Observational study of the urban heat island and the urban impact on precipitation of Hamburg

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Abstract

Both urban heat island (UHI) and urban impact on precipitation (UIP) are investigated for the city of Hamburg. For this purpose up to 7 temperature stations and up to 45 precipitation stations in the metropolitan area of Hamburg are statistically analyzed. The results show that Hamburg exhibits an average UHI of up to 2.3 K based on minimum temperatures. However, the annual cycles differ from station to station. Using a new method to detect the UIP a significant downwind enhancement of precipitation is found for almost half of the stations. Idealized model studies are performed to identify possible causes for this enhancement and for missing enhancements.

Key words: urban heat island, urban impact on precipitation, observations

1. INTRODUCTION

Urban areas impact the temperature, which results in the so-called urban heat island (UHI). Temperatures in large cities can be up to 10 K higher than in the surrounding rural areas (Yow, 2007). In general, the highest temperature differences occur for calm cloudless days 3 to 5 hours after sunset (Oke, 1987). In addition to the diurnal cycle the UHI exhibits an annual cycle as well. Most cities in the mid-latitudes have their UHI maximum in the warm season and the minimum in winter (Arnfield, 2003). In addition to the impact on the atmospheric temperature urban areas have an impact on precipitation as well. Studies show that cities can lead to a downwind enhancement of precipitation and primarily on convective precipitation (e.g. Shepherd, 2003; Van den Heever and Cotton, 2007). One reason for this enhancement is the UHI, which leads to an updraft downwind the city. In addition, the higher roughness of urban areas results in a convergence zone upwind of the city and the urban aerosols can act as additional cloud condensation nuclei. For the green city Hamburg with its 1.8 Mio inhabitants and its maritime climate Schlünzen et al. (2009) investigated both the UHI and UIP.

2. URBAN HEAT ISLAND OF HAMBURG

An analysis of observations in and around Hamburg shows that Hamburg exhibits an average UHI of 0.6 - 1.2 K based on mean temperatures (Schlünzen et al., 2009). However, the UHI is not only defined as the mean temperature difference, but also as the difference between night-time temperatures. Figure 1a shows the differences between the minimum temperatures at urban and suburban stations and a rural station, Grambek. Grambek is a small town (400 inhabitants) in situated 37 km from downtown Hamburg. The minimum temperature differences (0.9 - 2.3 K) are larger than the mean temperature differences as it was expected. In addition, the differences of the maximum temperatures are calculated (Figure 1b). The values of -0.1 - 0.3 K are in the range of measuring errors. These results fit well with the theory of the diurnal cycle of the UHI with a maximum of the UHI at night and minimum during the day (Oke, 1987).

The annual cycle of Hamburg’s UHI differs depending on the temperatures used (min, max, mean) and from station to station. The latter is probably caused by local effects of the close surrounding. For the minimum temperature differences most of the stations show a maximum in the warm months and a minimum in summer as it was found for other cities. As found for other cities, the UHI of Hamburg depends on wind speed (Schlünzen et al., 2009). The best fit is the inverse square root as it was proposed by Oke (1973). However, it explains only a small part of the UHI-variance.

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3. URBAN IMPACT ON PRECIPITATION FOR HAMBURG

The detection of the UIP with observations is more difficult than the detection of the UHI. Schlünzen et al. (2008) developed a new method to detect the UIP by using daily precipitation and wind direction values. Applying this method a significant downwind enhancement at almost half of the analyzed stations (primarily north and southeast of Hamburg) was found (Figure 2a). The magnitude of this enhancement ranges from 5% to 20%. However, dependence of enhancement on distance is not found (Figure 2b). Some stations show a downwind reduction in precipitation. This could be caused by orographic effects due to hills (up to 150 m) south of Hamburg. This effect could counteract the urban effect. To proof this explanation and to find possible causes for the significant enhancement model studies are performed.

4. IDEALIZED MODEL STUDY

In a first step, Hoffmann (2009) performed idealized 2D model studies with the non-hydrostatic mesoscale model METRAS (Lüpkes and Schlünzen, 1996). For this study a convective summer day was simulated (horizontal resolution 1 km) for an idealized city (30 km) surrounded by meadows. As it was expected for this model setup convective cells develop, which produce heavy precipitation downwind of the city (Figure 3, black line). Sensitivity studies that separately investigate effects thermodynamic properties and roughness reveal for a flat model domain that both, the thermodynamic differences and the higher roughness of the city contribute to the precipitation maximum downwind of the city. To investigate the impact of orography a small hill (30 m) 10 km upwind the city is implemented in the model area. For this model run stronger cells develop downwind the city as a result of orographic lifting. On this account the whole precipitation distribution is shifted upwind (Figure 3, red curve). Therefore, for this specific model setup the orographic effect of a small hill is stronger compared to the urban effect. However, the results of such model study should be interpreted with caution because they depend strongly on the model resolution.
Figure 3: Precipitation distribution for the reference model run (black curve) without hill and for the sensitivity study with a 30 m hill upwind of the city (red curve). The dashed lines indicate the city boundaries and the dotted lines the half-width of the hill.

4. CONCLUSIONS

Data analyses for Hamburg reveals that the urban area has a typical UHI as found for other cities. It seems that the near surrounding of a station has an impact on the measured data and thus of the spatial and temporal distribution of the UHI. The UHI of Hamburg depends on the wind speed (inverse square root), but only a small part of the UHI-variance can be explained with this relation. Other factors such as cloud cover shall be included in multivariate analyses. Hamburg shows a significant UIP with downwind precipitation enhancement for specific wind directions. The downwind enhancement is significant at almost half of the stations and ranges from 5% to 20%. One explanation why the other stations do not show a significant enhancement or even a reduction are orography effects that counteract the urban effect. An impact is found for a sensitivity study with a hill (max. height 30 m) in an idealized 2D model. Idealized studies also show that both, the UHI and the higher roughness of the city could be responsible for the downwind enhancement. Due to the complexity of the precipitation processes and the resolution dependency of the model results further studies with a more realistic model setup will be performed.

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References


