VERIFICATION OF URBAN-INDUCED PRECIPITATION FOR A CENTRAL EUROPEAN MAJOR CITY

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Abstract
The effects of urban heat island and of increased surface roughness over cities are plausible causes for the occurrence of urban impact on the amount and spatial distribution of rain and snow. An investigation of urban influence depending on the weather type is carried out in Berlin (Germany) with daily precipitation amounts for a period of 50 years. A lee ward increase of convective rain could be confirmed. A case study is presented, that illustrates the idea for an urban anomaly in connection with frontal precipitation events. Therefore spatial interpolated precipitation data are averaged along an adaptive climatological analysis transect and classified according to the weather type.

Key words: urban climate, precipitation, Berlin (Germany), ACAT

1. INTRODUCTION
Lowry (1998, p. 511). cited „Atkinson’s summary of 1968 Brussels symposium referred to rainfall: ‘The problem is as much to prove the influence of towns as to explain it’“. Investigations on urban modified precipitation, carried out for several cities, were mainly focused on the urban lee anomaly through enhanced convective events e.g. Shepherd, Pierce et al. (2002), Carra and Collier (2007) and Diem (2008). We pursue an approach to identify the urban influence on precipitation depending on different weather types, with an emphasis on frontal precipitation. The research area is located in Central Europe around Berlin, where spacious lifting of air masses at synoptic fronts, predominantly approaching from west and northwest, is the most important process to generate precipitation (Hendl 1995). In summer also convective lifting plays a roll on the formation of rain. A promoting criterion for the research on this topic is the availability of the big pool of precipitation data in Berlin.

The city of Berlin, the biggest city in Germany, has good preconditions to analyse urban impact on precipitation. Its administrative borders have not changed since 1920. However the built-up areas grew after the destruction during world war 2nd. Growth of suburbs started only since the reunification. There are no big towns all around neither big water bodies in the neighbourhood (cf. Map 1). The area under investigation covers Berlin and its surroundings within a circle of 120 kilometres in diameter, three times the diameter of the city itself. The maximum difference in elevation in the research area equals 150 metres, it stretches over relieve of ground moraines and glacial valleys between two final moraines of the last ice age.

2. DATA BASE AND DATA PROCESSING
Following steps of data preparation were carried out:
- create daily maps of precipitation and precipitation anomaly (defined below),
- specify the prevailing wind direction for each day and
- define the weather types.

The analysis procedure includes:
- categorisation of days according to the weather types,
- calculation of climatologic parameters within an adaptive climatological analysis transect (ACAT) which crosses the city centre parallel to the mean daily wind direction (cf. Map 2) and
- apply basic statistical analysis on these values.

For the analysis a dataset of daily precipitation sums at 160 measurement sites over a period of 50 years (1951-2000) was compiled. The data were measured by the German Weather Service (Deutscher Wetterdienst), the company Berlin Waterworks (Berliner Wasserbetriebe), the Berlin Forest Administrations (Berliner Forsten) and the Meteorological Institute of the Free University Berlin. The wind data of the synoptic station Berlin Tempelhof, a former airport inside the city, were taken as representative description of the approaching flow. The categorisation of the weather types was based on observations of precipitation type in Tempelhof together with information about frontal passage plus air masses extracted from the ‘Berlin weather map’ (Vogt 2000) and synoptic weather situation according to Hess/ Brezowsky (Gerstengarbe and Werner 2006).

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To get an area-wide gridded cover of precipitation amount the data were interpolated with a ‘quadrant method’ based on inverse distance interpolation. This method compensates the unequal occurrence of stations. The precipitation in every grid is calculated from the nearest station within four directional sectors of 90° (Pfützner, Lahmer et al. 1997). The precipitation values of the calculated grids were further averaged within the elements (10 km x 10 km) of a wind parallel adaptive climatological analysis transect. The ACAT thus includes upwind, urban and downwind regions (cf. Map 2). This concept was chosen to reduce the spatial information into linear distribution and to avoid artefacts. The width of the ACAT was chosen adequately narrow to minimise the smoothing effect on the spatial differences while calculating mean precipitation within the transect elements, because of the high variability of wind direction and precipitation pattern.

Map 1: Land cover/land use classes derived from CORINE in the research area
- boundary Berlin
- research area
- altitude [m]
  - 40
  - 60

Map 2: Precipitation distribution sample, Berlin and surroundings at 20th of March 1991
ACAT angle 250 degree
- centre of AOI
- boundary Berlin

ACAT precip. [mm]
- 0.0 - 1.8
- 1.8 - 2.1
- 2.1 - 2.4
- 2.4 - 2.7

AOI precip. [mm]
- n.n - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
3. RESULTS AND DISCUSSION

The mean annual precipitation amount shows a coherent spatial minimum from the centre to the south of the city. There are distinctive maxima in NW, SW and SE of Berlin. In relation between the prevailing wind directions from west and south a wide-stretched maximum occurred in lee of the city. The mean depth of precipitation in the hydrological winter half-year appears extensively harmonised with decreasing values in southern direction. The spacial variabilities were similar in both half-years, but in the summer half-year the rain distribution had stronger structuring and increasing values in the eastern and southern parts.

To compare the typical decadal patterns of the mean precipitation amount independent of the humidity level the anomaly of the mean precipitation sums to the precipitation mean of the investigation area was calculated. The identifiable maxima in the western areas of Berlin do not reveal significant inter-decadal differences. The positive anomaly eastward of the city exhibited an increase in dimension and intensity. The precipitation in this area acted contrary to the widespread observed trend in the research area. This indicates a definite bias to an amplifying contrast between the metropolitan area and the area that might have urban-affected rainfall. Especially this urban lee maximum could result from superposition of orographic enhancement on the luv exposition of the Barnim Plateau and urban enhancement of convective rain in the downwind region. Schlaak (1972) as well as Malberg and Frattesi (1990); declared this overlapping condition in the eastern parts but on the other hand mainly orographic determined higher precipitation values at the western border of Berlin.

To illustrate a situation with frontal precipitation an example of a randomly chosen weather phase of zonal circulation with frontal weather characteristics is shown in map 2 and figure 1. On 20th March 1991 a warm front passed from West with moderate rain rates and wind from WSW (250 degree). A typical rain day with maximal measured precipitation amount of 6,4 mm is shown. Along the ACAT values are getting higher from upwind surroundings to the wind facing areas of the city. The values decrease before increasing again at the lee side of the city synchronised with the terrain rise. Three days later at the 24th of March 1991 light rain fall with no significant change of air masses but with opposite wind direction (060 degree). A maximum could be recognised at the eastern ascent to the Barnim Plateau and in front of the city. An intense precipitation event linked to a warm front with West wind occurred at 1st of April 1991. In this direction the wind moves the air over slighter relief amplitude. Only a pronounced luv and urban maximum appeared. In figure 1 the relations between upwind, urban and downwind regions at this three days are exemplified presented.

Summarising these examples a luv maximum independent of the wind direction could be observed referring to the passage of frontal weather systems in the research area. For Detroit-Windsor in Canada Sanderson and Gorski (1978) described a maximum of precipitation amount at the windward side of the city, too. The authors attribute this effect to the turbulence resulting from the high surface roughness and thermal convection. With an anemometer network in New York City Loose and Bornstein (1977) figured out that the frontal movement during non heat-island periods retarded probably due to the increased surface frictional drag. With his research Stulov (1993) confirmed an urban luv maximum of precipitation because of fast moving cold fronts and occlusions are slowed over the Moscow. Belger (1940) already mentioned decelerated front movement in Berlin especially on the reverse side of the rain field to rise rain sum over the metropolitan area.

The linkage between the spatial distribution of precipitation and the altitude in Northeast Germany was assessed by Hendli (1969) with surprise because the differences in elevation are rather small. The shown examples support the relevance of even small orographic features on precipitation distribution. The strongest urban effect on thermal convection was recognised in interaction with the minimal orographic lifting. Hupfer and Chmielewski (1990) declared the urban maximum does not result from additional urban induced precipitation but also due to redistribution of the precipitation. This aspect indicates urban-affected rainfall distribution also for the minimum of precipitation amount in the central parts of Berlin. Anthropogenic reasons for the inner city minimum of precipitation are not yet discussed.

4. SUMMARY AND CONCLUSION

This paper examines the distribution of precipitation amount in Berlin and its surrounding areas along wind-adaptive climatological analysis transects. On days with frontal passages relative maxima of precipitation are induced at the windward parts of the metropolitan area. Also a geographic link to orographic influence on the spatial precipitation structure in North German lowlands was confirmed. Beside the published urban lee anomaly through intensification of convective precipitation events an indication for an urban caused modification of advective precipitation appeared with space-oriented, statistical analysis in the research area. Process modelling will be necessary to uncover and explain the exact physical mechanisms responsible for the rainfall enhancement beyond the urban boundary layer.

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2 The Barnim Plateau, a Vistula-stage ground moraine plate, is located in the northeastern part.
Figure 1: Wind-adaptive climatological analysis transects of mean terrain elevation and mean precipitation amount of advective rain events in Berlin and its surroundings

References