NOCTURNAL COOL ISLAND AND A THERMAL WIND SYSTEM – TWO FEATURES OF THE LOCAL CLIMATE IN OUAGADOUGOU, BURKINA FASO

Jenny Lindén*
Department of Earth Science, Urban Climate Group, University of Gothenburg, Sweden

Abstract

The tropical city of Ouagadougou has been examined during three field studies in order to describe physical processes determining the urban climate during dry season. Ouagadougou is located in the West African Sahel region, one of the poorest regions of the world, and urbanization is expected to quadruple the number of inhabitants over the next thirty years.

During field work, car traverses was used to measure air temperature and humidity. Air and soil temperature was also measured at a network of fixed stations in and surrounding the city. Furthermore, wind and radiation was measured and at two reference stations. Results indicate some important differences in processes determining the urban climate here compared to temperate cities. A strong nocturnal urban cool island/oasis effect, on average -5 °C, was found in examined vegetated areas compared to non vegetated area, regardless of urban or rural setting. This greatly exceeded the urban heat island effect which was less than 2 °C. At the same time, a thermally induced wind system was developed during nights with high atmospheric stability. This wind system was mainly noticed in the areas where the weak urban heat island was present, and notably changed wind direction throughout affected nights.

Key words: oasis effect, urban vegetation, open water, thermal wind system, sub Saharan Africa,

1. INTRODUCTION

Cities in the least developed countries, many of which are located in dry-tropical sub-Saharan Africa, are projected to triple in size over the next 30 years (United Nations Population Division, 2008). A review show that less than 20% of all urban climate studies are from (sub) tropical areas, and that only a handful of these are from the dry-tropical regions of Sub-Saharan Africa (Roth, 2007).

Differences in physical properties in urban and rural areas located in arid versus temperate or humid regions may provide very different climatic responses (Jauregui, 1997, Pearlmutter et al., 2007). For example, in dry climates vegetation has been suggested as a more important factor compared to urban geometry and thermal properties of urban surfaces (Jonsson, 2004, Pearlmutter et al., 2007). The type of vegetation may also differ between humid and arid climates as plants in dry areas often are forced to adapt water saving behavior for survival, thus resulting in different effects on the urban climate. Studies have shown that the main effect of irrigated vegetation on the urban climate is an afternoon park cool island effect due to shading and evaporative cooling (Potchter et al., 2006). However, non-irrigated vegetation in arid areas often have a mid day depression in the evapotranspiration process for water saving purposes (Maroco et al 2000, Gindaba et al 2004) Evapotranspiration is instead active when vapor pressure deficit decreases in evenings, thus allowing effective cooling from evapotranspiration during evenings instead of days.

Air quality of often very poor in cities in sub-Saharan Africa with important local pollution sources such as traffic and industries (Han and Naeher 2006). Studies have shown that concentrations of pollutants in the sub-Saharan city of Ouagadougou often greatly exceeded WHO recommendations for maximum human exposure (Boman et al 2009, Lindén et al 2008). Pollution levels in Ouagadougou varied with atmospheric stability, where higher levels of air pollution occurred during periods of very stable nocturnal atmospheric conditions. The high stability could greatly effect the exposure situation as the low winds and turbulence during stable episodes prevents dispersion and transportation of the pollutants away from the city. Local, intra-urban wind patterns can be created during periods of high atmospheric stability (Thorsson and Eliasson 2003). These winds could have an important impact on the transportation of pollutants from their emission source, and thus effect on where high pollutant concentrations occur.

Described in this paper are intra urban and urban-rural thermal variations in relation to land use in the Sahelian city of Ouagadougou, Burkina Faso. Focus is on the role of vegetation and of a large, centrally located dam, and based on data from field studies in 2003 and 2004. Also presented are preliminary results on the behavior of a thermally induced wind pattern in Ouagadougou. Wind data was collected as part of a larger measurement campaign in Ouagadougou in 2007, focusing on urban climate and air pollution.

2. BACKGROUND

The capital of Burkina Faso, Ouagadougou (12˚ 22´N, 1˚ 31´W, 300 masl), is located in the in the hot semi-arid steppe climate of the Sahel as shown in figure 1. The climate consists of a dry period from October to April with wind blowing in from the Sahara in the north and north-east, and a wet period from May to September averaging 700 mm of rain (Direction de la Météorologie Nationale, 2001).

* Jenny Lindén, Department of Earth Science, Urban Climate Group, University of Gothenburg,
Box 460, SE-405 30, Gothenburg, Sweden. Email Jenny.Linden@gvc.gu.se

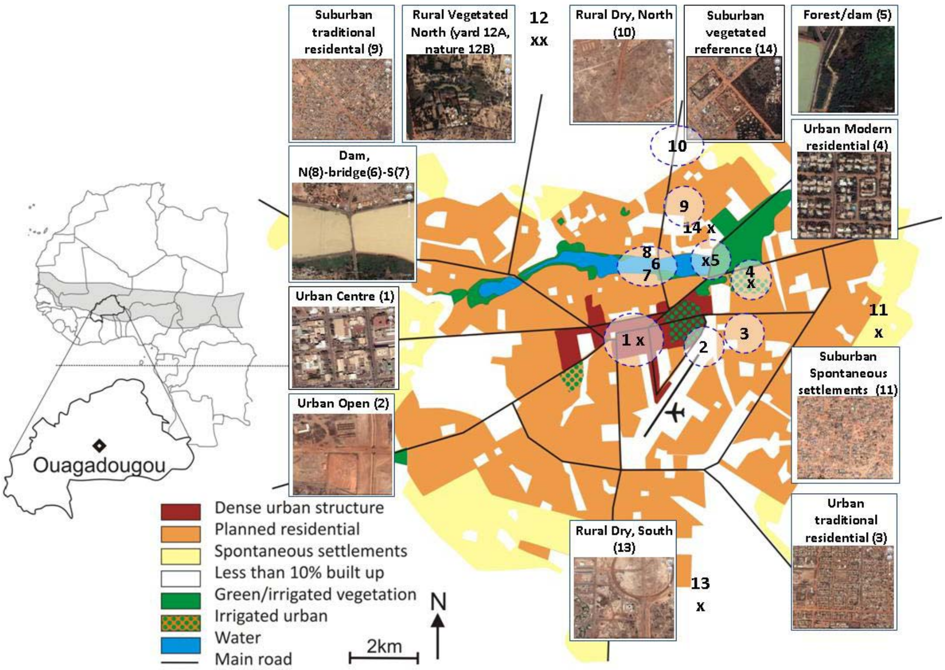

Figure 1. Location of Burkina Faso and Ouagadougou (Sahel region shaded), and a map of Ouagadougou classified in respect to land use with marked location of areas covered by measurements and satellite images (google earth). Circled areas (1-10) are covered by car traverses. Fixed site measurements are marked by X. Wind measurements are from areas 1 and 14.

Average daily temperatures range from 25°C to 33°C. Ouagadougou has approximately 1.2 million inhabitants today with a population density of about 660 inhabitants/km^2. Urbanization in Burkina Faso is projected to generate an exceptional growth of urban dwellers that will increase the number of urban inhabitants by four times in the next 30 years (United Nations Population Division, 2008). The urban structure in Ouagadougou is spread out and generally dominated by low buildings and sparse vegetation, with many dry, open areas spread out over the city.

3. METHODS

Data was collected during three field studies; Oct.-Dec. 2003, Nov.-Dec. 2004 and Nov.-Dec. 2007 with the aim to describe the urban climate of Ouagadougou. In 2003, measurements of air temperature and humidity (Rotronic Hygromer MP100A) were collected during car traverses twice daily (starting at 13:00 and 20:00) for 17 days in 9 different urban sites and one rural site (figure 1). A suburban reference station measuring temperature and humidity as well as wind was placed at the Direction de la Météorologie National, DMN (Suburban vegetated reference, area 14). Air and ground temperature (Tinytag plus) was continually measured at fixed locations in and around the city both 2003 (37 days) and 2004 (20 days). The examined areas were chosen according to their land cover. In 2007, two instrumentally identical reference stations were set up, one on a three floor building at rooftop level in the urban centre (1), and one at ground level at the DMN (14), measuring wind (UltraSonic Young 81000), radiation (Kipp&Zonen CNR1), air temperature and humidity (Rotronic Hygromer MP100A) during a period of 12 days.

4. RESULTS AND DISCUSSION

4.1 Thermal patterns in relation to land use

Results from this study show nocturnal cool islands in all vegetated areas that considerably exceeds the UHI effect in the city. Average urban-rural temperature differences from car traverses (T_{Ux-R}) demonstrate that while the evening UHI reach only 1.9 °C (Urban centre,1), the cool island in a densely vegetated area (forest/dam, 5) is 5.0 °C cooler than the dry rural reference (figure 2). Diurnal data from fixed site measurements show that the areas can be divided in to two groups in view of nocturnal temperature differences that persist throughout the night(figure 3). Regardless of urban or rural setting, all cooler areas have a high coverage of vegetation while non-vegetated areas are warmer.

A linear regression analysis of data show that green vegetation is the most important land-cover parameter for generating nocturnal temperature variations (y = 3,60 - 0,11X, R^2=0.74), far exceeding that of built up and paved

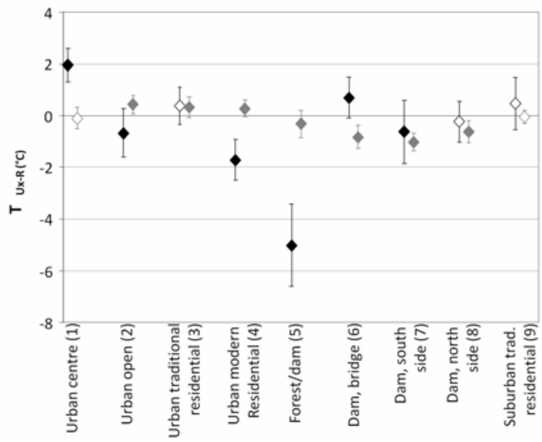

Figure 2. Mean Urban – Rural temperature differences in °C for areas examined during car traverses. Error bars describe one standard deviation. Black marks represent evening values, grey represents daytime values. Areas not significantly different to rural area are presented by hollow marks.

areas (y = -0,61 + 0,05X, R^2=0.28). A limited temperature difference between urban and rural areas have been noticed in a study of Kuwait city (Nasrallah et al 1990) and was attributed to the use of mainly local building materials such as clay brick which have thermal properties comparable to the rural surroundings. However, in this study, nocturnal thermal patterns are very similar in the Suburban spontaneous settlements (11), where almost exclusively local materials are used, and in the urban centre(1), where mainly modern materials are used, suggesting that the choice of building material are of less significance in Ouagadougou.

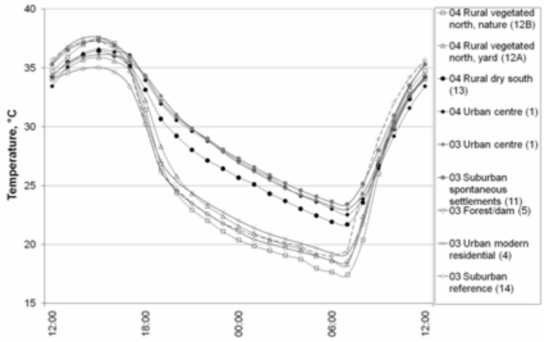

Figure 3. Hourly means of diurnal temperatures from fixed site measurements in 2003 and 2004.

While vegetation cooling is the superior temperature affecting factor during evenings and nights, effects were greatly reduced, and sometimes even opposite, during daytime in contrast to findings by Potcher et al. (2006). The explanation for this might be that vegetation in Ouagadougou has adapted to the water stress in this region during dry season by shutting down stomata, thus preventing respiration, when vapor pressure deficit is high during the hottest part of the day. Stomata is instead opened when vapor pressure deficit decreases in evenings. This has been shown to be the case for several species in the Sahel region (Maroco et al 2000, Gindaba et al 2004). An additional cause might be that a larger part of the vegetation is using the CAM-photosynthesis process where CO2-uptake (thus plant evaporation) is taking place during night (Raven et al 2005). This would create a strong cooling by plant evapotranspiration during evenings possibly causing the large cool islands in vegetated areas shown in this study. The limited daytime plant evapotranspiration process would prevent daytime cooling of vegetated areas, allowing greater importance of for example the lower albedo of vegetation thus increasing temperatures.

The open water of the dam is instead the most important parameter during daytime, generating cooler temperatures in all areas in close proximity to the dam. During evenings and nights, direct effects of the open water of the dam are very limited, varying from slightly cooling in areas surrounding the dam to slightly warming on the bridge across the dam. A warming nocturnal effect of the water of the dam would be expected due to the high thermal admittance of the water increasing nocturnal air temperatures by sensible heat transfer. The slight cooling in the dam surrounding suggests that the availability of water for enhancing vegetation cover is of greater importance compared to the water itself.

4.2 Thermally induced nocturnal wind system

Preliminary results from measurements of wind in Ouagadougou during a period of very stable nocturnal conditions show clear differences in nocturnal wind direction within the city (figure 4). The large intra urban thermal differences presented above indicate that this could be a resulting thermally induced local wind pattern. Daytime regional winds during this period are generally northerly at both stations with a slightly larger variability at the rooftop urban centre station. Wind speeds are higher day compared to nights. At the *Suburban vegetated reference* station (14), nocturnal wind directions are similar to daytime, mainly north and north-easterly, while at the *Urban centre* station (1), wind direction turn towards east and later south-east during the night, though variability is large.

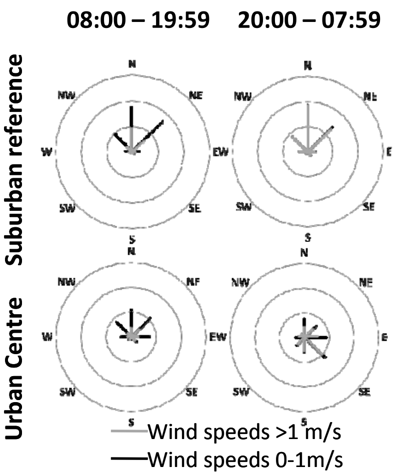

Figure 4. Wind roses from all days/nights with very stable atmospheric conditions

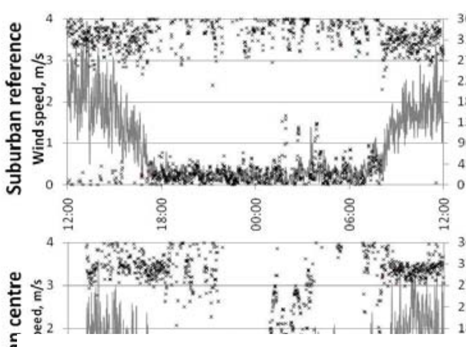

Figure 5. Change in wind speed and direction with time on November 24 to 25. The grey line shows wind speed, x marks wind direction.

The reason for the large variability at urban centre during very stable conditions can be explained by looking at changes in wind speed and direction with time, as in the case study presented in figure 5. During the presented night, the difference between the two stations is clearly visible. While the DMN station shows a turn in direction towards the north-east lasting throughout the night, winds turn towards the east and later south at the urban centre. An increase in wind speed at approximately 04:00 at the urban centre station causes a change in wind direction back towards the north that lasts until sunrise. This type of break-through of a larger scale wind, causing major directional changes in wind direction can be seen during most nights at the urban centre station. This happens at different times, often several times in one night, causing the large variability in data as shown in figure 4.

The cause of this change in wind direction in Ouagadougou is likely found in the high nocturnal stability and large intra-urban thermal differences (Thorsson et al 2003). A schematic illustration of the general pattern is presented in figure 6. Daytime winds are generally north or north-easterly at both stations. During evenings the heat centre is located in the area by the *urban centre* (1). Evening wind directions are the same as daytime wind direction at the *suburban reference* (14), while at the *urban centre* (1) winds turn towards the east. The large temperature gradient between the more vegetated areas in the north-east and the heat centre is a likely cause for a thermally induced wind from the north-east. The more easterly direction at the urban centre might be a higher temperature gradient between the centre and the nearby cooler vegetated residential areas to the east. As the night continues, winds at the urban centre station keeps turning towards the south. This continued turn in wind direction might be caused by differences in cooling rates during the night. As the urban centre cools of, the high thermal admittance of the water of the dam prevents cooling at the same rate in this area, thus causing a shift of the heat centre from the urban centre towards the dam. Thermally induced winds would then turn towards the south as the heat centre is moved north of the urban centre. This pattern is also visible in figure 5 (before "break-through" of larger scale winds in early morning as discussed above). In figure 5, daytime wind is mainly north-westerly, while after sunset direction turns towards the north and north-east at both stations. As the night goes on, wind direction stays the same at the suburban reference, while at the urban centre station wind keeps turning towards the east and later south.

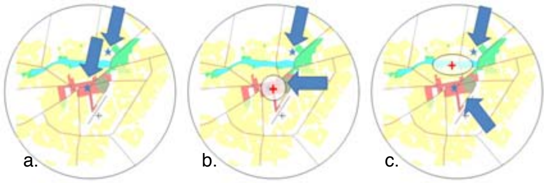

Figure 6. Schematic illustrations of development of a thermally induced nocturnal wind pattern in Ouagadougou during a. daytime b. evenings and c. nights

5. CONCLUSIONS

Results from these studies show that vegetation is the most important land cover parameter in creating nocturnal urban thermal variations. A strong nocturnal urban cool island/oasis effect, on average -5 °C, was found in examined vegetated areas compared to non vegetated area, regardless of urban or rural setting. Large intra-urban thermal variations were found on relatively short distances within the city. The steep temperature gradients between warm and cool areas are likely to be the cause for a thermally induced local wind system found mainly in the urban centre during very stable nocturnal conditions. This wind system notably changed wind direction in the urban centre area during affected nights.

6. REFERENCES

Boman J., Lindén, J., Thorsson, S., Holmer, B., Eliasson, I. 2009 A tentative •study of urban AQ1 and suburban fine particles (PM2.5) collected in Ouagadougou, Burkina Faso. *X-ray spectrometry*, 38.

Direction de la Météorologie Nationale. cited 2008. Humidité et température à Ouagadougou. [Available online from http://aochycos.abn.ne/HTMLF/ETUDES/METEO/INDEX.HTM.]

Gindaba, J., Rozanov, A., Negash, L. 2004. Response of seedlings of two Eucalyptus and three deciduous tree species from Ethiopia to severe water stress. *Forest Ecology and Management*. 201. 121-131.

Han X., and Naeher L.P. 2006. A review of traffic-related air pollution exposure assessment studies in the developing world. *Environment International* 32, 106 - 120.

Jauregui, E. 1997. Heat island development in Mexico City Atmospheric Environment, 31, 3821-3831.

Jonsson, P. 2004. Vegetation as an urban climate control in the subtropical city of Gaborone, Botswana. *International Journal of Climatology* 24, 1307-1322

Lindén J., Thorsson, S., Eliasson, I. 2008. Carbon Monoxide in Ouagadougou – a Comparison between rooftop, road-side and in-traffic measurements. *Water, Air and Soil Pollution188*, 345.

Maroco, JP., Pereira, JS, Chaves, MM. 2000. Growth, photosynthesis and water-use efficiency of two C-4 Sahelian grasses subjected to water deficits. *Journal of Arid Environments*. 45, 119-137.

Nasrallah, HA, Brazel, AJ, and Balling, RC. 1990. Analysis of the Kuwait-City Urban Heat Island. *International Journal of Climatology* 10, 401-405.

Pearlmutter, D, Berliner, P, and Shaviv, E. 2007. Urban climatology in arid regions: current research in the Negev desert. International *Journal of Climatology*, 27, 1875-1885.

Potchter, O, Cohen, P, and Bitan, A. 2006. Climatic behavior of various urban parks during hot and humid summer in the Mediterranean city of Tel Aviv, Israel International Journal of Climatology 26, 1695-1711

Raven, PH, Eveer, RF, and Eichhorn, SE. 2005. Biology of Plant. 7 ed. W.H.Freeman and company Publishers.New York, USA.

Roth, M. 2007. Review of urban climate research in (sub)tropical regions. *Int. J. of Climatology*, 27, 1859-1873.

Thorsson, S and Eliasson, I. 2003. An intra-urban thermal breeze in Goteborg, Sweden *Theoretical and Applied Climatology*, 75, 93-104.

United Nations Population Division, 2008: World Urbanization Prospects: The 2007 Database.