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Challenges and results from conducting eddy covariance observations in areas of tall buildings

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1. Introduction

The urban growth rate in eastern China is much faster than the world average since China's reform and opening up policy in the late 1970s (Zhao et al., 2006). Alteration of the surface characteristics and of the atmosphere leads to modification of the urban surface energy, mass and momentum exchanges, which in turn results in the creation of typical urban climates like the urban heat island and extreme events. Therefore, understanding of interactions between the surface and the atmosphere is essential for mitigating urban climate effects.

The objective of this study is to investigate the diurnal and seasonal variability of radiation, surface energy and carbon dioxide exchange from a densely built-up, tall building area in subtropical Shanghai using a full year measurements.

3. Methods

3.1 The site

Shanghai (Fig. 1), with a population near 24 million (Shanghai Municipal Statistics Bureau, 2011), is the economic, financial, shipping and trade center of China. The measurement site located in Xujiahui (XJH, 31.19 °N, 121.43 °E), is at the headquarters of the Shanghai Meteorological Service. The densely built-up commercial and residential area (Fig. 1), is similar to large parts of central Shanghai.

The micrometeorological instrumentation was mounted on the top of a 25 m tower installed on the roof of a 55 m high building which houses part of the Shanghai Meteorological Service at Xujiahui (Fig. 1). The main sensors are thus, 80 m above ground level (m agl).

An in-situ, open-path infrared absorption gas analyzer integrated with a three-dimensional sonic anemometer (IRGASON, Campbell Scientific) was used. The infrared gas analyzer measured fluctuations of water vapor and carbon dioxide. The EC signals were sampled at 10 Hz by a CR3000 (Campbell Scientific) datalogger. A net radiometer (CNR4, Kipp & Zonen) measured the four components of net all-wave radiation. A Vaisala HMP155A temperature and relative humidity probe measures air temperature and relative humidity. The turbulent fluxes and statistics were calculated and corrected using the software package EdiRe (Moncrieff 2006) written by Robert Clement, University of Edinburgh.

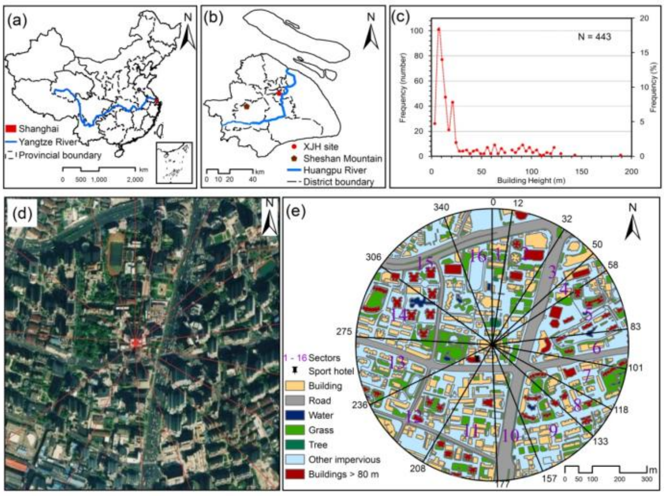

Fig. 1 Location of (a) Shanghai in China; (b) study site Xujiahui (XJH); (c) height (storeys) and number of building within 500 m of the XJH site; (d) aerial photograph of the study site (red cross: tower location); (e) land cover map (500 m around XJH site) with 16 wind sectors indicated.

3.2 Turbulent characteristics

The distribution of the C_D by wind direction has some correlation with building height. This influence can also be seen in the distribution of the normalized longitudinal wind velocity standard deviation (σ_u/u^*) and the lateral turbulence intensity (σ_v/U) by wind direction.

Analysis of the drag coefficients by wind sector and stability provides one way to identify the wind sectors most likely to yield fluxes from the inertial sub-layer, representative at the local scale, and those from the roughness sub-layer (RSL), representative of the micro scale. The five sectors (1, 2, 11, 13, 16) with the lowest u^*/U are those most likely to have measurements above the RSL (i.e. local-scale). In contrast, the 11 other sectors, which had larger values, indicative of turbulence caused by roughness elements (individual buildings) within the RSL, are more likely to have yielded measurements within the RSL. The subsequent analyses presented in this paper, are stratified into these two groups.

3.3 Radiation

All four components of the radiation balance were observed. The daytime maxima of incoming shortwave radiation ranges from about 600 W m^{-2} in winter to 950 W m^{-2} in summer. Daily maxima of the reflected shortwave radiation ranges between 80 W m^{-2} in winter and 150 W m^{-2} in summer.

3.4 Characterization of the local scale fluxes

The seasonal median hourly peaks of sensible heat flux Q_{HL} occurred in the early afternoon (Fig. 2), and remained positive throughout the year, except for a few small negative median values in the early morning during autumn.

The seasonal median hourly latent heat flux (Q_{EL}) also remained positive throughout the year. The winter time median values were much smaller than for the other three seasons, with daily peak values (25.9 W m^{-2}) only about half values in spring (48.7 W m^{-2}). The median diurnal peaks in summer and autumn were very similar.

The seasonal carbon dioxide fluxes (F_{CL}) exhibited two diurnal peaks in all seasons. These were more distinct in spring and summer (Fig. 4). The morning F_{CL} peak median values were around 16, 23, 16, 22 µmol m^{-2} s^{-1} for winter, spring, summer and autumn, respectively. The stronger evening CO_2 emission peak was about 24, 29, 29, 37 µmol m^{-2} s^{-1} in winter, spring, summer and autumn, respectively.

3.5 Characterisation of the micro-scale fluxes

Analysis of data from the 11 other sectors data, those interpreted as micro-scale fluxes (subscript m), reveals that the median daily peaks of sensible heat flux Q_{Hm} occurred in the early afternoon. The seasonal pattern of Q_{Hm} was similar to that of the local scale fluxes but the median values were much large (Fig. 3).

The hourly median Q_{Em} is positive throughout the year, with lowest values in winter and highest in summer.

For these sectors, the data also show that this densely built area of Shanghai site was a net source of CO_2 with positive monthly median hourly F_C throughout the year. Similar to the local scale CO_2 flux, transportation emissions dominate the micro-scale.

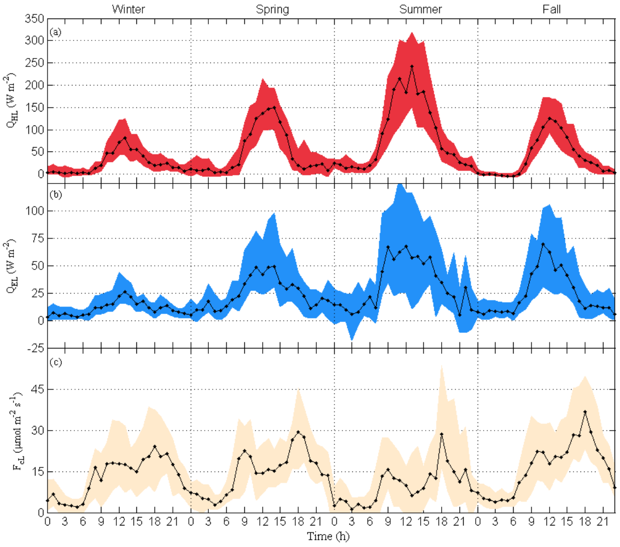

Fig. 2: Median diurnal variation of local scale turbulent (a) sensible heat (b) latent heat and (c) carbon dioxide fluxes for each season: winter (DJF), spring (MAM), summer (JJA)

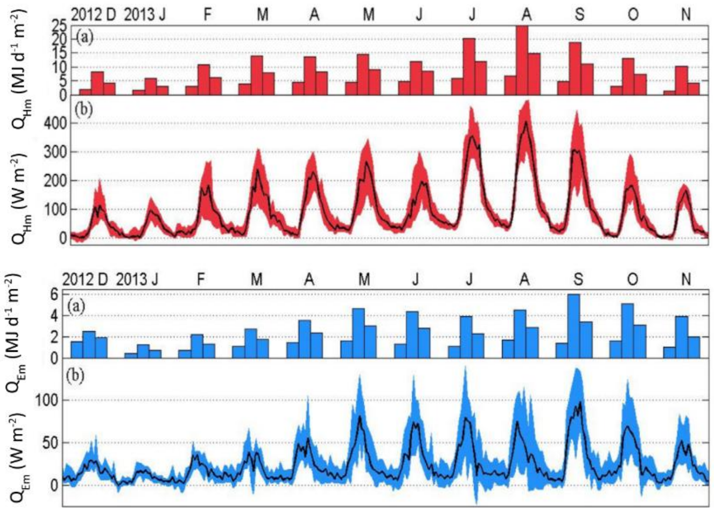

Fig. 3: Monthly micro-scale sensible heat fluxes (Q_H) and latent heat flux (Q_E) at Xujiahui (12/2012–11/2013): (a) mean flux for night (left bar), day (middle bar) and total 24 h (right bar) ; (b) median (line) diurnal patterns with inter-quartile range (shading); (c) temporal variation of average sensible heat fluxes (Q_H) (2 week intervals) by time of day.

4. Conclusions

This paper reports results from an analysis of eddy covariance turbulent heat, water and carbon dioxide fluxes for a year (1 December 2012 to 30 November 2013) for a central business district (CBD) area of Shanghai, China.

Based on analysis of drag coefficients, fluxes were stratified by wind direction and interpreted in terms of those representing local-scale and those micro-scale fluxes.

At 31.19 °N latitude of Shanghai, the annual range of incoming short-wave radiation is much smaller than for more northerly European cities.

Local scale median daily peaks of sensible heat flux occurred in the early afternoon. Latent heat fluxes were smaller but not negligible. The daily median Q_{EL} remained positive throughout the year, with variations driven by rainfall and available energy. Patterns of micro-scale fluxes were similar, but the magnitude of Q_{Hm} was much larger.

This dense urban site was a net source of CO_2 for the whole year, dominated by of traffic emissions with two prominent peaks in the morning and evening rush hours. The evening peak was much stronger than the morning peak. Vegetation at the site does offset some CO_2 emissions, although the uptake effect is relatively small.

For further research, we’ll seek more reasonable method to divide micro and local scale fluxes.

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