URBAN CLIMATOLOGY

VI. Precipitation in urban areas

Paper to read

Asia-Pacific J. Atmos. Sci.
DOI:10.1007/s13143-014-0016-7

REVIEW

Urban Impacts on Precipitation

Ji-Young Han[1], Jong-Jin Baik[2], and Hyunho Lee[2]

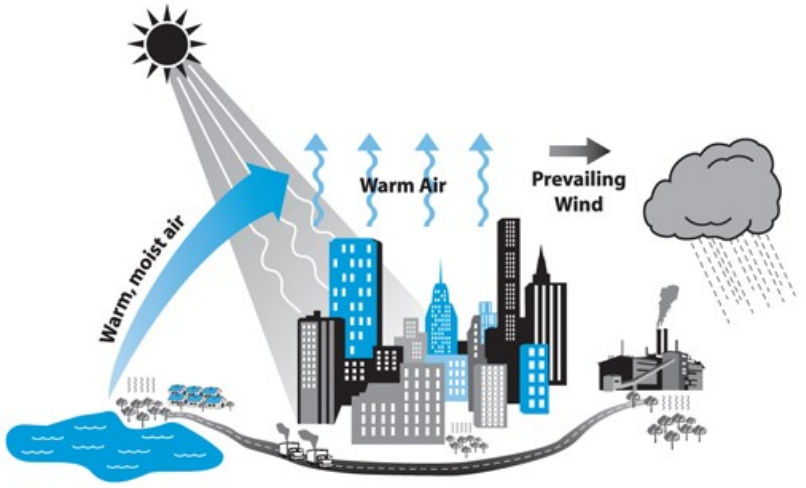
[1]*Korea Institute of Atmospheric Prediction Systems, Seoul, Korea*
[2]*School of Earth and Environmental Sciences, Seoul National University, Seoul, Korea*

(Manuscript received 27 August 2013; accepted 4 November 2013)

https://is.muni.cz/auth/el/sci/jaro2021/ZX601/um/67875456/06_Urban_impacts_on_precipitation.pdf

6.1 Urban precipitation

Conceptual model



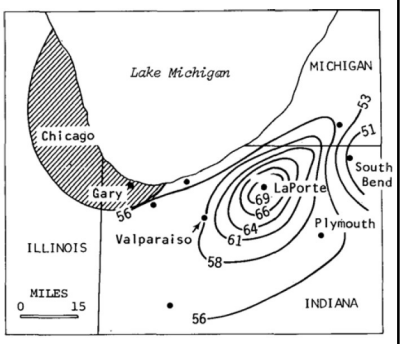
Modification of precipitation regime in urban environment; a general model adopted from http://www. ucar.edu/communications/staffnotes/0603/cities.shtml)

Urban precipitation

https://kids.frontiersin.org/articles/10.3389/frym.2018.00038

- Precipitation is not continuous in time and space
- It is hard to separate urban influence from others (position, relief, …)
- Closely related to meteorology and climatology of clouds
- Precipitation regime si modified by wind direction
- There can be different effects on convective precipitation and atmospheric fronts (advection systems)
- It is not clear whether urban environments initialize new precipitation events or whether they just intensify existing precipitation
- Empirical studies sometimes show contradictory results

Urban precipitation



- Precipitation anomaly in La Porte, USA (Changnon 1968)
- METROMEX project (St. Louis, 1971-1975)

- Most studies proved that precipitation totals in cities and in their leeward side are 5–15% higher compared to rural areas
- The summer is the time of maximum urban effect on precipitation (in other seasons effects may be quite different)
- Some studies show no local effect on precipitation or even deficits in precipitation that accompany urbanization

Urban precipitation

Warmer urban climate (UHI) positively impacts convection that is supported with numerous processes in urban environment (Shepherd, 2005):

- sensible heat flux enhancement
- urban heat island-induced convection
- the availability of more cloud condensation nuclei
- urban canopy alteration
- disruption of precipitation systems
- increased surface roughness convergence.

The urban heat island can induce or modify local flow/circulation.

Larger urban surface roughness can, however, disrupt or bifurcate precipitating convective systems formed outside cities while passing over the cities.

Such urban-modified precipitating systems can either increase or decrease precipitation over and/or downwind of cities.

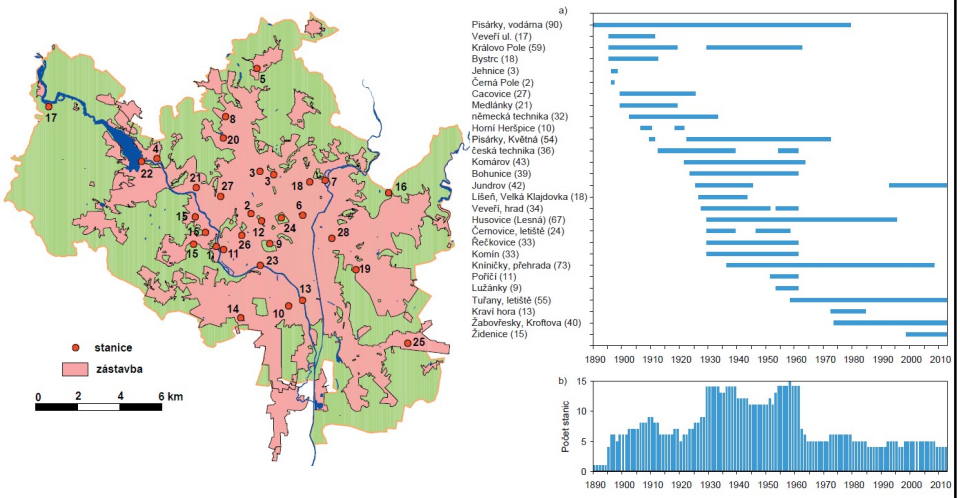
Urban precipitation

Precipitation regime in urban areas is modified due to **three different effects**:

- **thermal effect** (UHI causes larger surface sensible heat flux in urban areas than in surrounding rural areas; stronger convection in summer -> more showers and thunderstorms)
- **mechanical effect** (higher roughness -> lower velocity of atmospheric fronts -> more precipitation)
- **pollution effect** (more condensation nuclei)

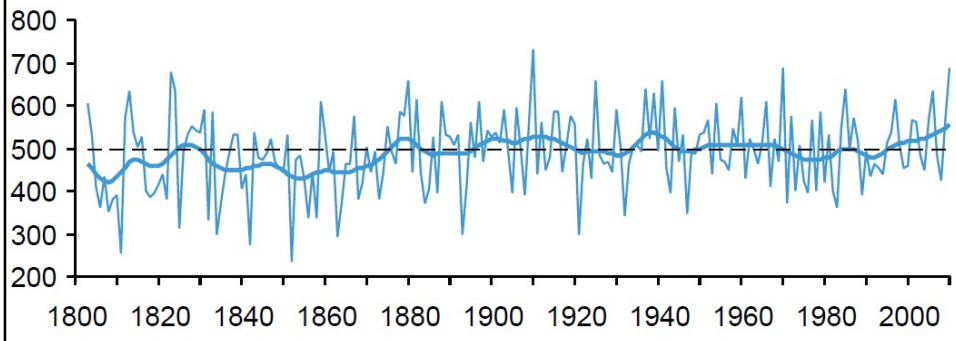
- Due to UHI there is lower proportion of precipitation in the form of snow
- Ice particles of anthropogenic origin -> condensation nuclei for stratus clouds -> more frequent light snowfall in city

6.2 Observational evidence (precipitation regime in Brno)



Network of stations in Brno area and its temporal development in the period 1890–2012: a) period of measurements; b) number of stations

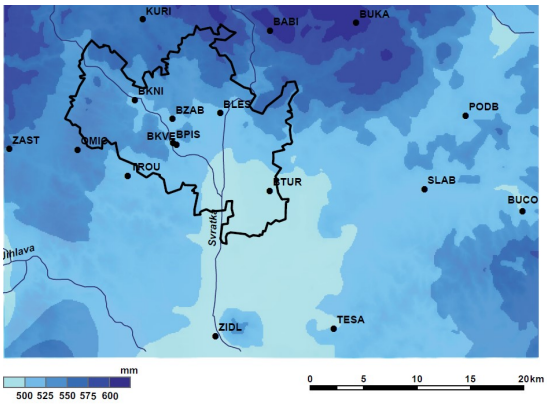
Long term variability of precipitation in Brno



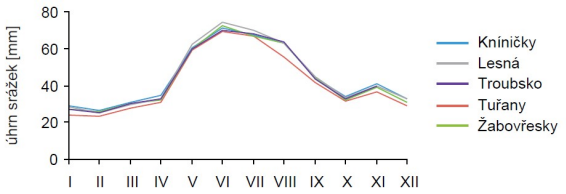
Fluctuation of mean annual and seasonal precipitation totals in Brno in the period 1803–2010; annual values smoothed with Gaussian filter for 20 years are in bold and horizontal line is the mean for 1961–2010 reference period

Precipitation regime in Brno

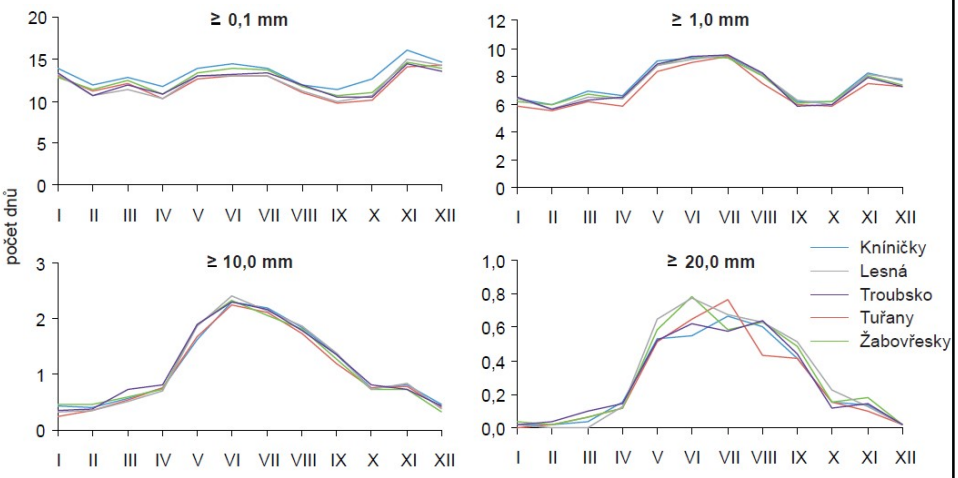
Spatial distribution of mean annual precipitation totals in Brno region in the period 1961–1990



Comparison of mean annual variation of precipitation at selected stations in Brno in the period 1961–2010

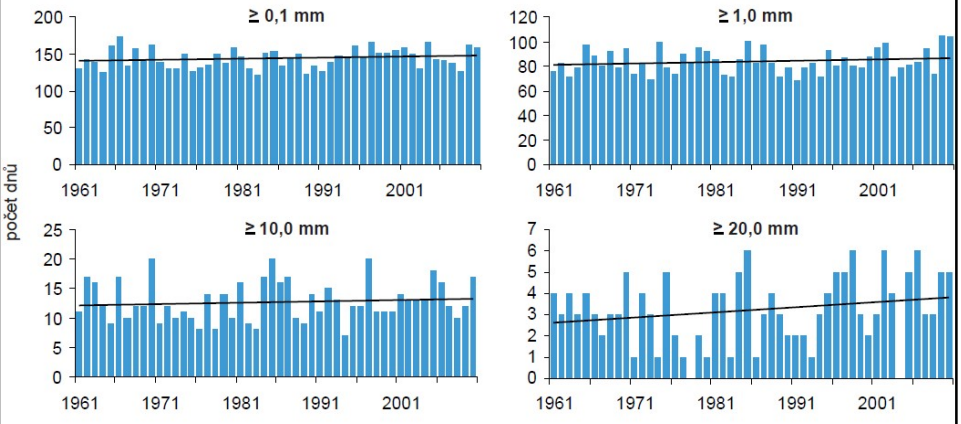


Number of rainy days



Variability in annual number of days with precipitation totals ≥ 0.1, 1.0, 10.0 and 20.0 mm including linear trends at Tuřany station, period 1961–2010

Number of rainy days

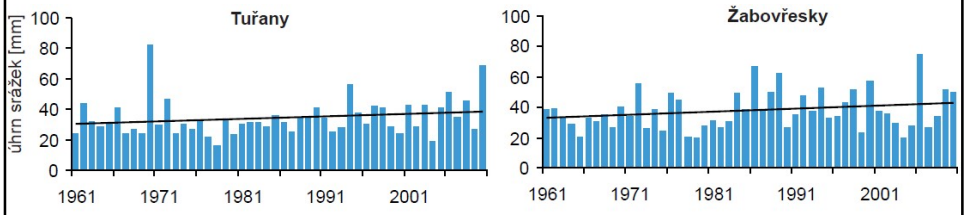


Variability in annual number of days with precipitation totals ≥ 0.1, 1.0, 10.0 and 20.0 mm including linear trends at Tuřany station in the period 1961–2010

Maximum daily precipitation totals

Maximum daily precipitation totals and assessment of mean return periods at selected stations in Brno in the period 1961–2010

stanice	max. denní úhrn srážek	datum výskytu	doba opakování (roky)
Brno-Kníničky	88,5	15.6.2002	65,4
Brno-Tuřany	82,1	16.6.1970	145,7
Brno-Žabovřesky	74,9	7.8.2006	76,5
Troubsko	70,8	23.7.2010	46,2

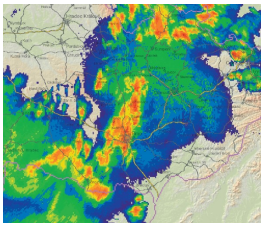


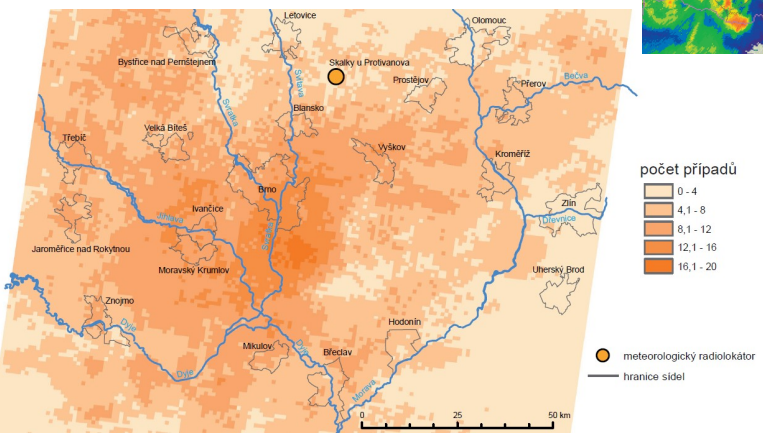
Variability of maximum daily precipitation totals including linear trends at two stations in Brno in the period 1961–2010

Conclusion: there are several signs that the precipitation regime become more extreme

6.3 Urban Precipitation Radar Observations

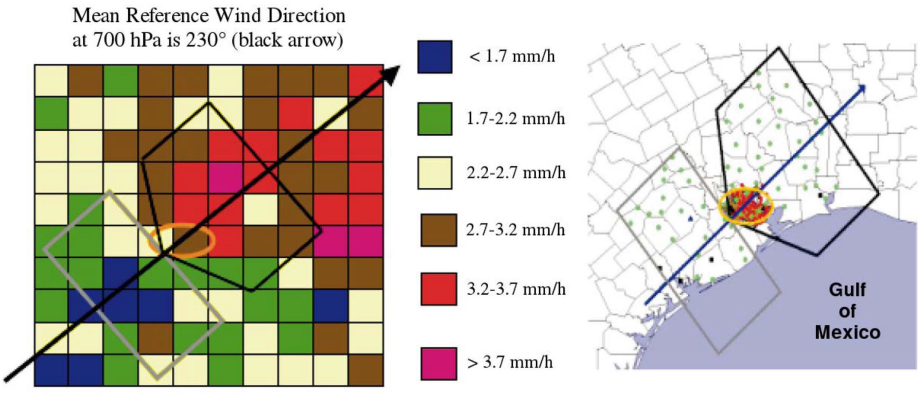
Weather Radar (Ground located)





Frequency of the above-average maximum radar reflectivity in Brno region composed from 26 situations with extreme convection at Tuřany station in the period 2000–2007

Spaceborne Rain Radar on the TRMM Satellite



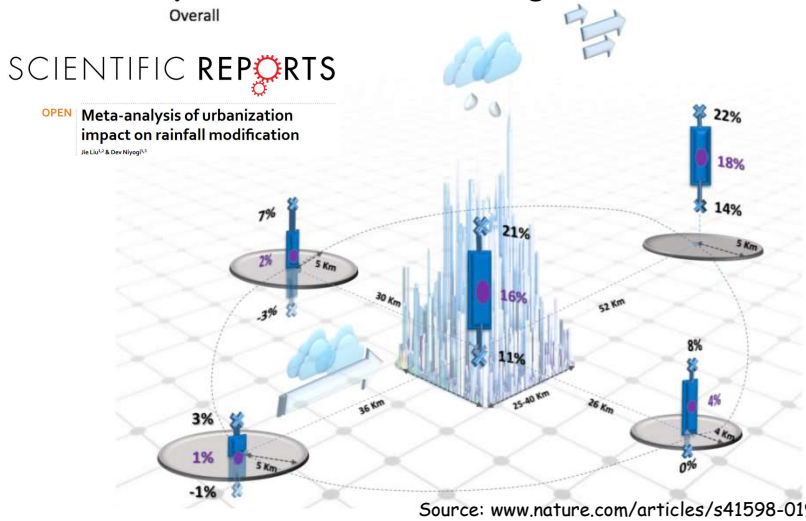
TRMM PR at 0.5 Degree with Coordinate System

Houston Area with Coordinate System and Gauge Locations

Mean annual distribution of the Tropical Rainfall Measuring Mission (TRMM)-derived rainfall rates from January 1998 to May 2002 (excluding August 2001). The oval is the approximate Houston urban zone. The vector indicates the mean annual 700-hPa wind direction over the Houston area. The pentagon-shaped box is the downwind urban-impacted region, and the rectangular box is the upwind control region. [after Shepherd and Burian (2003).]

6.4 Atmospheric fronts vs. strong convection

Overall

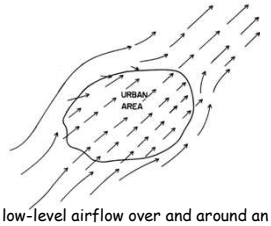


Source: www.nature.com/articles/s41598-019-42494-2.pdf

The bars indicate the sample standard deviation for the precipitation change, and circles correspond to the mean change in precipitation location. **On average, urban areas and the surrounding region experienced precipitation increases.** The largest signal noted in a number of studies, was prominently in the **downwind** region of the city and experienced the highest rainfall change: **18% increase on average**, (a range of 14 to 22% with one standard deviation). The distance over which these changes occurred (mostly increases in rainfall) is approximately 52 km downwind, and about 31 to 41 km upwind.

Urban precipitation at atmospheric fronts

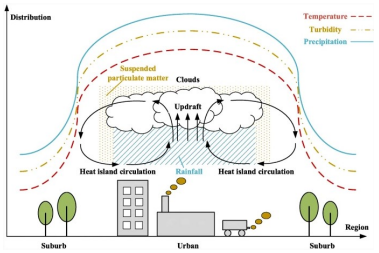
- **Cloud systems** crossing the city show the disruption of a frontal system passing over the city and the reshaping of the frontal system after crossing it.
- **Moving thunderstorms** with strong regional flows tend to bifurcate and move around the city due to the urban barrier effect in the New York City area



Schematic of low-level airflow over and around an urban area due to changes in surface roughness. (Cotton and Pielke 1995)

- Larger surface roughness in a city than in its surrounding rural area causes air approaching the city to **slow down** near the upwind city boundary and/or over the city.
- In addition, the air approaching a city tends to **divert around it** and the diverted air can converge on the downwind side of the city, yielding upward motion there.

Strong convection and thunderstorms



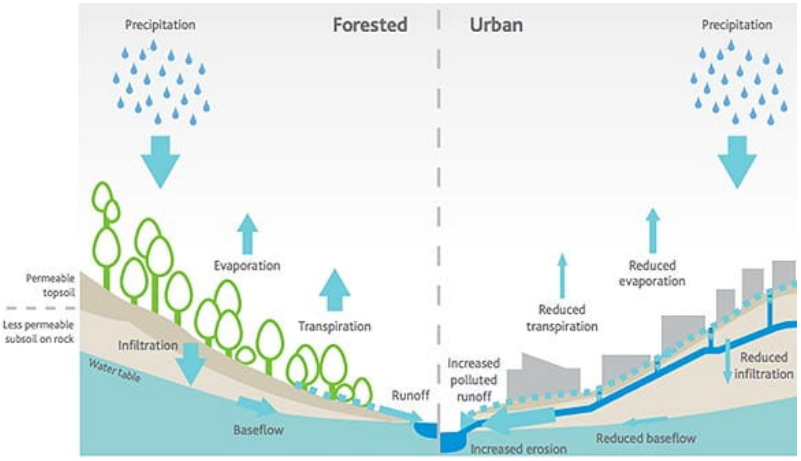
Source: https://jipr.springeropen.com/articles/10.1186/s43065-020-00003-0

Convective thunderstorms were initiated in urban heat island-induced convergence zones.

The rapid growth of moving storms passing over cities was observed in some major urban areas, such as in the London area (Atkinson, 1971) and the Chicago area

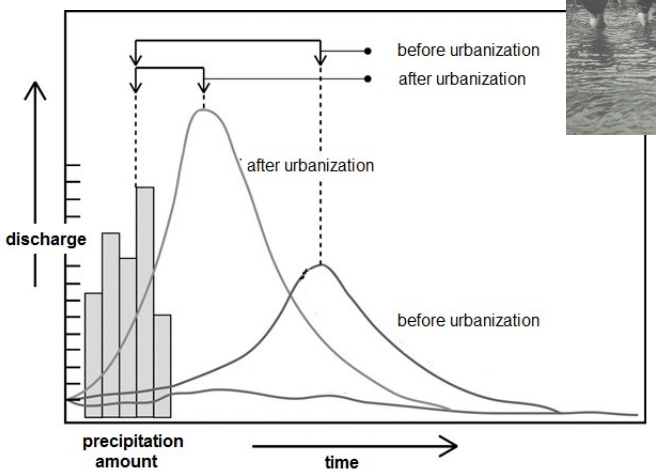
- It is not confirmed that roughness alone can initiate moist convection (or the roughness can play an important role in initiating moist convection)
- There is a possibility that updrafts produced by high-rise buildings in highly built-up urban areas can initiate moist convection

6.5 Water runoff in urban environment



Source: https://www.melbournewater.com.au/sites/default/files/forested-urban-stormwater.jpg

Water runoff in urban environment



Before and after urbanisation hydrograph (adopted from Christopherson 1997)

6.6 Final remarks and questions

Urban precipitation and Global warming projections

- Higher probability of occurrence of short-term extreme precipitation totals and flash floods
- Longer periods without any precipitation, higher probability of drought occurrence
- Non-uniform precipitation distribution during the year

1. What are the main impacts of changed precipitation regime on people living in cities?
2. How we can define extremity of precipitation regime?
3. What is the role of other factors such as relief, position, land use etc.?
4. How can be negative effects mitigated in urban-planning design?