COMPARISON OF MEAN FLOW AND TURBULENCE CHARACTERISTICS AT DIFFERENT SUB-URBAN MEASUREMENT SITES

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Abstract:
As part of the NSF-funded project ILREUM, mean flow and turbulence characteristics have been measured at different sites and with different types of instrumentation. At one site, a near-surface site in a fairly open area, measurements with sonic anemometers and a surface-layer scintillometer were conducted. At a second site, a roof-level site on a 5-storey building, RM Young sonic and cup anemometers were deployed on two 10-ft masts, and four CSAT sonic anemometers were mounted at different heights on a 15-ft tripod. The instruments were sited such that the influence of roof structures on the measurements could be discerned. Despite the often observed acceleration zone on building roofs, an initial analysis of our data has shown that the wind speeds measured at the roof site tend to be lower than near surface winds. Recirculation vortices were observed at sites close to a tall roof structure. Our further analysis has focused on a comparison between data collected with different sensors and on how buildings structures of different size as well as roughness transitions influence the mean flow and turbulence characteristics.

1. INTRODUCTION

Recent reports published by the United Nations conclude that 50% of the present world's human population, and more than 75% of the human population in developed countries, live in cities (United Nations, 2004). The ongoing trend of increasing urbanization is expected to continue (Brockerhoff, 2000) and urban areas face a number of serious environmental challenges such as air quality management or heat waves. For example, due to the complex nature of urban flow and turbulence patterns, predicting the dispersion of pollutants in urban areas is extremely challenging. The National Research Council recently concluded that no model system exists that fulfills all critical requirements for emergency response (NRC, 2003). Due to their simple use and short runtimes, several authors have suggested using simple Gaussian-based urban dispersion models, where key components of the models are parameterizations of the low wind speeds, high turbulence intensities, and tendency towards neutral conditions in urban areas. Examples of these models are given by Britter and Hanna (2003), Venkatram et al. (2005), and Hanna et al. (2003). These authors demonstrate that simple models perform adequately against urban field observations of tracer dispersion in several cities (Hanna and Baja, 2009). Further, as the spatial resolution of numerical weather prediction models continues to decrease, the representation of urban areas in these models should also be improved. So-called urbanized mesoscale models have been developed, in which urban effects on the boundary-layer dynamics and thermodynamics have been parameterized (see. e. g. Dupont et al., 2004 and Martilli, 2007). Using such models, the simulated flow and turbulence structure over urban areas is in much better agreement with observations and also the urban heat island phenomenon (Lemonsu and Masson, 2005) has been successfully reproduced. However, as Martilli (2007) points out, it is still questionable to what extent these models can qualitatively and quantitatively reproduce the conditions within the urban canopy layer (UCL). Given that human activities take place within this layer, further evaluations and improvements of urban parameterizations are crucially important for urban climate and air quality applications. New measurement techniques such as scintillometry provide the possibility to measure spatially averaged fluxes, which has advantages in complex terrain. However, their usefulness in urban areas must be further assessed (Roth et al., 2006). The main objective of the presented studies was thus to investigate the flow and turbulence characteristics at two sub-urban sites with different types of sensors, and to assess the agreement with the observations from other urban studies and standard surface layer parameterizations.

2. MEASUREMENT SITES AND INSTRUMENTATION

Measurements were taken at the two sites, A and B, shown in Fig. 1. Site A is located on the northern edge of Norman near Max Westheimer airport and the Norman Mesonet site. Two measurement campaigns were conducted at this site in the summers of 2007 and 2008. A close up view of the site with the location of the instruments and near-by buildings, a photo of the deployment in 2008, and an overview of the data availability are shown in Fig. 2. The site is located in a suburban environment with conditions close to the ideal (flat and homogeneous). The purpose of the campaign was to further test the skill of a Scintec displaced beam small aperture scintillometer (DBSAS) of providing accurate measurements of turbulent fluxes in the surface layer. The scintillometer data are compared with simultaneous sonic anemometer measurements and against traditional gradient or profile flux estimation methods. For this purpose, one RMYoung sonic (RMY) was placed in the center (location R in Fig. 2a) of the scintillometer paths in 2007, and four additional Campbell Scientific sonics (CSAT) were deployed along the scintillometer path (two at locations C and two R as shown in Fig. 2a) in 2008.

Site B is located on the southern edge of Norman Oklahoma. At this site two instrumented 10-ft roof masts and one 15-ft tripod with 4 CSAT have been installed on the outdoor roof observation deck of the National Weather Center (NWC). The NWC is a 5-storey building and the roof observation deck is ~27 m above ground with several higher roof structures (elevation shaft, observation deck and antenna mast) surrounding the masts and tripod from the North and West (Fig. 3). The 10-ft masts both include a RM Young sonic and cup/vane anemometer. Air temperature, relative humidity and solar radiation sensors are also placed on these masts and wind profile measurements with a sodar are also taken on the NWC roof. The primary use of the observation deck is for educational purposes as students can easily be involved in hands-on activities with instrumentation and the data nicely demonstrate exposure effects on meteorological measurements. As an example, at both the East and West mast the wind speeds tend to be lower for most wind directions than the wind speeds measured at a 10-m level at the Norman Mesonet site which is counter intuitive to what most students think because the anemometers on the NWC roof are located ~30 m AGL. Another interesting aspect that has been observed is a recirculation type vortex pattern developing at the West mast due to the roof structures to the north and west of that mast. We thus decided to deploy the 15-ft tripod with four CSAT sonics (mounted at 1, 2, 3.5 and 5 m above roof level) to investigate these recirculation patterns further and evaluate how well standard theories would apply at such a complex site, as well as test some new techniques to detect coherent structures. Important to note is that we are fully aware that this site is very unique and that the findings are not easily transferable to other sites. We primarily wanted to contrast the findings at this extreme site to findings at more ideal sites, and also conduct some instrument inter-comparisons at complex urban settings.

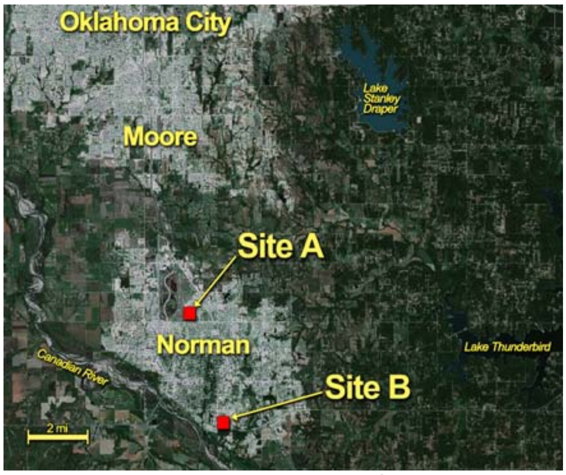

Fig 1: Aerial photo of Norman, OK with the two measurement sites A and B (see text for more details about the sites).

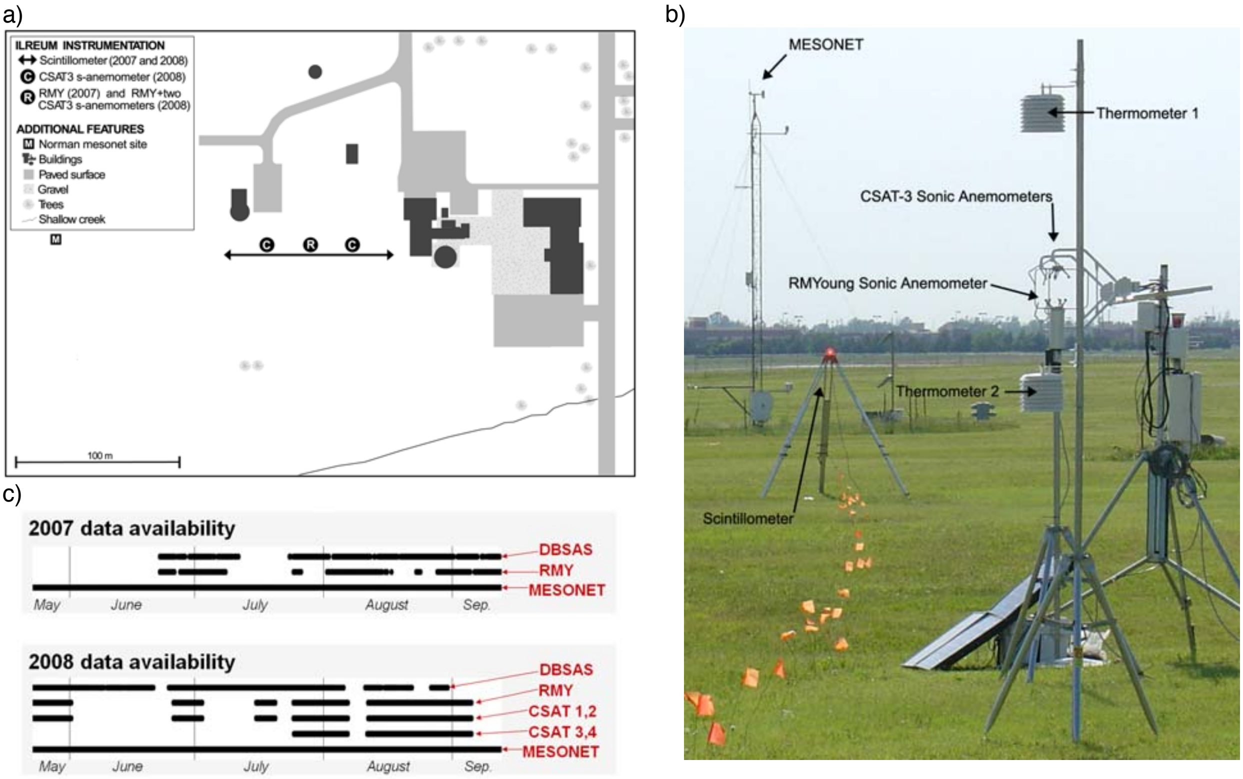

Fig 2: Map (a), photo (b) and data availability for the 2007 and 2008 ILREUM measurement campaigns at OU's north base in Norman, OK.

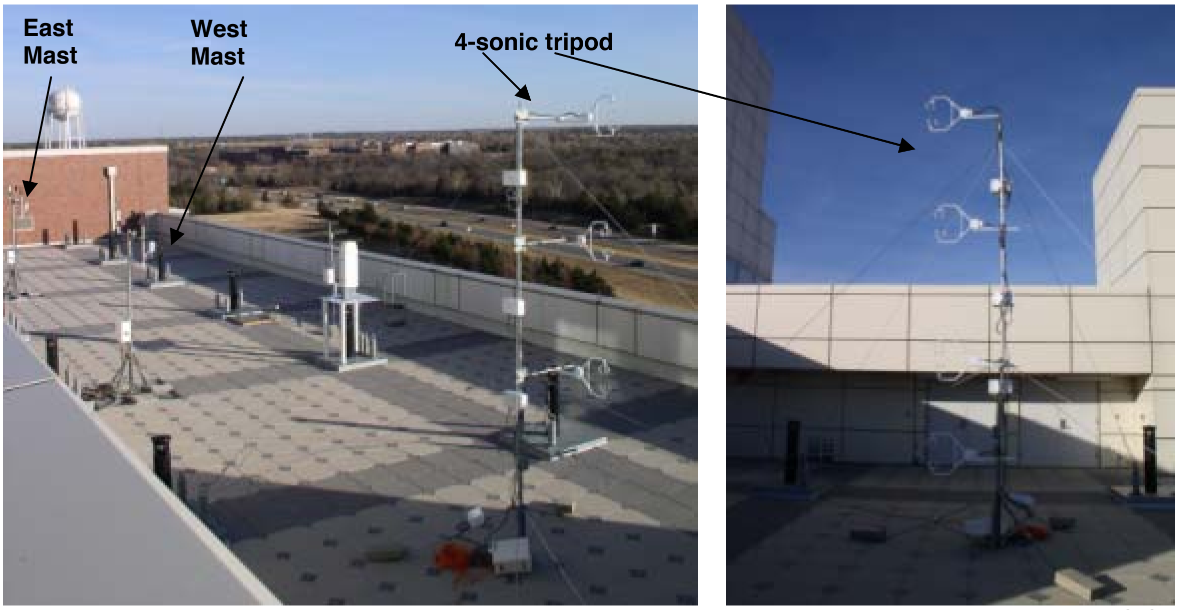

Fig. 3. Deployment of two 10-ft roof masts (Easy Mast and West Mast) and a 15-ft tripod with 4 C-SAT sonic anemometers on the outdoor classroom of the National Weather Center in Norman, OK. The left image shows a view to the southwest, the right image a view to the north.

3. RESULTS

Given the page limit only some exemplary results of the data collected at the two sites will be shown. More details will be provided in the actual conference presentation and future publications. Fig. 4 shows the diurnal variation of the heat fluxes measured with the RMY sonic anemometer (a) and a comparison between the sonic (x-axis) and scintillometer (y-axis) measurements of the heat fluxes. In the left plot the black line corresponds to the mean diurnal heat flux and the red dots demonstrate the scatter of the individual days; in the right plot the black line is the best fit line. The agreement between the scintillometer and sonic heat fluxes is generally very good, but the scintillometer tends to underestimate the sonic fluxes. For the momentum fluxes the scatter is much larger and the low bias of the scintillometer is even stronger (not shown here).

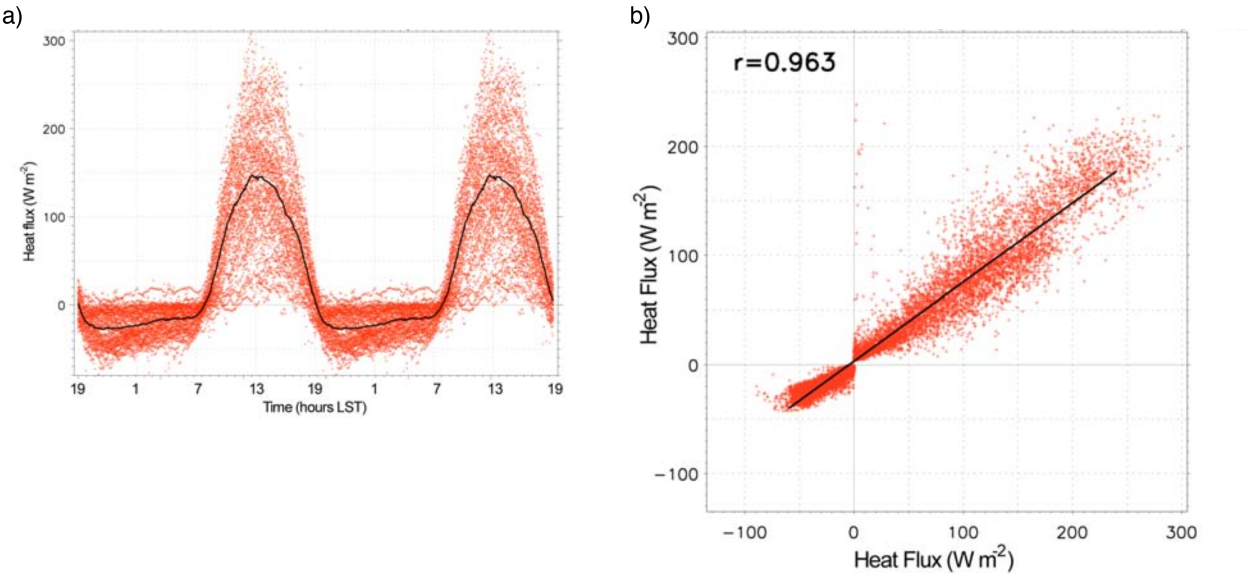

Fig. 4: Typical diurnal heat fluxes measured with the RM Young sonic anemometer (a) at site A during 2008 and comparison of these eddy-covariance heat-flux data with scintillometer observations (b).

The mean wind speed, wind direction and vertical velocity components (Fig. 5) measured with the four CSAT sonics on the 15-ft tripod deployed on the NWC roof clearly show the recirculation patterns that develop whenever the sensors are downwind (northerly winds) or upwind (southerly winds) of the roof structure seen in Fig. 3. For both cases strong vertical wind sheer is observed with the winds at the lower levels being almost opposite to the upper level winds. For southerly winds, the wind speeds at the upper tripod levels exceeded the 10-m level winds at the Norman Mesonet site, but for all other wind directions the roof level winds were significantly lower despite being measured ~30 m AGL. The turbulent flow properties have also been analyzed and will be included in the presentation.

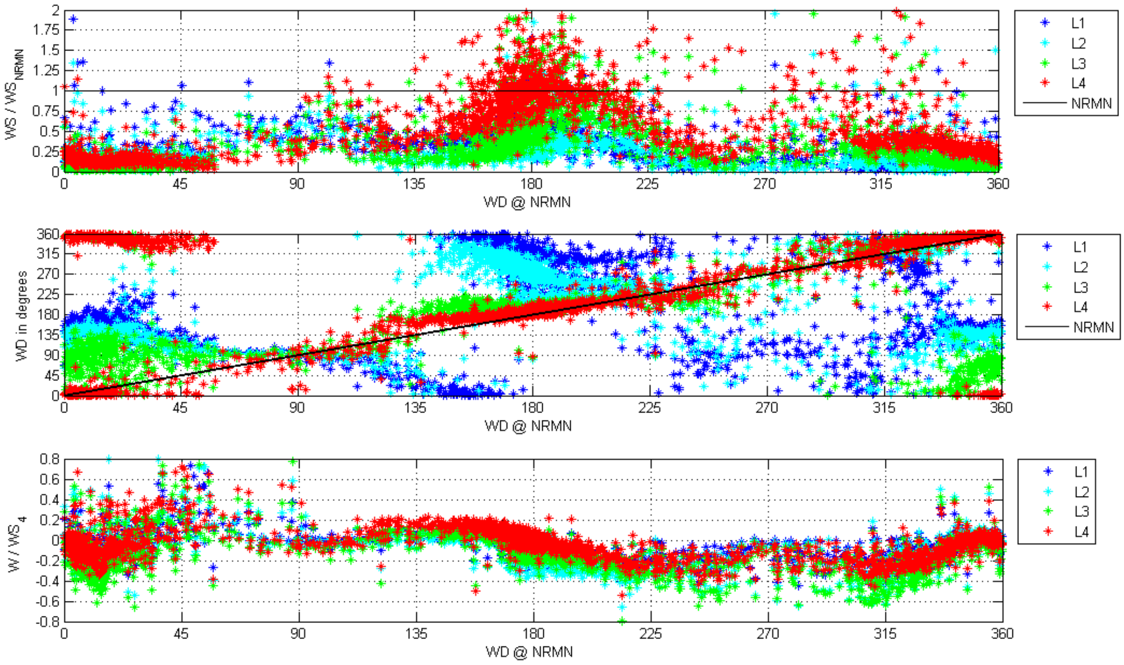

Fig. 5. Comparison of mean wind speed WS, wind direction WD, and vertical velocity component W measured at the four levels of the CSAT tripod. All data are plotted as a function of the wind direction measured at the Norman Mesonet site (NRMN). The wind speeds are normalized by the wind speed measured at the Norman Mesonet site, the vertical velocity components W are normalized by the value of W measured at the top tripod level (L4: 5 m above roof level).

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