo and Bowen ratio have values of 0.12~0.13 and 7~8, respectively. And the results for the monthly mean values show that (1) net radiation, sensible heat flux show a maximum near noon in May, which is related to the small cloud cover as well as relatively high solar declination angle, (2) latent heat flux shows a maximum in the afternoon in July, (3) monthly mean sensible heat flux shows positive values with a small seasonal range, (4) As month goes from January to July, daytime Bowen ratio decreases steeply from 15 to 4, while nighttime Bowen ratio increases slightly from 5 to 8, (5) CO_2 concentration (flux) shows a maximum at rush hour in January (February), (6) As month goes from January to July, CO_2 concentration decreases from 850 to 600 mg m-3, (7) diurnal variation of CO_2 flux shows a positive value throughout the day for all months.

Multi-year energy balance and carbon dioxide fluxes over a residential neighborhood in a tropical city

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To be able to mitigate potential unwanted consequences from the local to global scale as an outcome of urbanization, it is necessary to understand the heat energetics and characteristics of trace gas emissions of the urban system. This has consequences for e.g. the magnitude and dynamics of the urban heat island, human thermal comfort or the net exchange of carbon dioxide (and other trace gases) which reflects the balance between carbon emissions from human activities and the dynamics of a number of terrestrial processes that remove or emit carbon dioxide. While such process-based work has been carried out in an increasing number of cities in the developed world in the primarily mid-latitudes, similar work is notably absent in the (sub)tropics where many of the cities with the largest projected future growth rates are located. This presentation will focus on the results from a long-term (7-year) study of energy balance and carbon dioxide fluxes for a residential neighborhood in a modern city located in a tropical-wet climate, viz Singapore. Despite the uniformity of the general tropical background climate, a clear seasonality in energy balance fluxes emerges in response to monsoonal shifts in wind direction. Ensemble averages show that across all seasons the energy partitioning at the surface at this site favors sensible over latent heat and therefore the Bowen ratio is clearly larger than unity. This is somewhat surprising for a city in a wet climate with high availability of water for evaporation. The CO2 fluxes show exchanges on averages are always positive at this residential site despite the relatively large amount of greenspace. This result is consistent with data from other urban studies conducted in mid-latitude cities. The data presented enhance the geographic range of similar work to a grossly understudied region.

Micrometeorological impacts of an ephemeral desert city: The Burning Man experiment

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This paper presents the results from a micrometeorological study of Black Rock City, NV (BRC) during the annual Burning Man festival. Observations were made from 22 August to 2 September 2013 to include the initial construction of the city, the fully populated city during the main event week (69,000 total, ~12,000 km^-2) and the rapid exodus from the city at the end of the event. Built on a flat, arid, playa surface devoid of vegetation or surface water, the city provides a striking contrast in surface roughness as well as the size of sources and sinks of CO2, water and heat. Due to the temporary nature of the city and the high degree of spatial organization, the effects of changing population density and surface cover could be captured in a very short observational period. Eddy covariance measurements of CO2, water vapor, heat and momentum fluxes were made at 12 m and a profile of temperature, humidity, wind speed and direction was measured from 1- 30 m. A second smaller meteorological station was placed on the outskirts of the city and mobile bicycle observations were used to obtain cross-sectional temperature profiles of the urban area.

In this paper, we present the impacts of the urban development on surface roughness, surface energy, water and carbon exchanges, and resulting temperature and humidity signatures. Net CO2 fluxes were negligible prior to urbanization and grew steadily with population density within the flux footprint until they reached rates of 26 gC m^-2 d^-1, similar to large, dense cities observed elsewhere. Diurnal CO2 flux patterns were controlled most strongly by dynamic surface layer drivers, including large swings in surface layer stability and convective transport. The signal from human activities is also clear, such as vehicle migration patterns and even the effect of the culminating event gathering. Also discussed is the role of changing surface roughness on turbulence and vertical exchange processes as well as much smaller changes found in the surface energy balance, Bowen ratio and urban heat island.

Eddy covariance flux towers as urban monitoring systems of greenhouse gases: the Mexico City experience

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Monitoring systems of greenhouse gases (GHG) are needed to evaluate the effectiveness of past and current mitigation policies, and for the design of new environmental strategies. These monitoring systems should provide independent scientific information to validate the predicted emissions at scales used in emission inventories covering all urban elements (e.g. buildings, vehicular traffic, vegetation, etc.) of relevance in the GHG control management. To achieve this goal, the monitoring systems have to rely on a combination of measurement techniques at the micro-, local- and meso-scale. At the local scale, the eddy covariance (EC) flux method (i.e. flux towers) has been increasingly used to evaluate the exchange of CO2 and other trace gases over urban surfaces. Short and long term EC flux measurements in Mexico City have demonstrated the usefulness of the method to validate the accuracy of gridded emission inventories, support traffic regulations, investigate the potential carbon sequestration by urban vegetation, and in general, to improve the GHG mitigation and air quality management of the city. In this context, this paper reports the findings from the most recent CO2 flux measurements conducted in a residential/commercial neighbourhood of Mexico City in 2011 and 2012. These findings have contributed to the verification capabilities of the local GHG mitigation management, and are expected to serve as a reference for other subtropical cities with similar urbanization patterns. Finally, the experience achieved in Mexico City and other cities should promote the use of EC flux towers to better understand the urbanization's influence in the biogeochemical cycles, as well as a functional tool for making policy relevant decisions in the context of a changing climate.

Carbon dioxide flux measurement in the central area of Tokyo

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Eddy covariance measurement of carbon dioxide was implemented for one year from November 2012 in the central area of Tokyo. The annual total CO2 flux was estimated to be 4400 gC/m2/yr. The monthly mean CO2 flux was upward to the atmosphere throughout the year. Clear seasonal variation was observed, where the largest flux occurred in winter. Local-scale emission inventory revealed that the seasonal variation of observed flux would be owing to the gas consumption in the residential houses. In winter, clear diurnal variation with the morning and night peaks was observed. Emission inventory with high-temporal resolution indicates that increase of traffic and gas consumption would cause the morning peak, while the night peak would be caused by the gas consumption.

Carbon dioxide fluxes of turfgrass species in urban turfs in Hong Kong

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The world is experiencing a historical shift in urbanization which has many and varied consequences. The best-documented phenomenon is the urban heat island (UHI) effect, with both local and global effect on climate change which can greatly affect our sensation of thermal comfort. One way to mitigate the UHI effect is urban greening, as plants can provide evaporative cooling effect and shading benefits. Besides, urban greenery can also sequester CO2 in vegetation and soils. On the other hand, urban greenery systems which are under intense management and maintenance may contribute to the emission of CO2 or other greenhouse gases.

We determined the carbon storage of urban turfs, which was 0.05 to 0.29 kg C m-2 for aboveground grass biomass, and 0.18 to 4.89 kg C m-2 for soils (to 15 cm depth). We also measured CO2 fluxes for urban turfs in the wet season of 2012 and dry season of 2013 using a chamber-based technique. Our data demonstrated that grass species played a dominant role in CO2 fluxes with seasonal changes, with CO2 fluxes of all turfgrass species significantly higher in the wet season than in the dry season. Besides, maintenance practices of turfs in terms of fertilization and irrigation also contributed to CO2 emission, which may affect the carbon balance of urban greenery systems and their environmental benefits.
Key words: urban greenery, CO2 flux, turfgrass, carbon balance, urban heat island (UHI) effect

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Net turbulent fluxes of methane and carbon dioxide in the city of Łódź, Poland – comparison of diurnal and seasonal variability

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Exchange of greenhouse gases between the ground and the atmosphere is one of the key processes determining the Earth's climate. This issue is very important, especially in the case of the currently observed climate change. According to the results of measurements conducted for last several years, one of the factors that determined the global warming is the increase of the concentration of atmospheric greenhouse gases. Precise measurements of these gases exchange in environment are crucial for understanding their role in climate system. The appearance about 20 years ago of suitable instruments have enabled the study of turbulent exchange of greenhouse gases between the ground and the atmosphere. These measurements resulted fairly well description of turbulent carbon dioxide flux variability at different time scales (diurnal, seasonal, annual variations), as well as the relation between the intensity of the exchange and land use. Research of turbulent exchange of CO2 between the urban surface and the atmosphere has provided a lot of information about the temporal variability of FCO2 flux in several cities around the world. Therefore, the basic characteristics of the daily and seasonal variation of FCO2 fluxes are known, in some cases, the annual exchange was also estimated. Unfortunately, there is no similar knowledge about methane, which concentration in the air is approximately 200 times smaller, but it's global warming potential is much higher than carbon dioxide. Measurements of methane flux are carried out for several years but mainly in the areas identified as the main sources of methane to the atmosphere e.g. wetlands and rice fields. Unfortunately, only few measurement campaigns are carried out in urban areas, which may also be an important source of methane to the atmosphere (gas leaks from gas networks, sewer systems, garbage dumps, traffic , domestic heating, etc.). The number of stations equipped with instrumentation enabling measurements of the turbulent flux of methane, especially in comparison with the number of carbon dioxide sites, should be considered as definitely insufficient.

The aim of this work is to present preliminary results of methane turbulent net flux measurements carried out in the center of Łódź (central Poland), in comparison with carbon dioxide fluxes. Continuous measurements of these gases are carried out in the center of Łódź by Department of Meteorology and Climatology, University of Lodz since July 2006 (carbon dioxide) and July 2013 (methane). The values of turbulent fluxes has been calculated with eddy covariance method with use of the standard instrumentation set (sonic anemometers and H2O, CO2 and CH4 infrared open-path gas analyzers). So far, more differences than similarities of temporal variability FCH4 in relation to FCO2 were observed. In both cases annual rhythm exist, but variability of FCH4 is much lower. A significant diurnal variability of FCH4 was observed primarily in the warm half of the year, while, in contrast to FCO2, diurnal rhythm of FCH4 in winter is much less diverse. A characteristic feature of the diurnal variability of FCO2 in the city center in the cold half of the year is the presence of two peaks, associated with morning and afternoon and car traffic. In the case of FCH4 such variability does not occur. Temporal variations of both fluxes is characterized by the weekly rhythm (elevated FCH4 and FCO2 on working days from Monday to Friday). The maximum average monthly exchange of CO2, recalculated to pure carbon, is observed in winter (~ 300 gC•m-2•month-1) and the lowest in summer (~ 140 gC•m-2•month-1). Monthly exchange of methane is much less intense, respectively ~ 0.75 gC•m-2•month-1 and ~ 1.1 gC•m-2•month-1. Funding for this research was provided by National Centre of Science under projects 2011/01/D/ST10/07419.

Seasonal and inter-annual variation of CO_2 flux and concentration in Basel

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Measurements of flux (F_c) and concentration (ρ_c) of carbon dioxide are carried out in different ecosystems since several decades. Nevertheless, multiyear records in the urban environment are rare and, when available, cover at most a few years. In Basel, Switzerland, F_c and ρ_c are measured continuously since May 2004 by an eddy covariance system at 38 m above street level at Klingelbergstrasse (BKLI) covering in the meantime a full decade. Analysis of this unique time series contributes to an enhanced understanding of controlling factors of ρ_c and F_c as well as their seasonal and inter-annual variation in the urban environment.

The urban ρ_c-values compare well with background concentration measurements from Schauinsland (Germany) and Jungfraujoch (Switzerland). Furthermore, a good agreement between local and background ρ_c is found with respect to seasonality and long term trend (1.5-2 ppm y^{-1}). Compared to these background measurements, ρ_c at BKLI is clearly higher and daily fluctuations as well as seasonal amplitude are larger, as a consequence of distinct local sources. Inter-annual differences of the local ρ_c at BKLI, when corrected for long term trend, do not vary more than 10 ppm.

F_c is examined for the diurnal, seasonal and inter-annual variability with the use of sectorial analysis. Furthermore, the controlling factors of F_c, as investigated by a footprint analysis, show clear separation of an eastern “traffic”- and a western “residential”-sector. This is a direct result of the local wind regime with a distinct diurnal pattern. To validate the measurements on a neighbourhood scale (about 400 m) fluxes are scaled up by taking into account the varying relative frequency of occurrence of the different wind sectors. The resulting up-scaled average neighbourhood net ecosystem exchange (NEE) totals up to 4.3 kgC m^{-2} y^{-1}, and is thus slightly higher when compared to the measured NEE of 4.1 kgC m^{-2} y^{-1}. Both results are still clearly lower than the 6.33 kgC m^{-2} y^{-1} from the inventory based approach by the local authorities.

Quantification of the surface-atmosphere exchange of energy and carbon dioxide of an extensive urban green roof by eddy covariance measurements

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Current regional climate model projections state the number of hot days with maximum daily temperatures > 30 °C to quadruple until the end of the century in most parts of Germany (scenario A1B; Jacob et al. 2008, Klimaatlas DWD, 2014). Besides global mitigation measures there is need to implement local adaptation strategies in response to urban warming.

Urban green roofs are discussed as one important local urban adaptation strategy. Several studies have already described local meteorological and ecological properties of green roofs, e.g. lowering extreme temperatures by evaporative cooling, rainwater retention and potential air pollution removal (e.g. Ng et al. 2012, Rowe 2011, Yang et al. 2008). However, in situ data on the complete energy balance of extensive green roofs as well as data on the potential of green roofs as carbon sinks is still missing. Such data is important to understand the interaction of green roofs with the urban boundary layer and to validate current green roof models (Sailor 2008). Therefore the eddy covariance measurement technique is applied in order to quantify the turbulent surface-atmosphere exchange of an extensive green roof at the Berlin Brandenburg airport. The green roof covers an area of about 8900 m2 and has a south-west north-east orientation with a length of 168 m. The measurement period started in July 2014 and is planned to be continued until the end of August 2015 in order to get a complete picture of the variability of turbulent fluxes during all seasons of the year.

Seasonal variation of the carbon dioxide exchange and water vapor dynamics of the extensive green roof for the first ten months of the measurement period will be presented and discussed. Furthermore our attention focusses on the evapotranspiration behavior of the green roof during warm periods. First results indicate that during a seven day heat period, maximum daily latent heat fluxes may drop by about 80 % comparing the last versus first day of this period (01.07.2014 - 07.07.2014).

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Urban-rural differences in longwave radiation – Łódź case study

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The influence of the city on shortwave radiation is well established. It is well accepted that the solar radiation is reduced about 10% in the case of annual totals, about 20% for monthly totals and more than 30% for selected days. In contrary, the city role in modification of longwave radiation is poorly documented, even if general processes leading to alternation of this radiation by a city are well understood. The pollution in urban atmosphere increases downward longwave radiation, Ldown, about 6-10%, but this estimations based on a few available publications only. Here will we present a comparison of data based on three years measurements at two sites in central Poland. The urban site is located in the centre of Łódź (population 710 000), and the rural point is about 50 km east, at typical Polish agricultural area. The large distance between sites reduces probability of the city influences on rural site, but needs a careful data selection to exclude influence of synoptic variability of cloudiness. The preliminary results show that under favourable weather conditions Ldown can be about 8-14% lower at rural site. In the same time the upward longwave radiation in the centre of Łódź is about 10-20% higher.

Spatial variability, horizontal anisotropy and diurnal evolution of measured infra-red fluxes in a city neighborhood of Toulouse

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In flat and uniform terrain, the infra-red (IR) fluxes are horizontally homogeneous and isotropic, depending only on the vertical direction. The diurnal evolution, with ground cooling at night and heating during the day is very uniform. This can be modeled with the "plane-parallel" approximation where the fluxes depend only locally on the vertical coordinate and that is the basis of a number of radiative models.

In urban area, however, local variations of the urban fabric, such as big buildings, little houses, parks …, lead to both a horizontal variation of the upward IR fluxes and to an anisotropy of their horizontal component. For example in a northern hemisphere mid-latitude city, a southward facing wall receiving the sunlight will radiate more than its north facing counter part and this will evolve throughout the day and will depend on the local building layout. At night this will tend to equilibrate with the neighboring buildings. To take these effects into account the radiative model needs to be three dimensional.

In order to document and quantify these effects experimentally and in the framework of the EUREQUA project (Environmental improvement of neighborhood, sponsored by French ANR), we have deployed an IR imager accompanying a mobile meteorological measurement system and sound recordings. These mobile systems were walked in the neighborhood of Toulouse approximately every three hours during three days. At each of the 9 stop points for each hourly walk, we took one ground picture and eight horizontal pictures one for each direction. The imager records simultaneously a visible picture, an IR picture and a text file containing the IR measurements that can be later reprocessed. The images then needs to be manually tagged to each stop point and direction. These two parts have been the most labor intensive of the data collection. For image processing, we have then developed a python script to plot histograms, group images and compute simple statistics, such as the mean for each image that we will discuss here.

For each hourly walk we have collected around 100 images (x2 with the visible ones) that amounts to 2500-3000 for one Intensive Observing Period (IOP) of 3 days, which has been repeated in January, April and June in Toulouse (the project also did 2 IOP in Paris and Marseilles but they will not be discussed here).

If we first look at spatial variability of the ground IR fluxes, we notice that the variability is very small in early morning (6h UTC; all stop points around 400 W/m2 for June) but that it is maximal at 15h UTC (3h time resolution). At this time, some stop points can be around 500 W/m2 whereas as others can be close to 700 W/m2. To characterize anisotropy, based on each set of 8 horizontal pictures, we have computed the mean, minimum and maximum. Again in early morning, when the mean horizontal fluxes are minimal, all three values are very close (+- 20 W/m2). At its maximum, the anisotropy measured can reach above 100 W/m2. These measurements will be used in the future for the validation of our 3D IR radiative scheme.

Investigation of the effect of different sealed surfaces on local climate and thermal stress

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Local climate is driven by the interaction between energy balance and energy transported by advected air. Short-wave and long-wave radiation are major components in this interaction. Huge differences in temperature (~10°C) between sunlit and shadowed surfaces may result from the radiation balance. Hence adjusting the grade of reflection of surfaces is an efficient way to influence this range of temperature. While reflectivity is growing with the amount of reflected radiation the absorbed radiation is transformed into thermal energy heating the affected body and giving off heat to the air.

In urban areas the specific geometry of the building structure leads to a larger surface area, thus the absorbable amount of solar radiation is higher. On the contrary undeveloped areas do not heat up like urban areas because of the higher amount of shadow and the higher capacity of evapotranspiration from vegetation. On hot summer days when the heat exchange is on a low level, buildings begin to heat up and act as a thermal storage system, leading to the well-known “heat island” effect.

Climate warming at global- and urban-scale enhance this effect, therefore using different materials for buildings or streets can be considered as an effective method to influence urban microclimate. Santamouris et al. investigated the influence of albedo of asphalt materials on air temperature. They found a decrease of surface temperature of 12 °C and of air temperature of 1.9°C - compared to a conventional asphalt surface - above an asphalt surface with a reflection of 47% in the visible and 71% in the infrared spectral range.

The goal of the present study is the comparison of two urban energy balance models (TEB and EnviMet) and their output with respect to different building and road surfaces. The models are used to simulate the air temperature of the local climate for an urban canyon in Vienna. In a next step thermal stress indices (UTCI, PMV) are calculated based on the simulations. Input parameters are taken from routine measurements of the radiation balance, of the ground and of the air temperature and humidity at different heights above the ground and from measurements of the SW and LW optical properties (albedo, emissivity) from/above 6 different types of sealed surfaces. During this measurement campaign the above mentioned components were measured over a duration of 4 months above 2 conventional asphalt surfaces, one conventional concrete and three newly developed concrete surface with increased reflectances. Measured albedo values amounted to 0.12±0.02 for the asphalt surfaces and to maximum values of 0.56 for concrete.

UCP7: Air Quality in Urban Boundary Layer : processes

A numerical study of pollutant entrainment in a street network

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Entrainment of pollutants into the urban canopy from outside sources, or from material originally released within the canopy (re-entrainment), is a little-understood aspect of urban dispersion. We analyse data from direct numerical simulations (DNS) over an idealised street network to shed light on entrainment, and compare it with the vertical detrainment of material out of the street network and with horizontal dispersion processes. This gives insight into differences in the resulting plume patterns within and above the street network. The transient evolution of the concentration through the network is interpreted in terms of timescales linked with different processes. Lagrangian simulations are performed to shed light on associated dispersion pathways. We then use a simple street network approach to model entrainment and re-entrainment and apply it to model localised releases within and above an urban area. The results will help to inform the representation of entrainment processes in dispersion models.

Impact of heat waves (hws) on air pollution (case study for hws episode in June-August 2010 in the Kiev city (Ukraine)

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Episodes in summer with an extremely high near-surface air temperature lasting several days or longer are termed as heat waves (Robinson, 2001; Lau and Nath, 2012). Under a meteorological point of view they are generally associated with quasi-stationary anticyclonic circulation anomalies, which produce subsidence, clear skies, warm-air advection and prolonged hot conditions in the near-surface atmosphere (Fischer et al ., 2007; Barriopedro et al ., 2011).

HWs represent a natural hazard and have significant impacts on wellbeing, efficiency and health of humans, which can lead to marked short-term increases of morbidity and mortality (Kovats and Ebi, 2006; Basu, 2009), particularly in cities, where most humans are living. From WMO Report (2013), the number of casualties of HW was increased by 2298% in 2001-2010 as compared with 1991-2000.

Our study of HWs in Ukraine (Shevchenko et al., 2014) for the period 1911-2011 indicate, that in contrast to other decades, the number of HW episodes was highest for almost all stations in the decade 2001–2010. For many stations, the longest HW duration occurred in the first two decades of August 2010, i.e. in the period of the extremely severe HW in Western Russia.

HW’s duration in Kiev was 18 days (from 31 July to 17 August 2010). During this period excess of the average daily temperature was at least 5 ◦C; about 10 days this excess reached 8-10 ◦C; maximal days temperature reached 38,2◦C (8.08.2010).

During periods of HWs in urban areas created ideal conditions for the accumulation of a number of pollutants and formation of photochemical smog. Hot weather tends to acceleration of photochemical processes and increase particulate matters (PM), ozone (O3), formaldehyde and other pollutants concentrations.

In Kiev have seen during last 20 years a significant increase in the concentration of ozone precursors, especially NOx (by 50%) and non-methane VOCs, for example formaldehyde (by 200%) due to the increasing number of road transport in the city.Mean annual concentration of PM10 (calculation method) increased by 150% for the central part of the city Kiev and 6 times exceeds European threshold value 40 µm (Snizhko, Shevchenko,2013).

Usually, during HW periods air quality gets worse. Concentration of O3, the photochemical air pollutant, can rise dramatically during the periods of warm and sunny weather that is characteristic for prolonged HWs. Hot weather also tends to the increase in the concentrations of PM and other pollutants.

To estimate the impact of HW on air pollution we have performed a comprehensive analysis of climatic characteristics and some air pollutants, in particular NO2, formaldehyde and AOT-index (Aerosol Optical Thickness). Statistical analysis shoved high positive correlation between temperature indexes and concentrations of pollutants. Significant values coefficients of correlations reached for connection between Tmax daily and concentrations of formaldehyde 0,56; for Tmax daily and NO2 - 0,62.

The accumulation in the urban atmosphere during HW period significant amount of NO2, as main precursor of photochemical smog, led to production of enormous amount of formaldehyde. Maximal concentration of formaldehyde reached 0,037 mg/m3 on 8 August 2010. This amount exceeds 12 times of threshold values and exceeds 2 times pre-HW’s level of concentration. At the same day concentration of aerosols reached maximal level too (AOT=1,31) and exceeds 4 times of its pre-HW’s level.

Concentration of NO2 was changed from 0,2 to 0,25 mg/m3, its sufficient increasing during HW period was not detected. During HWs periods by accelerating photochemical processes it take part as ozone-precursor in photochemical reactions.

Using statistical multivariate methods we made approximation of multivariate regression equation for short-time forecast of critical level of formaldehyde in urban air during HW taking into account both precursor concentration of NO2 and maximal daily temperature in the city.

A WRF-Chem modelling study to analyse the effect of urban greening and white roofs on urban air quality.

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Until 2050, the fraction of global urban population will increase to over 69%, which means that about 6.3 billion people are expected to live in urban areas. Although covering less than 3 % of the land surface, cities are the main contributor to global greenhouse gas emissions. With 78 % of total global carbon emissions, they are heavily implicated in global climate change. The Urban Heat Island (UHI) describes the tendency of an urban area to remain warmer than its rural surroundings. Urban planning strategies such as urban greening and bright building materials help to mitigate UHI formation but can also promote secondary effects on air quality.

This study presents a numerical modelling approach to analyse the effect of urban planning strategies on the urban heat island (UHI) intensity and further the feedback on the chemical composition of the urban atmosphere. The urban area of Stuttgart acts as test bed for the modelling.

The mesoscale chemical transport model WRF-Chem is used to investigate the effect of these urban heat island mitigation strategies on the surface concentration of primary (CO, NO, PM10) and secondary pollutants (O3).

Known mitigation strategies such as bright roofs and façades, urban greening and modification of the building density are in the focus. All these measures are able to reduce the urban temperature and thus mitigate urban heat island intensity.

Model results reveal that the most efficient way to cool down urban areas is the increase in the surface reflectivity. Changing the building albedo in the model from 0.2 to 0.7, lead to a reduction of the urban heat island by about 2 °C. The effect of urban greening and decreased building density is less.

The mitigation strategies which have been mentioned before promote changes in energetic and radiative properties of urban surfaces modifying the chemical nature of the urban atmosphere with regard to both primary and secondary compounds. A temperature reduction of 1 °C leads to an increase of NO and CO by 5-25 %, whereas the mean ozone concentration is projected to decrease by 5-8 %.

Reduced temperature on the surface and in the urban canopy layer influences the dynamical structure of the atmosphere, which leads to a reduction in turbulent mixing. The depth of the mixing layer is decreased accordingly. As a result, an increase of the near surface concentration of primary compounds is projected. Additionally, temperature directly controls the reactivity of chemical reactions, which explains the reduction of ozone concentration.

It has to be pointed out however, that different measures can generate secondary effects. The increased portion of short wave radiation due to a reflexion from white roofs for instance can promote photochemical reactions, leading to an increase of peak ozone levels although temperature has been reduced.

The additional emission of biogenic compounds (BVOCs) coming along with urban greening is also covered in this work. Besides the positive effect of urban greening on temperature and carbon sequestration it is important to discuss the BVOC emission potential of certain tree species. Especially in urban environments with considerable amounts of NOx, these biogenic compounds can act as precursor substances to the formation of secondary pollutants. This work tries to ponder the benefits and dangers from urban greening with regard to air quality.

Whereas in earlier studies the main effort had been put on the positive effect of temperature dependent reduction of urban ozone concentration, this work analyses a complete air chemistry, being able to show negative effects on primary compounds like CO, NO and PM10 as well. The main result of this work indicates the dominating role of atmospheric dynamics when analysing the impacts of urban heat island mitigation strategies on urban air quality.

Cfd modeling of reactive pollutants in an urban street canyon using different chemical mechanisms

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An accurate understanding of urban air quality requires consideration of the coupled behavior between dispersion of reactive pollutants and atmospheric dynamics. Currently, urban air pollution is mostly dominated by traffic emissions. Only fast chemical reactions have influence on street pollutant concentration due to the short distances between sources and receptors. Therefore, some low reactive traffic-related pollutants like CO can be considered as practically inert species at microscale. However, nitrogen oxide (NO) and nitrogen dioxide (NO2) reacts extremely fast (time scales of the order of tens of seconds), besides the fact that Volatile Organic Compounds (VOCs) are involved in this complex chemical mechanism. Usually, NO and NO2 are modeled as passive tracer or using a steady state photochemistry (NO-NO2-O3) at microscale. But to properly account for VOCs, a more complex chemical mechanism is needed with more chemical reactions and more required computational time. Including the vast number of chemical species and reactions that occur in the urban atmosphere is not possible, and it is necessary to choose the most suitable mechanism for each scenario in terms of accuracy and CPU time.

The aim of this work is to investigate the flow and dispersion of NO and NO2 with different chemical approaches in simple urban configurations using a CFD-RANS model, in order to quantify the errors linked with the use of a simplified chemistry. Three types of simulations are performed: a) NO and NO2 as passive tracer (no-reactive), b) steady state NOx-O3 photochemistry (3 reactions and 3 species), and c) a more complex chemical scheme based on the RACM ('Regional Atmospheric Chemistry Mechanism') in the case of an urban atmosphere, developed to reduce the chemical system to 23 species and 25 reactions using CHEMATA software (Kirchner, Atmospheric Environment 2005). The influence of different parameters (zenith angle, VOCs-to-NOx emission ratio or temperature) on the errors in NO and NO2 concentration is investigated. The main conclusion is that errors induced by the use of the simple photochemistry state are larger when the VOCs-to-NOx emission ratio increases. Considering VOCs chemical reactions, lower NO and higher NO2 concentrations are obtained in comparison with steady state photochemistry. In this work, some criteria about what type of chemical mechanism is necessary to reproduce NO-NO2 concentration within streets are provided for different scenarios.

Turbulence and pollutant transport in urban roughness sublayer under stable stratification: a large-eddy simulation

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Thermal stratification of the atmospheric surface layer has strong impact on the land-atmosphere exchange of turbulent, heat, and pollutant fluxes. Few studies have been carried out for the interaction of the weakly to moderately stable stratified atmosphere and the urban canopy. This study performs a large-eddy simulation of a modeled street canyon within a weakly to moderately stable atmosphere boundary layer. To better resolve the smaller eddy size resulted from the stable stratification, a higher spatial and temporal resolution is used. The detailed flow structure and turbulence in the street canyon and in the roughness sublayer are analyzed. The local scaling of turbulent quantities in the roughness sublayer is tested. The relationship of pollutant dispersion and Richardson number of the atmosphere is investigated. Differences between these characteristics and those under neutral and unstable atmosphere boundary layer are emphasized.

The clearflo project – Are sea breezes a mechanism to change the air in London?

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The ClearfLo project aimed to understand the processes generating pollutants like O3, NOx and particulate matter and their interaction with the urban atmospheric boundary layer. ClearfLo (www.clearflo.ac.uk), a large multi-institution NERC-funded project in the UK established integrated measurements of the meteorology, composition and particulate loading of London’s urban atmosphere accompanied by modeling of urban meteorology and air pollution.

The project established a new long-term measurement infrastructure in London encompassing measurement capabilities at street level, in the urban background, at elevated levels and in the rural surrounding to determine the urban increment in meteorology and air pollution. Two intensive observation periods (IOPs) in January/February 2012 and during the Olympics in summer 2012 measured London’s atmosphere with higher level of detail.

We know that sea breezes reach London and previous studies, for example New York, have shown that urban areas change (delay) sea breezes. However, we do not know how sea breezes affect the urban boundary layer structure and the surface energy balance in London due to a lack of vertically distributed measurements until now. This talk presents high-resolution surface energy balance measurements taken during the ClearfLo and ACTUAL projects (www.actual.ac.uk) at different locations and heights in central London alongside lidar and ceilometers derived backscatter and turbulence measurements of the urban boundary layer during a sea breeze event on 25th July 2012. Observations are compared against numerical model simulations with the UK Met Office UKV at 1.5 km horizontal resolution and higher resolutions to explain accompanying peaks in NOX and black carbon concentrations during the passage of the sea breeze.

Simulations of Pollutant Dispersal over Nairobi City, Kenya

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The current rapid deterioration of air quality in urban centres can be attributed to urbanization. Poor air quality has been associated with several negative effects on human health, climate and ecosystems. Most cities in developing countries, especially in Africa have poor or in some cases no air quality management systems in place despite having the fastest growing urban populations. City populations have high vulnerability to the impacts air pollution following high density of residents and economic activities as well.

Air pollution is evident in most cities; the case of Nairobi is an illustrative of this. The common air pollutants include carbon monoxide and total suspended particulates among others, the latter being the most widespread and the most serious for human health.

This study simulated air pollutant dispersal over the city using Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT), considering a case for emission of total suspended particles into the environment. The predominant wind speed over the city is 4-6 knots and the wind direction is easterly. The forward trajectory of a pollutant released in the city is generally observed to flow to the western side of the city. The pollutant is observed to be dispersed beyond 100 km from the city reducing the concentration of the same in the city.

The study thus recommends for a consultative planning process of the city that factors in the wind characteristics over the city; most industrial activities should be located to the extreme western side of the city to minimize concentration of pollutants over the city. The study further recommends studies that studies be carried out to ascertain the quality of rain water during the long rain season.

Key words: Pollution, Environment, HYSPLIT, Planning, Nairobi

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On the Transport of Chemically Reactive Pollutants over Urban Roughness in the Atmospheric Boundary Layer

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Air quality in urban areas is a crucial topic nowadays because of its substantial health impact on the general public. Transport and pollution chemistry over urban rough surfaces are complicated by many factors such as atmospheric turbulence, building geometry/orientation and thermal stratification. In attempt to elucidate their tight coupling, dispersion of chemically reactive pollutants in the atmospheric boundary layer (ABL) over hypothetical urban areas is numerically investigated using the large-eddy simulation (LES). In this paper, idealized street canyons of unity aspect ratio are used fabricating the LES model of urban roughness in order to study the transport processes in isothermal conditions. The worst scenario is considered in which the prevailing flow is perpendicular to the street axes. After arriving the pseudo steady-state flows, nitric oxide (NO) is emitted from the ground level in one of the street canyons into the urban ABL doped with ozone (O3). As a preliminary study to advance our understanding of flows and chemistry in urban areas, an irreversible bi-molecular chemical reaction (NO + O3 → NO2 + O2, where NO2 is nitrogen dioxide and O2 is oxygen) is used. Air exchange rate (ACH) and pollutant exchange rate (PCH) are used to analyze the ventilation and the pollutant removal of street canyons, respectively. Turbulence plays an important role in both the processes of pollutant removal and mixing that in turn influences significantly the chemical reactions and pollutant distribution. We specifically focus on the effect of urban roughness on the mixing of the chemically reactive pollutants. Detailed analytical approach will be reported in the conference.

Microscale modelling of effects of realistic surface heat fluxes on pollutant distribution within a simplified urban configuration

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Modelling micrometeorology and pollutant dispersion within urban areas is very important for both urban climate and air quality applications. The interaction between atmosphere and urban surfaces induces complex flow fields and large heterogeneities in temperature and pollutant distribution within urban canopy layer. These surface-atmosphere interactions may be classified as mechanical (blocking and deviation of the wind by obstacles) and thermal (buoyancy effects due to heat exchange between the atmosphere and buildings). Urban surface heat fluxes are responsible for temperature distribution within street inducing, in some scenarios, modifications of flow properties respect to a neutral case that can affect to pollutant dispersion. Thermal processes are usually neglected, or modeled in a simple way (one facet with different (but constant) temperature with respect to the other urban surfaces) in computational fluid dynamic (CFD) simulations. The main objective of this work is to analyse the effects of realistic surface thermal forcing on pollutant dispersion within a simple urban configuration. CFD-RANS simulations are carried out over a periodic array of cubes with a packing density of 0.25 using realistic surface heat fluxes as boundaries conditions at street and building walls. The microscale heat flux distributions are computed by the TUF3D model (Krayenhoff and Voogt, Boundary-Layer Meteorology 2007). Forty four scenarios with different solar position and ratios of buoyancy to dynamical forces are simulated (Santiago et al., Urban Climate 2014). In this work, one passive tracer is emitted for each scenario at the bottom part of the domain representing traffic emissions. Concentration maps within street and the changes with respect to neutral case are analysed. In addition, spatial average concentrations are also studied and related with properties of the flow. These results are focused on providing useful information to parametrize processes by urban canopy models. These processes are resolved by CFD but are subgrid scale with respect to typical mesoscale model grid resolutions.

Alpine pumping and urban climate in Munich, Germany

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Under clear and calm weather conditions thermal wind systems strongly influence air quality and heat load in urban areas. The city of Munich (Germany) is located in the northern foreland of the European Alps. Due to the undulating and only slightly inclined terrain in Munich, local slope and valley wind systems are found to be rather weak, while on the regional scale a diurnal reversing thermal circulation system is occurring regularly, extending from the Alps to the Danube Valley, i.e. about 50 km north of Munich. The influence of this so-called 'Alpine pumping' on urban climate in Munich is currently investigated in a cooperative project of the City of Munich and the German National Meteorological Service (Deutscher Wetterdienst).

Regional climate simulations for a 20 year period using the COSMO-CLM model are carried out to identify days with Alpine pumping and to determine the mean diurnal variation of the direction, intensity, and extension of the regional thermal circulation. In a further step local scale temporal observations and high resolution simulations with the urban climate model MUKLIMO_3 are used to quantify the impact of Alpine pumping on ventilation and thermal conditions in Munich.

High frequency recovering technique of turbulent inflow for LES of urban wind

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In evaluation of unsteady heat and pollutant diffusion, or wind resistance design of buildings and structures in cities, large eddy simulation (LES) is one of the best appropriate numerical techniques for prediction of the wind flow and transport phenomena. Especially it is important to capture the near-ground flow field within the urban canopy layers. Some researchers carried out LES for wind flows over actual urban districts.

However, in order to reproduce the flow field in the urban canopy, not only the local effect by surrounding detailed geometry but also the long-ranged effect based on the developing atmospheric boundary layer should be considered. In particular, the urban geometry located in the windward area is an influential factor determining the development process and the turbulent characteristics of atmospheric boundary layer.

Therefore, this study carries out LES in the large region over 10km and analyzes the statistics of turbulent flow in the development process of atmospheric boundary layer. Moreover, the effect of turbulence characteristics in large region on the flow field in the urban canopy layer is examined.

First, we consider the generation technique of inflow turbulence for connecting with LES in the large urban region. In the process of generating inflow turbulence the driver region is set in order to add high-frequency fluctuation to filtered flow field with low-frequency which is usually obtained by the other type of simulation such as unsteady RANS or the meteorological model. Here, we decompose the obtained unsteady flow field by filtering technique and the fluctuating part of the unsteady flow is used for recovering the fluctuations in the high frequency region. As a result of the spectrum analysis for the obtained time series data, it is confirmed that the wide range of distribution of power spectrum density can be obtained recovering the high frequency fluctuation.

Next, one example using above technique is shown. In order to reproduce the complicated flow field in the urban canopy layer, GIS data of building geometry and topography in the large region over several 10 km is applied to construction of the urban model. Mesh grids, which reproduce detailed geometry such as roughened actual building shape or vegetation aspect in actual urban area, are generated from the collected GIS data. Then, LES computation in the 10km region is performed by using the generated inflow turbulence for inflow boundary condition. In this LES, several sampling points are set along the streamwise direction in order to check the change of vertical profiles of mean flow and turbulent intensity.

In the present study, we consider Tokyo area as numerical model which is located on the coastline. We set the measurement points along 2 straight lines from the sea, which pass over skyscraper and low-rise residential areas. We should note that the boundary layer thickness becomes thin on the sea.

As a result of the simulation, the atmospheric boundary layer develops gradually in inland of the urban districts where the middle rise buildings are packed densely. The thickness reaches to up to 600m in the sky scraper area, which is several km away from the coast of Tokyo bay. On the other hand, the analysis of wind profile on the way passing low-rise residential area shows the smaller development compared with the wind profile on the other way. Moreover, the vertical profile of turbulent intensity at each point shows that some effects of the oncoming turbulent flow generated by the windward isolated building remain even in the point a few km away from the windward building. Also it is recognized that the turbulent fluctuation characteristics in the urban canopy layer are formed due to the surrounding circumstances. It can be said that the characteristics of urban canopy flows are determined by various effects of the approaching turbulent boundary layer itself, some disturbance generated by buildings at relatively distant location and the wake flow of the surrounding obstacles.

Observed and modeled summer thermal gradients and sea-breeze in Southern California

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Understanding the interaction between large-scale atmospheric and oceanic circulation patterns and changes in land-cover (LCLU) due to urbanization is a relevant subject in many coastal climates. Recent studies by Lebassi et al. (2009) found that summer average-maximum air temperature in two populated California coastal areas showed cooling trends at low elevation coastal areas open to marine air penetration and warming trends at inland and high elevation coastal areas due to an increase in sea-breeze activity during the period. These results require further analysis of the influence of changes in LCLU and other large-scale signals in these changes in the Los Angeles area through numerical modeling.

The aim of this work is therefore to quantify the thermal response of the land-surface and impacts on sea breeze to answer science questions for this process and to assess the suitability of the regional atmospheric modeling system to be used in long-term modeling studies. A field study was configured to observe the sea-breeze intensity and penetration via 18 surface ground stations along the projected transect of the sea breeze during September 24th 2013, one of the days of the NASA HyspIRI Mission preparatory flight campaign over Southern California. The land surface temperature (LST) map collected at approximately 1200 Local Time (LT) over the area with the MASTER sensor showed land-sea surface temperatures differences in the order of 20 ˚C for great part of the domain. The observed wind speeds reflected the thermal response to this gradient through an increase in the sea-breeze speed from 2 to 5 m s-1 only at coastal sites at 0900 LT to a 9 m s-1 in coastal and inland locations at 1600 LT. New urban land classes were derived from the broadband albedo of the AVIRIS sensor and then ingested into the Weather Research Forecast (WRF) model to represent these coastal/urban processes. Results from the modeling showed an improvement of modeled surface temperatures and wind speeds using the higher resolution HyspIRI derived products into the model against the default model characteristics. The model also captured the diurnal spatial and temporal patterns of the sea breeze in the region. These new data records and updated modeling are enabling numerical ensembles to respond to science questions related to causes of the coastal cooling process due to land use, global warming and large scale oceanic processes.

The effect of urban environments on storm evolution through a radar-based climatology of the central United States

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The influences urban environments have on storm development and patterns have been understudied to date, particularly for small to mid-sized cities. Using data from the multi-year reanalysis of remotely sensed storms (MYRORSS), climatological aspects of thunderstorms and their associated hazards have been examined in and around urban areas of varying size, shape, and growth in the central United States. The MYRORSS dataset provides a uniform grid of quality-controlled multi-radar data from the Weather Service Radar 1988 Doppler network that can be used to quantify the spatiotemporal characteristics of hazardous weather such as hail and storm rotation. Output from severe weather algorithms (including hail-size estimation, vertically integrated liquid, azimuthal shear and mesocyclone detection) are compared to complex urban areas and changes in these urban areas over three different periods across the past 10 years. Additionally, these climatological patterns are compared to individual storm behavior in and around the urban environments of Minneapolis-St. Paul, Dallas-Ft. Worth, Omaha, and Oklahoma City. Results will examine the differences in storm size, track, and severity prior, during and after crossing each of the different urban domains. We will also examine differences that arise due to diurnal effects, seasonality, and varying the storm type and size relative to urban size and shape.

Impact of Urbanization on Local Circulation and Precipitation over the Leeward Mountain

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Thermally induced local circulation, such as valley circulation, sea breeze circulation, or heat island circulation, is generated on sunny days with weak winds in mountainous, coastal and urban areas. A close relationship is known to exist between such local circulations and diurnal variation in precipitation.

It is conjectured that sea breeze circulation and heat island circulation contribute to the generation of precipitation. In recent years, research has been conducted on the effects of complex systems involving sea breeze circulation and heat island circulation on precipitation occurring in coastal cities.
Tokyo is the world's largest coastal city with mountains on the windward side and the sea on the leeward side of the environmental wind. In this area, convective precipitation typically occurs in the mountainous area around noon on sunny days in the warm season; after which, a precipitation system moves to the coastal area on the leeward side of the mountains in the afternoon, and eventually generates precipitation in the coastal area in the nighttime.

In this study, we evaluate the impact of the sea and city on diurnal variation in precipitation occurring leeward side of the mountain; that is, precipitation observed on the mountain in the daytime and in the coastal urban area in the nighttime.

Impact of urbanization on the Beijing Super-Storm of 21 July 2012 under current and future climatic conditions

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The Beijing Super-Storm produced more than 190 mm rainfall during 21-22 July 2012. With the maximum of 460 mm at the precipitation center, it was the heaviest rainfall event over the Beijing Metro area in the last six decades, and it took 77 lives and caused more than $161 million (U.S. Dollars) in property damages. This study employed the Weather Research and Forecasting (WRF) model coupled with urban modeling systems (WRF-Urban) to address two major issues: 1) What are important uncertainties affecting the forecasting this high-impact weather event? To which degree does an ensemble approach could improve the prediction of the location and amount of this urban flood? How does urban expansion contribute to the formation and evolution of this storm? and 2) What would be the impacts of future climate change on this event? These two objectives were achieved through conducting and analyzing a number of WRF-Urban high-resolution hindcast and future-climate sensitivity experiments. Hindcast results indicated that initial atmospheric conditions and time used in WRF-Urban substantially affected the forecast of this storm regarding its initiation, location and intensity. Complex terrains in the western regions outside the Beijing Metro played the most important role in triggering the storm and determining its movement paths. Various properties in the urbanized regions (such as roughness, the representation of multi-layer urban canopy in the model, anthropogenic heating, etc) played secondary and yet not negligible role in modulating the movement of the storm, especially the bifurcation of precipitation, and the amount of rainfall. For future climate-change simulations, we used a pseudo–global warming (PGW) approach. The 11-year-average data from global climate-model simulations were used to generate the climate signals, which were used to perturb the initial conditions based reanalysis data. The perturbed fields include wind speed, geopotential height, relative humidity, sea-surface temperature, and soil temperature for the future climate simulations. Preliminary results from WRF-Urban simulation under future warming climate conditions showed that the Beijing Super-Storm are intensified with more widespread rain in the region.

Numerical simulation of urban influence on summertime precipitation in Tokyo: How does urban temperature rise affect precipitation?

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Precipitation modification due to increasing urbanization is one of major topics in the urban climate research, because precipitation amount and spatial distribution are fundamentally important for both water resource management in cities in arid area and disaster prevention in urban areas vulnerable to flash flood. Recently, Fujibe et al. (2009) showed that precipitation amounts observed in central Tokyo had statistically significant increasing trend and positive spatial anomaly to those in surrounding areas in the afternoon of warm season. However, the detected change in precipitation can be influenced by factors other than urbanization, such as global warming and associated regional climate change. For the better understanding of urban impact on precipitation, numerical simulations for recent eight years August have been conducted.

The Non-hydrostatic Model (NHM) of Japan Meteorological Agency (JMA) is utilized in the simulation. Horizontal grid interval is 2km and model domain covers central Japan region. The Square Prism Urban Canopy (SPUC) scheme is incorporated in the model to represent heat and radiation exchanges by urban canopy elements. To investigate how increasing heat island intensity in Tokyo affects precipitation in the metropolitan area, comparative experiments have been done for August from 2006 to 2013. Realistic urban surface condition was given in one of the experiments (SPUC experiment). Less urbanized surface condition was assumed in the other experiment, where only slab surface scheme was used (SLAB experiment). Mean temperature difference between the two experiments was at most one degree.

Simulation results suggest that mean monthly precipitation amount in the central Tokyo area is approximately 10% larger in the SPUC experiment than in the SLAB experiment, which is caused by the urban temperature rise. We also examined daily maximum amount in the urban area. On average, larger daily precipitation amounts were found in the SPUC experiment. However, differences in daily precipitation amounts and spatial distribution between the SPUC and SLAB experiments largely varied case by case. Processes associated with the simulated precipitation difference should be further investigated.

Modeling of the 26 August 2011 extreme precipitation event over Tokyo with Canada's subkm-scale Global Environmental Multiscale (GEM) model

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High-resolution atmospheric modeling systems with grid spacing of a few hundreds of meters are now at the front line of short-range deterministic numerical weather prediction (NWP). In this context, 1-km and 250-m versions of Environment Canada (EC)'s Global Environmental Multiscale (GEM) model are being configured and tested over a few key urban areas. Such a system has been set-up and tested for the 26 August 2011 extreme precipitation case over Tokyo, as part of EC's participation to the international research and development initiative for the Tokyo Metropolitan Area Convection Study (TOMACS).

It will be shown at the conference that GEM is able to realistically reproduce the intensity and structure of the mesoscale weather system responsible for the flooding event that took place over Tokyo on 26 August 2011. A series of sensitivity tests have been performed to assess the relative importance of urban surface processes, as well as other processes. Results emphasize the need for subkm-scale grid spacing for this event, and evidence the important role that the urban areas plays in sustaining intense precipitation rates over parts of Tokyo.

Cities & Storms: How Land Use, Settlement Patterns, and the Shapes of Cities Influence Severe Weather

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It has long been known that larger urban areas can affect the behavior of severe weather. However, only nine US cities have a population more than 1 million and 16 cities are larger than 800 sq km. The extent to which smaller urban areas influence severe weather has received less attention. This presentation will review findings to date from an interdisciplinary project funded by NASA to investigate the influences of urbanized areas on storm characteristics and behavior. Our research has focused on the Great Plains of the US where an abundance of warm season storms interact with cities of various sizes that are embedded within a matrix of agricultural land uses. Dynamical aspects of city-storm interactions were simulated using WRF-ARW using an inner domain with 500 m resolution. The approach presented actual configurations of various cities to a "well-behaved" supercell to assess various storm characteristics, e.g., updraft helicity, storm-relative helicity, absolute vorticity, following the encounter with the urbanized area. How aerosol loading in the urban dome influences storm behavior was probed using WRF-CHEM simulations at 4 km horizontal resolution, with a focus on cloud fraction, cloud effective radius, simulated reflectivity, and accumulated precipitation inside and outside of plumes of polluted urban air. Scenarios included doubling and halving baseline anthropogenic emissions. In addition to these simulations, we used time series of NEXRAD data series to explore the city-storm interactions from the perspective of weather radar and time series of space-borne remote sensors to evaluation the influence of city size and location on land surface phenology. Finally, we have been exploring how to use the concept of "land architecture" to facilitate knowledge transfer between the science and design communities.

Urban Impacts on Regional Rainfall Climatology

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This presentation will provide an overview of the recent work that documents the state of the science regarding the urban impacts on regional rainfall climatology. Multiscale datasets, and modeling studies will be presented to develop a comprehensive picture regarding the confounding role of land surface heterogeneity, urban/rural aerosols, regional topography and interactions in assessing and documenting these impacts.

Efforts underway in transferring the knowledge gained into future urban design modules and tools will also be presented.

Field Observation on Thermal Environment of an Urban Street with Roadside Trees in a Tropical Climate

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As the urban heat island (UHI) phenomenon is growing in conjunction with rapid urban development, the outdoor thermal environment from low to middle latitudes had since become a major concern on the well-being and health of the citizens. Urban greenery including roadside trees planting is believed to be one of the best remedy to these anthropogenic effects, however, less study and attention has been directed in understanding the cooling effects of roadside trees in a tropical city, hence, this study is carried out in Malaysia. This study aims to provide information on the effects of street trees to the thermal environment for future development and urban planning works in a tropical city. The outdoor field measurements of roadside trees in Kuala Lumpur will be conducted 4 weeks from January to February 2015. The targeted area consists of sparse and dense roadside trees and a reference site without vegetation. In each area of measurement, several sensors of air and globe temperature are recording with sampling interval of 10 minutes at 1.5m above the ground surface, while wind speed and direction along with relative humidity at 1.5m level above ground surface will be observed with sampling interval of 1 minute on selected days during the measurement period. Additionally, road and pathway surface temperature will be recorded at 30 minutes interval. The results of diurnal variation pattern of air and globe temperature are presented. To further analyse the thermal environment, mean radiant temperature (MRT) are computed and compared between different densities of trees. Wind speed reduction inside the canopy, variation of road and pathway surface temperature under different density of trees will be observed and presented. Therefore, from the results of this study, the evidence of cooling effect from roadside trees could be drawn and quantify so that suitable information for planners and designers could be presented for future development work in mitigating the UHI phenomenon in a tropical city.

Effects of Desert Tree Shade and Ground Cover Surface Cover on Human Comfort in an Arid City

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The magnitude of potential for urban vegetation types to mitigate human discomfort across seasonal changes is poorly understood. Further resolution of this relationship was undertaken to elucidate the role of desert tree shade and ground surface cover type on apparent temperature (TAP) within the undercanopy layer during summer dry and summer wet monsoon seasons in Phoenix, Arizona, USA. Micro-meteorological stations recorded diel patterns of air temperature and humidity, wind speed, direct and diffuse radiation, and net radiation at one-minute intervals in a factorial matrix of open full sun exposure or mature hybrid South American mesquite (Prosopis alba x Prosopis chilensis) tree shade and Bermuda grass (Cynodon dactylon) turf grass lawn or decomposing granite (DG) surface mulch cover in co-joining residential yardscapes of similar size and tree and shrub frequencies, but dissimilar landscape designs. TAP was calculated from these data averaged at 30-minute intervals during summer dry (Julian Days 165 to 179) and summer wet (216 to 241) seasons, 2010. During the summer dry season, average maximum TAP was about 15C or 8C higher than air temperature in sun or shade respectively, but was not affected by landscape design. During the summer wet season, average maximum TAP in in the DG covered yardscape was about 2C to 4C higher than in the turf grass covered yardscape in both full sun and under mesquite tree shade. These local differences in TAP were associated with seasonal changes in humidity, radiation balances, and differences in irrigation practices to support yardscapes with different vegetation types. +

Incorporating Resolved Vegetation in City-Scale Simulations of Urban Micrometeorology and Its Effect on the Energy Balance

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Urban vegetation plays a critical role in the exchange of heat and mass across a wide range of scales. Shading and evaporative cooling by trees reduces air and surface temperatures, which can increase human comfort, reduce building energy usage, and mitigate the urban heat island effect. Urban vegetation can also increase air quality through deposition and respiration processes. Despite the clear benefits of urban vegetation, it is difficult to determine how their local effects translate across neighborhood- and city-scales, and the degree to which their benefits offset their costs. The widespread effects of vegetation are extremely difficult to measure directly due to the complicated interactions between micrometeorology and topology. City-scale models are too coarse to represent localized changes in urban form, and building/tree-scale models are too inefficient to feasibly represent whole city-scales. To address these issues, we have developed a new modeling framework that includes highly detailed models for three-dimensionally resolved urban vegetation. Physically robust models were developed for radiation, evapotranspiration, and leaf temperature that can represent complex geometries with arbitrary leaf angle distributions. This level of physical realism comes at a hefty price, which is afforded by performing calculations in parallel on graphics processing units (GPUs). Additional algorithms were incorporated into the physical models to reduce computational cost. The resulting model can resolve urban topologies with hundreds of thousands of buildings/trees, using only a single commodity-level desktop workstation. The model was used to assess several urban design scenarios regarding vegetation or `green infrastructure'. The study focuses on the impacts of species diversity, and the placement of trees relative to buildings, roads, other trees, etc. Model outputs were used to determine how these variables act to influence microclimate in terms of their modification of the local energy balance.

A Comparative Study on Evapotranspiration of the Same trees in Urban Forests and Individual tree using Lysimeter method

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This research conducted long-term measurements of the effect of evapotranspiration of individual trees, which has not been observed to date, by using a full-sized tree.

Urban forestry plays a major role in the mitigation of hot urban environments. It is essential to accurately measure the amount of evapotranspiration, the source of its effect, but because related measurements of the change in overall weight of a standard-sized planting using a weight scale involve a total weight of 1 ton or more; with the amount of change only fluctuating on the order of several hundred grams, such measurements are extremely difficult.

The author has developed a new type of weight scale able to measure the amount of evapotranspiration from a large, full-sized tree (maximum weighing capacity 3t, measurement precision 100g), and is using the large-sized scale to carry out long-term measurements comparing the evapotranspiration of individual trees and those located in forests.

For this, 3 test pieces were prepared, 2 of which used Zelkova serrata with heights of 7m, eye-level circumferences of 50cm or more, and weights of 1.8t (including soil). One of these was planted as an individual tree specimen, and the other within a forest, while the 3rd test piece was intended only for measurement of evaporation from the soil. Zelkova serrata, the type of tree used in the test, is the 3rd most frequently-planted roadside tree in Japan. Measurements of the individual tree specimen in a temperate region of Japan during the summer season showed a maximum evapotranspiration of 44.6kg within a 12-hour daytime period. Measurements using the porometer method and leaf-cut method were also performed concurrently, and compared with the weight scale measurement results.

Weighing whole tree transpiration rate of urban trees and analysis of trees morpho-physiological effects

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Transpiration effect is expected to mitigate urban thermal environment but efforts to predict urban trees' transpiration are complicated by our limited knowledge of how much and different whole tree's water use is. The difficulty in understanding urban trees' transpiration is mainly caused by the limitation of measurement method, so we newly developed hanging-type gravimeter method using container grown trees and beam-type load cells, which is convenient to weigh a number of samples in a short period.

The purpose of this study is to (1) Classify morphological and physiological characteristics which help us to predict transpiration rate and (2) Investigate transpiration responses to vapor pressure deficit (VPD) as represented by the change of canopy conductance (Gc). We weighed 11 trees of 11 popular urban tree species in Japan at farm field, Aichi prefecture (35°8'N, 137°6'E) in summer 2010, 2012 and 2013. Studied trees are under isolated and soil-restricted condition which assuming urban environment and ranged 3~6.7 m in height, 1.5~9.2 m2 in crown projection area, deciduous/evergreen, and diffuse-porous/ring-porous/tracheid in xylem porosity.

First, we verified our new gravimeter accuracy using high time resolution recording and AR model and showed the mean value of relative error (95% C.I.) in half-hourly transpiration rate of all studied trees was 9.2%, and the error of Quercus myrsinifolia in 2012, which use least water and have largest error, was 19.8% when wind velocity is under 2 m/s.

Second, we compared transpiration rate of summer irrigation days and found (1) Daily water use vary 10~30 kg in individuals, equivalent to 0.62±0.36 times of water evaporation from the same size of crown projection area, (2) Maximum latent heat was 2.3 kW/tree of Zelkova serrata in 2010 and Quercus serrata, (3) Zelkova serrata and Quercus myrsinifolia changed Gc threefold due to physiological change, (4) Ring-porous species tend to use much water ($p=0.045$), which suggest the significance of hydraulic capacity under volume-restricted soil condition.

Finally, we tested the hypothetical relationship between Gc at VPD = 1 kPa (Gcref) and the Gc sensitivity to VPD (-dGc/dlnVPD) suggested by Oren et al.(1999) [Plant, Cell and Environment 22, 1515–1526]. The results showed good agreement between theory and measurement across almost all studied trees, but few were rather insensitive.

Transpiration of urban trees and its impact on nocturnal cooling in Gothenburg, Sweden

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One of the ecosystem services provided by urban trees is the cooling effect caused by their transpiration. However, while the transpiration of forest trees has been widely studied, little research has been conducted on the daytime and night-time transpirational cooling effect of mature urban trees. Knowledge about the transpiration of street and park trees and its response to different environmental factors can prove useful in estimating the thermal influence of urban greenery as well as in urban planning and management. The aim of this study is to i) quantify the magnitude and diurnal variation of transpiration of common urban tree species in a high latitude city (Gothenburg, Sweden), ii) analyse the influence of weather conditions and fraction of permeable surfaces within the vertically projected crown area on tree transpiration, and iii) find out whether transpiration of urban trees remains active during the night and therefore contributes to nocturnal cooling.

Measurements were conducted on mature street and park trees of seven tree species common in Gothenburg: Tilia europaea (Common lime), Quercus robur (English oak), Betula pendula (Silver birch), Acer platanoides (Norway maple), Aesculus hippocastanum (Horse chestnut), Fagus sylvatica (European beech) and Prunus serrulata (Japanese cherry). Stomatal conductance and leaf transpiration were measured using a LI-6400XT Portable Photosynthesis System (LI-COR Biosciences) at daytime and night-time on warm summer days of 2012-2013 in Gothenburg. Leaf area index (LAI) of the studied trees was measured with a LAI-2200 Plant Canopy Analyser (LI-COR Biosciences) in order to estimate the latent heat flux due to tree transpiration.

Leaf transpiration was found to increase with vapour pressure deficit and photosynthetically active radiation, with on average 22% of the midday incoming solar radiation being converted into latent heat flux. Midday rates of sunlit leaves varied between species, ranging from less than 1 mmol m-2 s-1 (B. pendula) to over 3 mmol m-2 s-1 (Q. robur). Daytime stomatal conductance was positively related to the fraction of permeable surfaces within the vertically projected tree crown area. A simple estimate of available rainwater, comprising of precipitation sum and a fractional surface permeability within the tree crown area, was found to explain 68% of variation in midday stomatal conductance. The results indicate that a high fractional surface permeability can minimize the frequency of water stress experienced by urban trees and enhance their transpirational cooling.

Night-time transpiration was observed in all studied species and was positively related to daytime tree water use. Nocturnal transpiration amounted to 7% and 20% of midday transpiration of sunlit and shaded leaves, respectively. With an estimated latent heat flux of 27 W m-2, evening tree transpiration enhanced the cooling rates around and 1-2 hours after sunset, but not later in the night.

The results of transpiration measurements will be combined with vegetation data derived from LIDAR and LAI measurements to estimate neighbourhood- to city-scale cooling effect provided by urban trees.

Temporal variations in microclimate cooling of urban trees – a case study in Mainz (Germany)

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Increasing the vegetation cover in cities is one of the key approaches to mitigate urban heat. Trees are the most important vegetation type since from their height they intercept sunlight, cast shade and cool the air by transpiration. However, still very little is known about the magnitude of the cooling related to the transpiration and how this varies on a diurnal scale and in response to heat and drought stress.

Here we present results from a study linking diurnal tree transpiration to urban cooling by comparing daily urban air temperature and humidity pattern from June 2013 to October 2014 in areas of contrasting tree cover (suburban park, an urban garden, a courtyard, a street and a square) in the city of Mainz, Germany. Transpiration is indirectly estimated by high resolution measurement of sap flow and stem radius change , which are indicators of tree stem water balance, in three common tree species in European cities; Platanus × acerifolia, Acer platanoides and Tilia platyphyllus. The measurements were analyzed in view of general weather situation and water availability in order to evaluate the effect of tree heat and drought related stress on the diurnal cooling.

As expected, we observed a cooling effect of the examined trees on the urban air temperatures both at day and night, although nocturnal cooling were more pronounced. Preliminary results of stem water balance indicate that transpiration of the examined trees can be linked to the magnitude of the cooling at a diurnal scale, since stronger cooling observed in the vegetated areas significantly correlate with increasing sap flow and daily stem radius changes. The cooling effect was especially pronounced in the examined urban courtyard. In this location, five large trees in an otherwise bare and dense urban environment caused a stronger cooling compared to the sparsely vegetated street directly outside, and humidity patterns more similar to those found in the suburban park than to the street.

The examined trees did not suffer from heat and drought stress, except during a prolonged hot and dry period during the 2013 growing season. Towards the end of this period we could observe that the stressed trees changed their evapotranspiration pattern. This changes corresponds to a weaker daytime and a stronger evening cooling of the air, possibly caused by a drought adaptive behavior where mid-day evapotranspiration is reduced for water saving purposes.

In this presentation, we present a first indication on how the cooling effect of urban trees vary on a diurnal scale, as well as in relation to heat and drought stress. This could provide very useful information in the approaches to mitigate heat stress for the urban inhabitants in a future warmer climate.

Numerical Evaluation of Heat Budget in Tree Crown Considering the Detailed Structure

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Planting trees is one of the countermeasures to urban heat island because of the cooling effect by the transpiration or the sunlight cover effect. It is difficult to construct the large scale forest in urban area, so isolated trees such as roadside tree are generally planted. In the case, it is desirable that trees are efficiently located on understanding the performance of heat exchange between the tree crown and the atmosphere. The heat budget related to the performance of a tree cannot be directly measured in detail. In this study, heat budget of isolated plant unit is numerically evaluated with thermal plant model including radiation transfer model for net radiation and transpiration model for latent heat transfer, and the numerical results are validated by comparison with that of outdoor measurement for a potted plant.

Heat budget is evaluated as the balance of net radiation, sensible and latent heat transfer between the leaves and the atmosphere and conduction heat transfer to the foliage. Conduction heat transfer is omitted in this study. Latent heat transfer related to transpiration on leaf surface can be evaluated by Jarvis model. Net radiation of foliage is evaluated by solving the Ross's radiation transfer equations and sensible heat transfer is by difference between the net radiation and latent heat transfer.

In the prediction of net radiation of foliage, Computer graphics (CG) model with software AMAP, which can draw tree characteristics such as shapes of a tree crown and a leaf and leafing arrangement on a branch, is applied to decision of structure parameters of leaf surface density and distribution function of leaf surface direction vectors which are included in Ross's radiation transfer equations in plant vegetation. It is necessary for evaluation of the net radiation to consider direct and diffuse insolation from the sky and scattering light in tree crown for the component of short wavelength and thermal radiations from surroundings including atmospheric radiation and from leaf surfaces for the component of long wavelength. Leaf temperature which is necessary in evaluating the thermal radiation from leaf surfaces and transpiration rate is evaluated as satisfying the heat budget on leaf surface. Parameters of Jarvis model in transpiration of leaves is decided by measurement of transpiration rate of actual leaves of several kinds of trees. By applying the numerical simulation, shielding efficiency of insolation and ratio of latent and sensible heat transfers to net radiation of isolated and vegetated tree are evaluated for several kinds of trees.

Microclimate regulation potential of different tree species: transmissivity measurements and their application in small-scale radiation modeling in Szeged, Hungary

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Heat stress modification capacity of urban trees is widely acknowledged and makes these natural landscape elements very important in the field of climate conscious urban planning. Many studies (measurement and/or modeling based investigations) have proven already that shading, i.e. the reduction of direct solar radiation is the most effective way to moderate summer heat stress among Central European climatic conditions. Shading potential of trees is described usually by their transmissivity values. Although the transmissivity depends on the leaf density, leaf orientation and other tree crown-related characteristics, most microclimate simulation software set this attribute as default in the case of all trees. The first goal of our investigation is to determine the transmissivity for four tree species which occur frequently in Hungarian cities: Sophora japonica, Tilia cordata, Celtis occidentalis and Aesculus hippocastanum. To accomplish, one-year long systematic measurement campaign is carried out in the South-Hungarian city of Szeged. Beside the measurement of short-wave radiation under the crown of different species, other microclimatic parameters and the actual condition of the tree crown (seasonal status of the canopy, health conditions) are also recorded. Although the results indicate clearly different average transmissivity values for the investigated species, transmissivity varies in a wide range in every case depending on many influencing factors (e.g. intensity of unobstructed global radiation, seasonal condition of tree crown). As a next step, simulations are carried out to investigate the effect of tree species selection (meaning transmissivity differences) on the resulted reduction of radiation load. Solweig software is applied to model the spatial distribution of mean radiant temperature (Tmrt) on a square planted with different types of trees incorporating the measurement-based transmissivity values. These types of assessments can help finding the appropriate tree species for urban landscape planning. Besides the micro-scale results, they can contribute to the methodological development of local scale heat stress mapping, moreover to the indicator development for mapping climate regulation ecosystem services of urban green spaces.

Long term impact of climate on tree-growth patterns in Paris street trees and its consequences on tree cooling potential: A dendroclimatic approach

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Water availability is widely recognized as being an essential factor for tree survival, growth and for maximizing their ability in mitigating urban heat islands (UHI) through evapotranspiration. In urban areas, where the ground surface is highly impervious and the trees are not regularly irrigated, the reduction of precipitation infiltration into the soils may put the trees face an increased water stress1,2. It is also generally predicted that trees in urban sites have higher water losses than trees in natural forests due to increased evapotranspiration demand3. There is currently insufficient data to generalize the physiological responses of trees to the complex urban environment, where both climatic and management factors are entangled. Especially, little information is available on the effect of water stress on tree health, and their consequences on ecosystem services such as UHI mitigation. Furthermore, on-going climatic changes make it all the more necessary to anticipate the potential trajectories of urban trees, in terms of (i) risk assessment of tree survival, and (ii) their potential ability to provide cooling services. In this context, a retrospective approach of the long-term relations of trees to urban climate can provide a way to enhance our understanding of current urban tree hydric state and to gain insights on future levels of water stress levels under future climatic conditions.

It is well known that there is a close relationship between tree growth and climate. Indeed, the size and the state of tree-rings are affected by the yearly sequence of favourable and unfavourable climates4. In turn, climate phenomena can be identified and reconstructed through ring-width sequences5. Thus, dendrochronology and study of wood structure can be used as informative tools in order to understand the long-term influence of past climate on urban trees growth. Consequently, understanding the past trajectory of trees under the past climate provides insights on their response to future climate projections. Since tree cooling potential is tightly linked to water availability, negative feedback of water stress to tree cooling potential can be expected.

To further investigate these issues, we are implementing a 3 years project, financed by CDC-Biodiversité and we are testing this approach by studying 95 urban Tilia tomentosa Moench individuals in Paris (France), selected along a 10-120-year age gradient. Tree age was estimated using wood core samples, and the health status of each tree was visually assessed according to the "Visual Tree Assessment". Number of tree-rings and ring-width were measured using a Lintab measurement table and compared to meteorological data at local and regional scales (Paris, Île-de-France region). The xylem vessel diameter and density were used as a proxy of hydraulic conductance efficiency, embolism vulnerability and health status of trees6,7. The sampling design will enable a comparative approach of trees of different ages, which is used to assess whether chronic water stress is influenced by both tree age and climate history.

The communication describes the current results, and we use them to discuss the ways climate change could further impact tree-growth and thus potential tree cooling effects in Paris City.

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The climatic and bio-climatic impact of a small central city park on the surrounding urban environment during extreme heat events

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Urbanisation and the extensive use of impervious materials has resulted in increased heat storage and runoff within urban areas and reduced evapotranspiration, leading to an air temperature increase within cities. Excess urban heat combined with the effects of global climate change will likely have a deleterious impact upon human health. However green spaces are known to be a most effective solution for reducing air temperatures and mitigating extreme temperatures in urban areas, through shading and increased evapotranspiration. Melbourne, like many Australian cities, has adapted a compact city policy and will become denser in the next few decades to accommodate the urban population growth. Therefore, the role and importance of small green spaces in densified urban environments becomes more critical. This study examines the climatic and bio-climatic effects of a small urban park in Melbourne on the surrounding urban environment, especially in relation to reducing air temperatures and improving human thermal comfort during extreme summer-time heat events. An on-site measurement campaign (i.e. fixed weather stations accompanied by transects) was undertaken for a representative period of the 2014 summer (January- March) to identify the cooling capacity of the park, with a particular focus on air, radiant surface and mean radiant temperature patterns inside the park and in the immediate surroundings, along with the propagation of influence downwind. Air temperatures as high as 44.0°C were recorded during the study period. According to the results, the park was found to be cooler than the surrounding built-up area at all times, whether air or radiant surface temperature was used as a measure. However, the magnitude of park-induced coolness (the park cool island (PCI) effect) was found to vary from 0.5-3.0 °C depending on the time of the day and park's soil moisture condition (i.e. irrigation). The maximum air temperature difference between the park and its surroundings occurred at midday and immediately after sunrise. Dynamic variations of surface temperature differences within the park and adjacent urban areas could exceed up to 35°C and depended on land surface type and moisture availability. A downwind propagation of cooling effects of the park that exceeded up one park-width of the park could also be observed, depending on the wind direction.

Experimental evidence of building cooling through green envelope

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Facade greening is expected to make a major contribution to the mitigation of the urban heat island effect through transpiration cooling, thermal insulation and shading. However, studies are neither available on water demand and transpiration of facade greenings, nor on the differentiation of the cooling effects.

This study quantifies transpiration rates, shading and insulation effects of an experimental facade greening as well as separates between these cooling effects for the building and the ambient urban air.

Four experimental facade greening lysimeters were installed in front of a west exposed facade centrally located in Berlin (Germany). They allow the direct measurement of water uptake. Lysimeters were greened with Fallopia baldschuanica while the other half of the building wall was bare. Measurements were carried out over two years from 2013 to 2014 with highest air temperatures of 39l°C during hot summer periods.

Transpiration rates of Fallopia baldschuanica were determined by weighing. We measured surface temperatures of the greened and bare exterior and interior wall as well as inside the wall (joint) and on the plant leaves. Furthermore, we measured air temperature, relative humidity, radiation behind the greenery and in front of the greened and bare facade as well as wind speed in front of the facade.

We will present daily courses of the measured parameters, especially transpirations rates which are as high as 3.1 L d-1 per greened m-2 wall area for a hot summer day. Surface wall temperatures behind the greenery were up to 12.7 K lower than those of the bare wall. We will also discuss cooling effects in relation to transpiration rates.

We conclude that greening is an effective strategy to mitigate heat stress in urban areas. However, thermal images show that leaf temperatures increase under water stress conditions. This means, plants must be sufficiently irrigated especially in hot dry summer days, otherwise the posited positive effects of facade green can turn into disadvantages.

Influence of urban vegetation.

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Greenery in city has a direct impact on the air temperature. This leads to an air temperature difference between build-up and green areas (usually called "Park Cool Island" effect), which affects the urban heat island effect. The influence of the greenery depends on its type and may vary along the day. The first part of this study analyses the park cool island effect of various types of greenery: large and small parks with different tree density, canal with roadside trees, green roofs. Seven places located in Paris are analyzed. The measurement campaign was carried out during 2014 cooling season, when the heat may have a negative impact on human health. The results show that air temperature of all those greenery devices is lower than air temperature of a reference build-up area during night-time except the canal with roadside trees. It is also shown that large parks better decrease the air temperature than small parks and green roofs. During day-time, no clear trend appears. It is not always possible to highlight a correlation between a temperature signal behavior and a greenery device. In a second part, the cooling effect of fresh or hot air "produced" in the greenery areas is evaluated. For each of the seven previous places, two peripheral stations are implemented at different distances of the greenery area boundary in order to identify a potential cooling effect. The analysis of the results is performed confronting to the low scale observation results that have been obtained by Spronken-Smith and Oke (1999). To conclude on the effect of each greenery device on the cooling effect, temporal evolution of the measurements carried out at the three locations are compared. Only the large park shows a cooling effect both during day-time and night-time. For the most part of the other places and because of the place location, it is not possible to conclude either or not a cooling effect exists. Guidelines concerning new locations choice for a future experimental campaign are selected from our results: at least two places should be located in the greenery area and three in the surrounding. The peripheral places should be located along a same axis in the same direction from the greenery type and in a similar geographical context (similar sky view factor and land-use type). For a better estimation of the cooling effect, several other peripheral axes may be instrumented in an other direction than the original one.

Temporal variations of transpiration and latent heat fluxes from isolated linden crowns and lawns in a park at Strasbourg, France

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In a context of global climate change, mitigating the “urban heat island” effect is becoming an urging necessity with respect to human health. Among the different mitigating strategies, increasing the vegetated surface areas, such as trees and lawns, is thought to induce a cooling effect by increasing the latent heat flux (E) from the transpiring plants. However, there is nearly no information on direct assessment of plant transpiration to the total latent heat flux of a city center.

The aim of this study is to estimate the latent heat flux emitted by a lawn surface (EL) and isolated linden crowns (ET) in the city centre of Strasbourg (France), and to characterize the seasonal evolution of these fluxes with respect to atmospheric and soil variables.

Six adult linden (Tilia tomentosa) trees grown in an urban park were equipped with Granier’s thermal dissipation probes for continuously monitoring the total crown transpiration starting from April 2013. The estimated total sap flux was assumed to be the total transpiration and converted into ET. The EL values were measured manually on two measurement locations using a closed chamber system during five summer diurnal cycles. Both ET and EL were expressed on ground surface area basis.

During the growing season, the ET varied daily, according to the main meteorological variables (global radiation, air temperature, vapor pressure deficit). The maximum ET values ranged from 183 W.m-2 to 284 W.m-2 during August, according to the crown size (and location). In comparison, the maximum EL values ranged from 290 W.m-2 to 302 W.m-2. When compared to the ETP values, the ET/ETP ratio increased from budburst to mid June according to leaf area development. The ratio remained rather steady within the 0.3-0.4 range (regarding the trees) until October. In late summer and autumn, the ET/ETP dropped below 0.1 several days, indicating a possible stomatal regulation of ET in response to soil water limitation. Further analyses will be conducted to better assess the water balance dynamics in this urban park. The daily variations in diameter of the trees, which reflect their hydric status dynamics, will be compared to stomatal closure. The measured values of linden and lawn transpiration will be used for validating the estimates of latent heat flux performed by the eddy correlation method on the same site.

Thermal effects of Woody Green Areas in Urban Landscapes in Campinas City, Brazil

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Urban Landscapes can be described by the density, occupation, land use, height-to-width ratio, soil permeability and green area percentage. These factors affect the local climate, distinguishing the neighborhoods cool and comfortable of the hot and discomfortable. This paper quantifies thermal effects of wooded green areas in different urban landscapes, classified according the urban climatic zone – UCZ. Also, it recommends the minimum percentage of wooded green areas to produce effects in the local climate. Measurement campaigns to obtain air temperature (oC) and specific air humidity (g/m3) were conducted over a 1 year (2010) in three times (9h, 15h, 21h), in seven neighborhood in Campinas City, Sao Paulo – Brazil. Data were collected by sensors located in representative points of the urban zones, above the roughness layer, by mobile transactions, and by tripods into the green areas. Thermal differences between urban landscapes, wooded areas and the official meteorological station were obtained. Air temperature can decrease up to ___ oC and air humidity can increase up to ___ g/m3. Results showed the green area dimension (m2) necessary to decrease air temperature and increment air humidity depends on the urban land characteristics. To the UCZ 1, minimum percentage of wooded green area obtained was %; to the UCZ 2, x%; to the UCZ 5, y%. Minimum of 20%, distanced approximately twice the wooded green area length, produce thermal effects in all urban landscapes studied. The results can be adopted by urban regulations and applied by urban planners to promote cool islands in Brazilian tropical cities.

Leaf area measurements of urban woodlands, parks and trees in Gothenburg, Sweden

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Leaf area of urban vegetation is an important characteristic since it influences e.g. the urban climate through transpiratory cooling, air quality through air pollutant deposition and water management through rainfall interception. Measurements of leaf area are fundamental to accurately model these processes. Few studies have however presented leaf area measurements in the urban environment.

The aim of this study was to i) describe the urban greenery based on measurements of leaf area index (LAI) of trees in different types of urban environments and ii) compare two different methods to measure LAI of urban trees.

During the summer of 2014, LAI was measured in a central urban deciduous woodland, a suburban mixed forest, a central old park, a grove adjacent to a traffic route and in allotment gardens in Gothenburg, Sweden. In addition, single urban trees of seven common urban tree species in Gothenburg were measured (Acer platanoides, Aesculus hippocastanum, Betula pendula, Fagus sylvatica, Prunus serrulata, Quercus robur and Tilia europaea).

Two different indirect methods were used; the LAI-2200 plant canopy analyzer (Li-cor Inc.) and hemispherical photography. The digital images were analyzed with Hemisfer (Schleppi, WSL). The canopy measurements were performed in a grid or cross with 8-32 points with fixed intervals. For single urban trees, 3-6 specimen of each species was measured.

Average LAI of the measured urban parks and forests ranged between 2.6 and 4.8. A better way to characterize the different sites was to use cumulative density functions, which visualized the degree of heterogeneity. The old urban park had the largest LAI range (0 - 8.3). As a comparison, LAI ranged from 2.4 to 5.9 in the more homogenous urban woodland. LAI based on hemispherical photos was similar to the values received by the LAI-2200 plant canopy analyzer.

Both methods had advantages and disadvantages. The urban environment offers challenges not present in forest canopies, such as interference of buildings. A combination of methods might be necessary for an environment as heterogeneous as the urban, with both single trees and forest canopies.

Employing Terrestrial LiDAR to detail Tree Canopy Structure and Shade for the Cooling Effect Analysis

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Urban warming has become a serious problem along with global warming and the rapid urbanization. One important phenomina is the increasing urban heat island (UHI) effect, which has caused serious negative impacts on energy consumption, environmental pollution and human well-being. Trees lower surface and air temperatures by providing shade and through evapotranspiration, and therefore, are a useful strategy to effectively mitigate the UHI effect. Cooling effects of different trees is different due to the different tree crown size, density and optical properties of their leaves. Selecting the best species to plant is important for the mitigation of the urban thermal environment and for saving energy as well as sustainability. In this research, we selected four woodlands with different vegetation structure. Three woodlands were dominated by common species (Cinnamomum camphora, Metasequoia glyptostroboides, Magnolia grandiflora) frequently planted in Nanjing city, China, and one is a mix-woodland with several different species. The HOBO meteorological stations were used to measure the microclimate environment. Terrestrial LiDAR was employed to detail the vegetation canopy structure and capture the three-dimensional point cloud of leaves as well as the shade at each station. The statistical analysis has been used to capture the cooling effect characteristics of different woodland and their related impact factors. The findings of this research revealed that the vegetation could influence the microclimate underneath the tree canopy and their impacts differed among species. The statistical analysis also showed that the woodlands have an obvious temperature reduction in the daytime (5:00 h-19:30 h) but weak during the night (19:30 h-5:00 h).The temperature reduction of different species was (in decreasing order) Metasequoia glyptostroboides, Cinnamomum camphora, Magnolia grandiflora and then the mixed broad-leaved woodland. Compared with LAI (Leaf area index) and SVF (Sky view factor) with the L_V3DPC and shade respectively, L_V3DPC and shade can more accurately reflect the impact that vegetation canopy have on the cooling effect. The correlation analysis between L_V3DPC and shade, microclimate and cooling effect proved that shading by trees is of prime importance in mitigating the thermal environment. The high significance of L_V3DPC and shade indicate that the tree canopy is a major component that is able to contribute to microclimatic environments- particularly the cooling effect under the tree canopy. The research presents an innovative technique for analyzing tree canopy shade by using ground-based LiDAR data to analyze the cooling effect of trees. The results can be used as a guide for selecting the best species for urban greenspace planning and designing to mitigate the urban thermal environment and enhance energy savings in urban environments.

UCP12: Flows & dispersion I : pollutant dispersion in urban canopy

Pollutant Exchange and Breathability in Urban Street Canyons

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As urbanization progresses, more comprehensive and advanced methods are required to analyze the modifications of urban microclimate. Street level air pollution due to vehicular exhausts is of concern in the urban environment and is significantly affected by thermal stratification, yet numerical studies of dispersion under realistic surface heating are scarce. To address this shortcoming, a detailed indoor-outdoor building energy model (TUF-IOBES) is employed to compute heat fluxes from street and building surfaces, which are then used as boundary condition for a PArallelized Large-Eddy Simulation Model (PALM). Series of fluid flow and thermal field simulations are performed for an idealized, compact mid-rise urban environment ($\lambda p=0.29$, $\lambda f=0.25$ with no vegetation). In comparison with previous studies, our model considers the transient non-uniform surface heating caused by solar insolation and inter-building shadowing, while coupling the indoor-outdoor heat transfer, flow field and passive pollution dispersion. Traffic emissions are characterized as a city-wide near-ground volume source. A horizontal (based on the temperature difference between the two walls) and a vertical (based on the difference between the street temperature and roof level air temperature) Richardson number (Ri_h and Ri_v) are used to characterize atmospheric instability and solar tilt with respect to the wind direction. The validity of this choice of non-dimensional numbers is investigated through simulations with different wind speed and surface radiative properties, but the same sets of Richardson numbers. The pollutant Exchange Rate (PCH) from the horizontal and vertical ventilating faces of the canyon, and the pollutant concentration at pedestrian level (z=1.5-2 m) are examined in order to quantify the effect of surface heating on air quality as a function of time of day and Ri_h and Ri_v. Local ambient conditions (wind speed) and surface material properties (ground and wall albedo) are modified to span a realistic range of buoyancy parameters. Quantifying the change in pollutant dispersion in street canyons based on these parameters can ultimately inform urban designers on the impact of their design on air quality, human health and comfort.

Characteristics of scalar dispersion from a continuous area source over a cubical array

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Understanding transport mechanisms for momentum or scalar between urban surfaces and the atmosphere is one of essential issues so as to predict flow and scalar distributions attributed to complicated urban climates. One of methods to relate these vertical distributions and surface effects, namely forcings such as momentum sink or scalar source/sink, are known as similarity theories. For example, under various conditions of thermal stratification, the vertical gradient of velocity or scalar can be expressed by the surface flux of momentum or scalar and the dimensionless shear or scalar function within the inertial sub-layer, where the flow and scalar distributions are horizontally homogeneous, as known as Monin-Obukhov similarity theory. In the case of neutral conditions, especially, more detailed investigation have been done in order to quantify the effects of surface geometries on aerodynamic parameters in velocity profile, such as roughness length or displacement height by means of both field measurements and wind-tunnel experiments. Moreover, similarity of the parameters between scalar and momentum has been also confirmed to be possibly applicable for urban surfaces.

In addition to the similarity theory in the inertial sub-layer, several features of flow distribution and turbulent statistics have been reviled in the layer directly influenced by roughness elements, namely the roughness sub-layer and canopy layer. For instance, it is known that velocity profile satisfies logarithmic law even within the roughness sub-layer, if spatial-averaged quantities are taken, even though, the layer does not satisfy the premise of the similarity theory in the inertial sub-layer. In addition, there are characteristic vertical trends on turbulent statistics; sweep events, or strong downward motions with high momentum fluid, are dominant near roughness elements whereas ejection events, or strong upward motions with low momentum fluid, dominate sweep events in upper part of the roughness sub-layer, being consistent with the tendency in the inertial sub-layer. Moreover, the visualization of turbulent structures around these events based on numerical simulations shows the existences of hair-pin and head-down hair-pin like vortices in the roughness sub-layer.

In contrast to these extensive understanding of characteristics of turbulent structure casing momentum transport, and consequently resulting spatially averaged fields of statistics, little of features for scalar dispersion are known especially in the roughness sub-layer. Non-uniformity of scalar distribution seems more easily generated in actual urban area than that of momentum, because scalar source or sink are usually rather scattered, meaning the situation in which horizontal homogeneity can be assumed is more rare for scalar. Although a few studies have revealed that there is similarity between scalar and momentum transport to some extent also in the roughness sub-layer, holistic understanding of scalar transport in the layer and the canopy layer with horizontally non-uniform flow distribution has not been reached yet.

Therefore, we have performed a large-eddy simulation on scalar dispersion from continuous area surface located on the floor of a rough surface. As the roughness condition, a cubical array in staggered layout is selected in order to generate both of the roughness sub-layer and the canopy layer. The scalar boundary layer can develop to streamwise direction and the height can reach up to four times of height of the cubes approximately. The purposes of this study are summarized as follows: (1) to quantify the streamwise characteristics of scalar boundary layer, including trends of concentration and turbulent flux for scalar, (2) to apply quadrant analysis so as to estimate the contribution of updraft or downdraft to total scalar turbulent flux, and then to discuss the similarity and dissimilarity of momentum and scalar in terms of flux decomposition, and (3) to visualize conditionally averaged flow filed which may strongly affect updraft or downdraft with scalar.

On the exchange velocity in street canyons with tree planting

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In this study an analysis of the exchange velocity (Ue) in a real street canyon with trees is presented. By recalling that Ue is a bulk velocity scale that can be used as a surrogate for the complex transfer processes between the canopy and the overlying atmosphere, we attempt to quantify it by means of experimental investigations and numerical simulations.

Specifically, we analyse the effect of trees on local meteorological variables through in situ measurements and Computational Fluid Dynamics (CFD) simulations. Measurements are taken in a neighbourhood of a medium-size Mediterranean city (Lecce, IT) with street canyons of aspect ratio H/W~1 (where H is the average building height and W is the average width of the street). Numerical simulations are performed with the commercial Computational Fluid Dynamics (CFD) FLUENT model with Reynolds Stress Model (RSM) for the treatment of turbulence. The effect of trees in the numerical simulations has been evaluated by considering them as a porous medium using a Leaf Area Index (LAI) measured in situ by a ceptometer. An extension of the current formulation for Ue given by the ratio between the pollutant flux at roof level through the exchange surface and the difference between the spatially-averaged pollutant concentration within the urban canopy and the background concentration is considered to include the direct dependence on the LAI.

Results provide evidence that flows and turbulent structures vary within the street canyon with and without trees. It is shown that Ue may diminish of factor about 10 in presence of trees with respect to the tree-free cases. This finding has clear influence on ground level concentration which may be substantially under-predicted if this effect is neglected. In this presentation we will show how the knowledge of Ue maps for a given city correlated with the local meteorology can be used for a more effective urban planning. This study also aims to stimulate the development of new numerical models which explicitly account for the effect of trees in urban areas.

Parametric studies of urban morphologies of high density cities and their air ventilation performance under neutral and unstable atmospheric conditions using advanced large-eddy simulations

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Providing good urban air ventilation is very important for quality and healthy living in a high-density city in the tropical regions. Rapid urbanisation in developing countries in the tropical regions means that a better understanding of how to design and plan a city with wind is needed.

Since 2006, based on our previous researches, a more scientific Air Ventilation Assessment (AVA) system to evaluate a development's project's urban air ventilation performance has been adopted by the Hong Kong Government for the city's design and planning practice.

However, one of the limits of current scientific understanding is that neutral atmospheric conditions are typically assumed when conducting experimental or simulation studies. Under weak background wind, as is typical for tropical and subtropical regions, local and mesoscale thermal effects start to dominate the mixing processes with a significant impact on the direction and speed of urban air ventilation. Studies for complex building structures under stratified atmospheric conditions do not exist. The 2006 AVA system therefore has limitations.

This study aims to fill this knowledge gap by conducting highly resolved large-eddy simulations (LES) for buoyancy dominating weak background wind atmospheric conditions. The project will use the PArallelised LES Model (PALM) developed at the Leibniz University of Hannover for simulating turbulent atmospheric flows. The model has been previously verified as being suitable for the task at hand. The code is highly optimised for massively parallel computers, and it can currently use up to 4,096 to the power 3 grid points, which makes it suitable for fine-scale investigation (1–2 m grid) within a very large computational domain (10–20 km) under different atmospheric conditions. The proposed turbulence simulations will be the first-ever to be carried out for complex urban terrain under such realistic conditions.

This study aims to provide a better scientific understanding of urban air ventilation patterns under "realistic" atmospheric conditions. Different urban layouts and morphologies will be tested to establish a parametric understanding between urban forms and urban air ventilation performance. The study will inform the current Air Ventilation Assessment (AVA) system in Hong Kong. The city's urban air ventilation will be more correctly predicted, thereby yielding better data for the design and planning of critical cases in the city's metro areas. This information on how to design with greater environmental sensitivity will be useful for architects and planners not only in Hong Kong, but also in other high-density cities in the tropical regions.

Analysis of spacing of streaky structures within surface layer above real urban

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Turbulence within the surface layer highly contributes momentum, heat and scalar transportation near the ground which is directly related to the human living environment. Understainding the occurence condition of several flow regimes in the boundary layer (Rayleigh–Benard cellular structure, streak, roll vortex and so on) is needed in order to properly apply models of each flow regime. And investigating statistical, dynamical and morphological characteristic in each flow regime is also necessary to develop accurate modeling.

This study investigated atmospheric flow patterns and morphology of the streaky structure within surface layer. We conducted continuous observation for three months using Doppler lidar and sonic anemometer in urban area (Tokyo, Japan). The spatial distribution of horizontal wind velocity was monitored by the Doppler lidar which was installed on the building rooftop of Tokyo Institute of Technology (55 m agl). The turbulent parameters were obtained from measurements by sonic anemometer which was installed on the building rooftop far from 500 m from the location of Doppler lidar (25 m agl).

The patterns of horizontal wind velocity distribution were visually classified into six groups, Streak, No streak, Mixed, Fishnet, Front, The others. From this analysis, Streak which has streaky wind velocity patterns along the streamwise direction appears most frequently and dominates about 60% of all valid data. Streak contains wider streaky pattern cases and narrower streaky pattern cases.

In addition, we analyzed the spacing of streaky structures in more than 100 cases, including under unstable, neutral, and stable condition. The spacing of streaky structures was estimated from the power spectrum density of horizontal velocity fluctuation. The relationships between the spacing of streaky structure and atmospheric stability and between the spacing of streaky structure and wind shear were discussed.

Variations in the power-law index with stability and height for wind profiles in the urban boundary layer

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Among the various methods used to express the relation between wind velocity and height above the ground, the power law (PL) is one of the most common methods employed in engineering fields. Although the theoretical basis of the PL is not as clear as that of the logarithmic law, past observations have shown its potential in modelling wind profiles in the atmospheric boundary layers (Counihan, 1975). The PL was originally proposed for use in a wind profile with an extremely high velocity in structural engineering (Davenport, 1960), and therefore a high velocity and neutrality are prerequisites for its use. It has also been applied to other problems, such as the wind environment and air pollution, because of its simple mathematical expression. However, in such cases, the neutrality of the boundary layer is not assured and the accuracy of the PL can change with stability. Previous studies have also reported the dependence of the power-law index (PLI) on the stability and height at which the PL is evaluated (Irwin, 1979; Hanafusa, 1986).

In this research, wind profiles were measured in an urban boundary layer to investigate variations of the PLI with stability and height. The Doppler lidar system (DLS) was used simultaneously with an ultrasonic anemometer (UA). Vertical profiles of wind velocity were measured by the DLS, and velocities and turbulent fluxes of momentum and heat were corrected by the eddy covariance method (ECM) using the UA. Observations were recorded between April and June 2014. The DLS was installed on the rooftop of a building at the Institute of Industrial Science (University of Tokyo, Japan). Velocities were measured at heights of 67.5 to 527.5 m at intervals of 20 m (24 height levels). The UA was set on a tower at the campus of Tokai University where the ground height of the measuring point was 52 m. The distance between the sites is about 600 m. PLIs were then calculated for each height measured by the DLS. The Monin-Obukov length L was calculated using the ECM and 1/L was employed as an index of the stability. In neutral conditions, the PLI in the lower height of the measurement (< 200 m) averaged in the range of 0.2 to 0.25. However, the PLI in stable cases increased with 1/L, and decreased in unstable cases where it approached around 0.1. Further, these changes of the PLI with stability became unclear when the measuring height used was increased.

Study of Stably Stratified Flows and Ventilation over Idealized Street Canyons using a Single-Layer Hydraulics Model

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Planetary boundary layer can be classified into three categories, namely neutral, convective (CBL) and stable (SBL) boundary layers, depending on the buoyancy exerted by density variation of air parcel. In SBLs, air is stratified with lighter air parcel flowing above the denser one. It is often observed in nighttime or overcasting sky because of radiative cooling. Study of SBLs is challenging manly due to diminishing eddy sizes and non-linear structures. In fact, the characteristic of strong SBLs is yet well understood.

It is well known that CBL turbulence promotes ventilation while SBL eddies are substantially suppressed, weakening the air entrainment/removal between the ground level and the atmospheric boundary layer (ABL) aloft. However, this finding is applicable only to horizontally homogeneous land surfaces. In high-Froude-number (Fr) flows over heterogeneous surfaces, such as urban areas, under SBL conditions, a non-linear phenomenon, known as hydraulic jump, commonly occurs that dissipates part of the mean kinetic energy into turbulence. Hence, the vertical fluctuating velocity scale is elevated that could subsequently improve the overall ventilation performance. In this study, we use a single-layer hydraulics model and attempt to investigate the ventilation mechanism of hypothetical urban areas in the form of idealized street canyons under stable stratification. Two immiscible fluids with a large density difference are used in the shallow-water equation and the density stratification is measured by the Froude number. A complementary approach, consisting of both laboratory experiments and large-eddy simulation (LES), is adopted.

Preliminary results show that two different mechanisms for street-level ventilation are clearly observed. With a slight change in Fr from 2.4 to 2.8, the original peak ventilation in the first few street canyons is completely impoverished. This sharp drop in ventilation attributes to the tremendous modification in mean and fluctuating velocities as a result of the change in Froude number. More detailed results will be reported in ICUC9.

LES analysis on atmospheric dispersion in urban area under various thermal conditions

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For keeping human health for the pollutant impact, it is important to predict accurately near-ground high concentrations for atmospheric dispersion in urban area. However, the dispersion characteristics are sensitively changed by convective phenomena based on the wind flows above and within the urban canopy layers. The aspect of urban surface is very complicated by various roughness elements such as houses, vegetation and buildings. Also, in the center of a large city tall buildings are densely arrayed in the limited region of a few km square. According to these aspects, different flow patterns like vortex shedding, separating shear flows or flow circulation, appear in the wake and determine the dispersion characteristics. Thus far, in order to classify and clarify these characteristics, many studies about atmospheric dispersion considering the detailed configuration of city have been carried out. But almost all of them were under the neutral condition for atmosphere and did not deal with the effects of waste heat from buildings. Studies on pollutant dispersion considering the thermal stability of the ambient wind or flows in the urban canopy are very rare in these days.

This study tries to carry out Large Eddy simulation (LES) which reveals the occurrence of high concentration by local flow phenomena such as cavity flows and separation around the surface obstacles. Also, taking into consideration great change of peak occurrence by the combined effect of atmospheric stability and local building waste heat over the roughened surface by dense buildings, its dispersion mechanism are investigated. Local thermal impact by wall and roof temperatures of building produce a stratification effect separately from atmospheric stability, and give a change in turbulent flow phenomena above and within the urban canopy. Accordingly, this study understands the exact concentration field, which needs to consider rough wall effect, atmospheric stability effect as a background, local heating effect from building wall. In order to elucidate such a specific urban dispersion process for safety and comfort of atmospheric environment, this study aims at obtaining the knowledge on detailed unsteady flow patterns accompanied with complex behavior. In the case of downdraft structure by stable stratification of rooftop radiative cooling in winter night time, we exhibit the importance of attention to local thermal effect in atmospheric diffusion process.

In this paper, an urban model is constructed using simple roughness block, which has the thermal boundary condition on building wall. Considering actual phenomena in cities, atmospheric stability is imposed in the computational domain. LES of atmospheric diffusion over urban roughness block elements is performed. In addition, the analysis on the obtained results focuses on the turbulent energy exchange between above and within the unban canopy, in order to clarify the generating, the developing or the decaying process of coherent structures such as streamwise vortices above urban canopy, updraft or downdraft inside canopy. Also, their flow visualization can exhibit roles of coherent structures for occurrence of high concentration. Finally, we conclude that above information makes a contribution to safety and comfort for human society.

The urban heat island circulation with idealized building clusters by up-scaling CFD model: from buildings scale to city scale

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The analysis of wind environment in neighbourhood-scale and meso-scale has been well studied by Computational Fluid Dynamic (CFD) model and Weather Research Forecast (WRF) Model, respectively. However neither of the two models can provide precise analysis for city-scale wind environment. In this paper, we propose a modification to up-scale CFD model to simulate city-scale wind environment. We focus on the simulation of urban heat island (UHI) circulation with the assumption that there is no background wind.

Stratification and atmospheric stability are considered in our model. To validate our model, we have carried out two simulations. One was a water tank simulation with comparison to the Cenedese's water tank experimental results. It was illustrated that our model could well simulate the laboratory water tank experiment. Another was acity-scale simulation (the domain size is about 100km) whose results were compared with the results of large eddy simulation (LES). It was shown that our up-scaling model could also simulate the UHI circulation well and could improve the flux exchange interface between meso-scale and neighbourhood scale simulations. Moreover, to save computation cost cause by a large number of buildings in a city, we treat the building clusters as porous media. Many previous related studies of using porous media to study the wind conditions do not consider the effect of heat, and thereby they are not capable of simulating the UHI circulation. In our model, both the porous media and the heat effect are included. We have conducted relevant simulations and the results show that when the building effect is considered, the maximum vertical velocity area in the UHI circulation is lifted.

Wind tunnel experiment on the Influence of approaching wind direction on flow field under wall surface heating and low wind velocity conditions

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Canopy structure is one of the most important factors that has significant influence on flow pattern in canopy, including aspect ratio, building shape, building orientation, etc.. Since wind flow field is strongly influenced by building configurations and building surface heating in urban area, we investigated systematically the effect of a long street canyon on wind field under five different approaching wind direction (included angles between wind flow and model's long side are 0° as parallel flow, 22.5°, 45°, 67.5°, and 90° as perpendicular flow), wall surface heating conditions (ground, leeward and windward wall heating), and different section of canyon (inlet, middle and outlet). Wind tunnel experiments were conducted using PIV (Particle image velocimetry), observing both vertically and horizontally. At inlet and middle section of neutral conditions, every direction of flow except parallel flow formed a vortex in the center of canopy. With the decrease of angle, at outlet section, the vortex became weaker until disappeared. For parallel, two parallel counter rotating vortexes were formed. There is a downward flow in the center of canopy, which induces the outside air going inside. In heating cases, a strong buoyancy flow generated and effected flow pattern and air exchange between inside and outside of the canyon.

Meteorological and land cover effects on local urban wind patterns

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Data from a suite of sonic anemometers situated in a range of urban land cover types has been analysed to assess the extent to which local air movements are influenced by meteorological parameters and site characteristics (surface cover, topography etc). For the case study area of Manchester, UK, data were collected from 4 sonic anemometers between June and October 2012. The measurement site land cover types included 'Urban Core', 'Manufacturing', 'Offices' and 'High Density Residential'. Preliminary results demonstrate significant differences between both horizontal and vertical air movements at the different sites, which are situated within 4 km of each other. The diurnal cycle is shown to play an important role with respect to site differences; the largest differences in mean horizontal wind speed between sites (1.4 ms-1) occurred during the mid-late afternoon (15:00-18:00), depending on the time of year. Land cover is shown to be a more influential factor on maximum windspeeds, compared to average or minimum flows. During extreme events (95th percentile) the difference in the maximum gust speed can exceed 3.5 ms-1 for the different land cover types. In general, vertical air flow showed smaller site differences, with inter-site variation typically <1 ms-1, although differences of more than 4 ms-1 were recorded when comparing the manufacturing zone with the area of residential housing. The results of this work are of relevance for urban planning and design. Knowledge of local- to mesoscale wind patterns is important for understanding processes linked to pollutant and heat removal within the urban environment, and also the contrasting problem of identifying locations of potential storm damage during extreme events. The results of this work can be used to inform adaptation of the urban environment to encourage ventilation in high risk areas during the summer, and to protect more vulnerable areas during the incidence of storm events.

Large-eddy simulations to characterize the role of turbulent and dispersive production, transport and dissipation of TKE over and within a realistic urban canopy

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In the past two decades significant efforts have been devoted to the characterization of turbulence in the roughness sublayer (RSL) over cities, in particular to enhance prediction of wind, dispersion and pollution in the urban canopy layer (UCL) it encompasses. However, due to difficulties in both conducting representative measurements and in performing robust simulations over such complex geometries, the role of dispersive stresses, transport and pressure effects is still inadequately understood. A characterization of such terms would allow to guide/improve simple models such as 1-D urban canopy parameterizations. The physics of UCL and RSL flow and turbulence are here investigated through large-eddy simulations (LES) of the airflow above a realistic urban geometry in the city of Basel, Switzerland, where extensive tower-measurements are available from the Basel Urban Boundary Layer Experiment (2001-02). We rely on a double averaging approach to separate turbulent fluctuations from dispersive terms, in order to determine how spatial variations of time-averaged quantities affect turbulent kinetic energy (TKE). A Lagrangian scale-dependent LES model is adopted to parametrize the subgrid-scale (SGS) stresses and buildings are taken into account adopting an immersed boundary (IBM) approach, with the geometry taken from a highly accurate digital building model. We consider fully developed flow over a 512x512x128m computational domain (mean building height is 15.3m) and adopt a 1m stencil. In agreement to measurements, TKE in the RSL is found to be primarily produced at roof-level. Here, turbulent production overcomes dissipation by SGS stresses and the excess in TKE is dislocated down into the cavities of the UCL (street canyons, backyards) and upwards into higher parts of the RSL by turbulent transport and dispersive transport terms. Turbulent and dispersive transport terms are comparable in magnitude and act as a sink of TKE in the upper RSL and as a source term in the lower RSL and UCL. The spatial heterogeneity of mean velocities and Reynolds stresses in the lower RSL and in the UCL results in a significant wake production rate of TKE. Moreover, pressure transport is found to be a significant source of TKE in the lower UCL, whereas transport by SGS stresses is negligible throughout the RSL.

Experimental and numerical studies of flow adjustment and drag forces through idealized urban models with different urban parameters

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Wind is important for ventilation and pollutant dispersion in urban areas. We first experimentally studied some 25-row and 15-column aligned cubic or square building arrays (the building width B=72mm and building heights H=B or 2B) in a closed-circuit boundary layer wind tunnel at Laboratory of Ventilation and Air Quality, the University of Gävle, Sweden. The working section of this wind tunnel is 11 m long, 3 m wide and 1.5 m tall. The approaching wind is parallel to the main streets. Effect of building area densities (lp=0.11, 0.25, 0.44 or street width W=B, 2B, 0.5B) and building height variations (H=B or 2B) on flow adjustment (velocity and turbulence profiles by hotwires) and drag forces of individual buildings were first measured in wind tunnel experiments, then the sectional drag coefficient and detailed flow mechanisms in adjustment region, interior region (or fully-developed region) and exit region etc were quantified by computational fluid dynamic (CFD) simulations. The distribution of pressure difference between windward and leeward walls was used to indicate natural ventilation potential in buildings.

We find that wind speed decreases quickly through idealized building arrays due to strong drag produced by buildings. For 25-row urban models with building area density of lp=0.25, the fully-developed region starts at about the 12th building, but not the 4th or 5th one as discussed in the literature. The adjustment length varies due to various building packing densities. For all 25-row urban models with uniform building heights (H=B,lp=0.11, 0.25, 0.44), denser urban models produce lower drag force by individual buildings and attain smaller velocity in urban canopy layers, which produce weaker urban ventilation capacity and less natural ventilation potential through buildings. For 25-row urban models (lp= 0.25, 0.44) with building height variations (H=B or 2B), taller buildings (H=2B) always produce much stronger drag force than lower ones (H=B). Drag force by the latter was small (lp= 0.44) or a little negative (lp= 0.25) because they were significantly sheltered by the former. Vertical profiles of sectional drag coefficient were also analyzed the show natural ventilation potential at different height levels. Results show that, taller buildings usually attain better building natural ventilation potential than lower ones. For urban models with the same building packing density, there is a dilemma that it is difficult to ensure the urban ventilation capacity and building natural ventilation potential at the same time. But ultilizing smaller building packing density can improve both.

The interaction between roughness turbulence generated by block arrays and wake around large obstacle

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The research communities of building physics and wind engineering have steadily focused on the effect of strong wind force caused by an isolated high-rise building on pedestrians for the last decades. In contrast, various researchers of urban climatology have investigated the turbulent boundary layer over urban building arrays for accurate prediction of urban climate. Under these circumstances, this study intends to examine the aerodynamic interaction between the before mentioned two research targets; the wake flow structure observed behind an isolated high-rise slender building and the turbulent boundary layer develops over urban roughness based on a wind tunnel experiment.

The experiment was conducted in a low-speed single-return wind tunnel with a test section of height 1m, width 1.5m and length 8m. The spatial uniformity of the inflow is carefully controlled by means of a honeycomb layer and several mesh screens with an open-area ratio larger than 0.57. To simulate the development of the urban boundary layer, the floor of a wind tunnel with a streamwise length of about 3m is covered by a staggered cubical array with a height of 25mm (hereafter, H), which means the fetch length is 130H, resulting in the boundary- layer height of about 6H (0.15m). In addition, a quarter-elliptic, constant-wedge-angle spire with a height of 32H (0.8m), which is higher than the depth of the boundary layer, is installed in the upwind region of the wind tunnel to generate the wake flow which is analogous to the flow leeward of an isolated slender building.

The detailed distribution of streamwise velocity in lateral¬-vertical planes which cover both within and above the boundary layer developed by an underlying block array is measured in leeward positions of the spire using a hot wire anemometry under a condition of a reference stream velocity of approximately 8ms-1. And the authors investigate how the turbulence characteristics of the wake of the spire are affected by the boundary layer of the block array based on the measurement data. In order to validate the experimental setting, the wake flows by the spire were then compared with the characteristics of two dimensional (2D) wake flow derived theoretically based on the gradient-diffusion model.

The followings were revealed: (1) The streamwise changes of the half width and the velocity deficit are similar to that of the 2D wake flow above the boundary layer generated by both a smooth wall and a block array; however, those within or near the outer edge of boundary layer shows totally different treads from that of 2D wake flow. (2) The spanwise development of the wake from generated by an isolated spire is oppressed in the wall boundary layer.