URBAN CLIMATOLOGY

VI. Precipitation in urban areas

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Urban effects on precipitation: Do the diversity of research strategies and urban characteristics preclude general conclusions?

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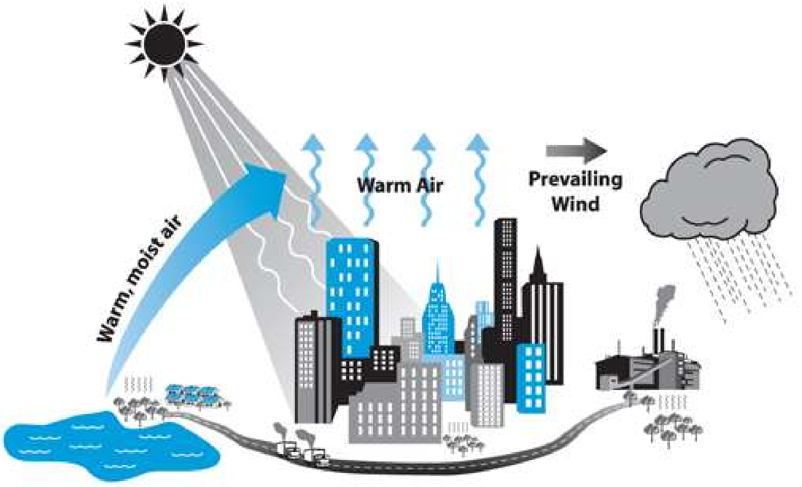
https://is.muni.cz/auth/el/sci/podzim2024/ZA311/um/67875456/06_Urban_effects_on_precipitation.pdf

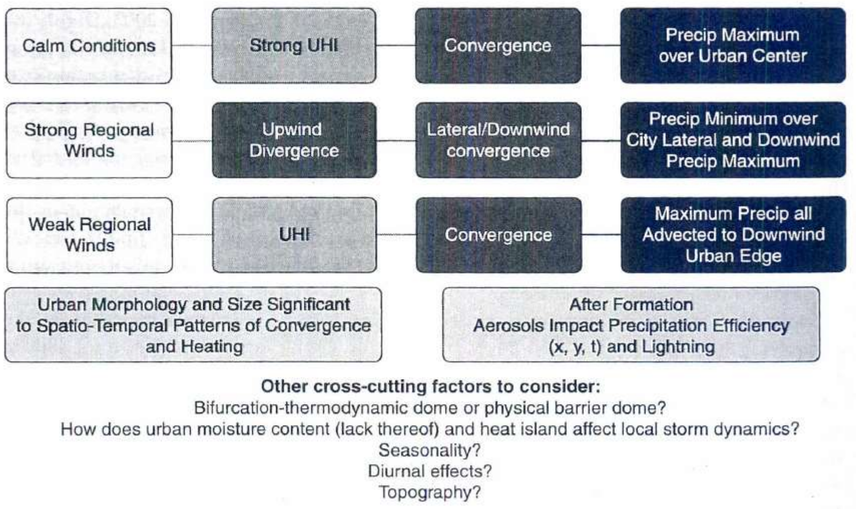
6.1 Urban precipitation

Conceptual model



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

Conceptual model II



Towards a conceptualization of the urban rainfall effect. Source: Original figure courtesy of R. Bornstein as adapted and presented in Shepherd (2013).

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

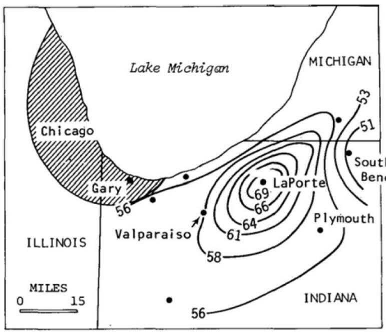
Typical features of urban climate

Table U2 Urban climate effects for a mid-latitude city with about 1 million inhabitants (values for summer unless otherwise noted)

Variable	Change	Magnitude/comments
Turbulence intensity	Greater	10–50%
Wind speed	Decreased	5–30% at 10 m in strong flow
	Increased	In weak flow with heat island
Wind direction	Altered	1–10 degrees
UV radiation	Much less	25–90%
Solar radiation	Less	1–25%
Infrared input	Greater	5–40%
Visibility	Reduced	
Evaporation	Less	About 50%
Convective heat flux	Greater	About 50%
Heat storage	Greater	About 200%
Air temperature	Warmer	1–3°C per 100 years; 1–3°C annual mean up to 12°C hourly mean
Humidity	Drier	Summer daytime
	More moist	Summer night, all day winter
Cloud	More haze	In and downwind of city
	More cloud	Especially in lee of city
Fog	More or less	Depends on aerosol and surroundings
Precipitation		
Snow	Less	Some turns to rain
Total	More?	To the lee of rather than in city
Thunderstorms	More	

(Landsberg 1981)

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

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

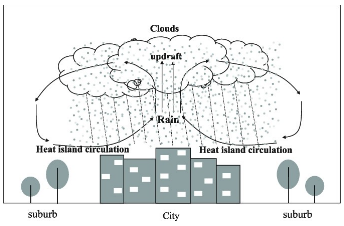
- **thermal effect** related to UHI formation
- **mechanical effect** related to higher roughness
- **pollution effect** related to more condensation nuclei

Processes of cloud formation, moisture sources, local wind systems as well as geography (topography) play an important role

Station measurements are insufficient, it must be accompanied with remotely sensed systems (satellite imagery, radar, lidar, ceilometer, etc.)

6.2 Thermal effect on urban precipitation

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

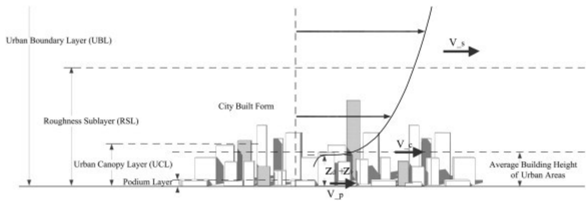


- urban heat island-induced convection
- higher instability of urban atmosphere
- sensible heat flux enhancement

Consequences:

- Stronger convection in summer -> more showers and thunderstorms)
- The urban heat island can induce or modify local flow/circulation
- Due to UHI there is lower proportion of precipitation in the form of snow

Mechanical effect on urban precipitation



- Higher roughness -> lower velocity of atmospheric fronts -> more precipitation)
- Higher roughness -> higher intensity of turbulence -> more precipitation

- Larger urban surface roughness can disrupt or bifurcate precipitating convective systems formed outside cities while passing over the cities.
- Urban-modified precipitating systems can either increase or decrease precipitation over and/or downwind of cities.

Polution effect on urban precipitation

- The availability of more cloud condensation nuclei in urban areas primarily influence **formation of clouds**
- Aerosol number, size, type and chemical properties initiate processes that may **enhance**, **suppress** or **delay** cloud formation and precipitation occurrence
- Different **pollution sources** generate particles of different chemical properties w.r.t. condensation processes and cloud formation
- More dust from cars fuel, industry and quarrying which contribute to the hydroscopic nuclei making them larger

- Cloud cover may also often be the result of **smog**, a mixture of fog and smoke (low-lying clouds).
- Ice particles of anthropogenic origin -> condensation nuclei for stratus clouds -> more frequent **light snowfall** in city

6.3 Clouds

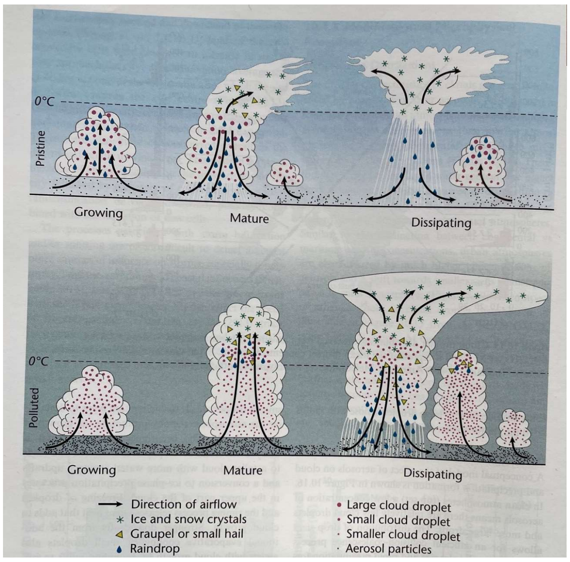
- There tends to be more cloud cover over urban areas; cities receive thicker and up to **ten per cent more frequent cloud cover** than that compared to rural areas.
- The reason for this is because there is more convection caused by higher temperatures and a larger number of condensation nuclei

- The increase or decrease in amount of cloud cover can directly impact the precipitation levels in urban areas

- Intensity, frequency and length of **fogs** are much greater in urban areas particularly under anticyclone conditions.
- For example, Kew in the middle suburbs of London has 79 hours of very dense fog, with visibility being less than 40metres. Whereas, London Airport on the outer suburbs has only 46 hours, and south east England (the mean of 7 weather stations) has 20 hours.
- This shows that further away from the urban areas of a city, towards rural areas, fog density decreases. Obviously, the larger the city and the greater the quantity of urban structures and materials the greater the impacts of these microclimatic changes.

Clouds

„Invigoraton effect" of aerosols on clouds in moist climate



Low concentration of aerosols, few cloud droplets, more large drops

Rapid precipitation formation

More condensation nuclei leads to greater number of small droplets

Precipitation suppression in the first phases

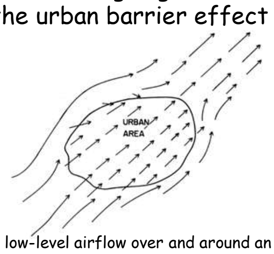
More liquid in cumulus clouds

Enhanced cloud development and more intense precipitation

Convective cloud development in clean (top) and poluted (bottom) atmosphere (Rosenfeld et a. 2008)

6.4 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

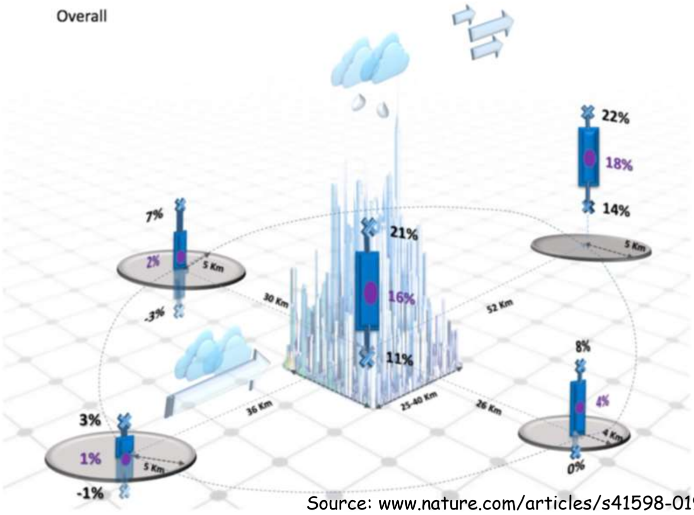


Schematic of low-level airflow over and around an urban area due to changes in surface roughness. (Cotton and Pielke 1995)

• 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.

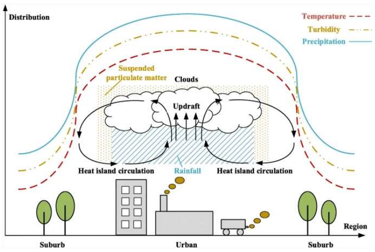
Atmospheric fronts vs. strong convection



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 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.

6.5 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

Strong convection and thunderstorms

- Higher temperatures of urban areas mean that the likelihood of thunderstorms is increased by 25%.
- Thunderstorms develop especially in hot humid air and are accompanied by numerous extreme phenomena (downpours, hail, lightning and thunder).
- They are particularly common in the late afternoon when heat energy has had the chance to build up in the atmosphere.

Unevenness in precipitation distribution

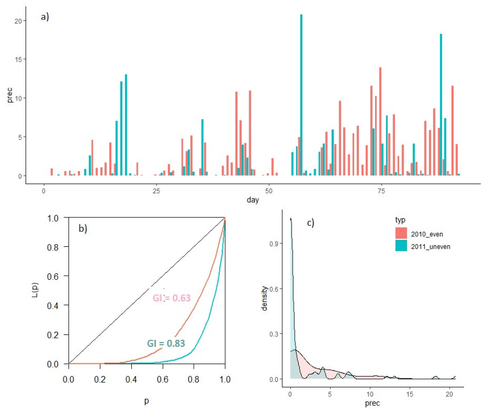
THE NEW INDIAN EXPRESS

NATION WORLD STATES OPINIONS CITIES BUSINESS SPORT GOOD NEWS MOVIES PHOTOS

Erratic rainfall patterns? Human impact to blame

https://www.newindianexpress.com/xplore/2024/Jul/31/

Moto: If your garden is flooded at times or, conversely, everything dries up, it does not necessarily mean that it is raining a lot or not enough. It can also mean that it rains very unevenly.



Daily precipitation totals for Brno area in spring 2010 and 2011 representing two seasons with even and uneven precipitation distribution as an example (a); their corresponding Lorenz curves and Gini index (b) and pdf estimates (c)

Unevenness in precipitation distribution

The mean annual precipitation total in an urban area and **the number of days with less than 5 mm** of rainfall can both be between 5-15% greater than in rural areas.

This means that cities get a **larger amount of dry days**, yet have **more rainfall when they do have rain**.

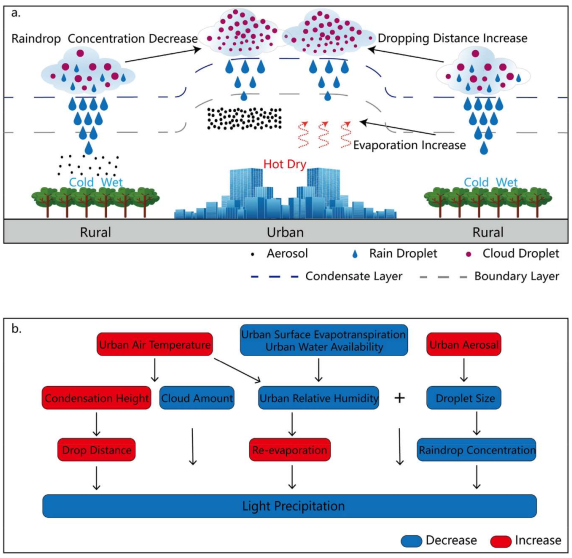
This happens because of convection currents which are generated by the higher temperatures, and due to an increased amount of microscopic condensation nuclei.

Decrease in light precipitation frequency has been reported in many regions and urbanization has largely contributed to the observed downward trend in it.

scientific reports

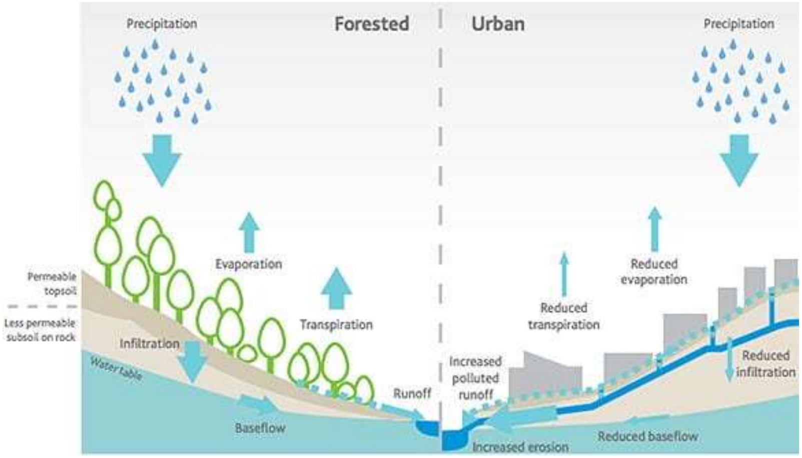
OPEN **Observed decrease in light precipitation in part due to urbanization**

Light and heavy urban precipitation



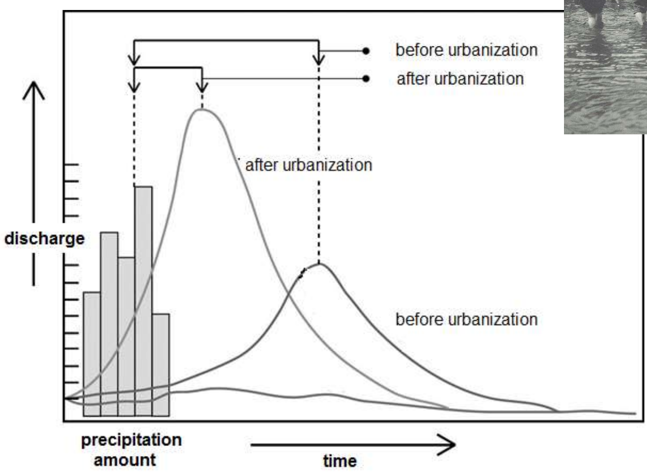
https://www.nature.com/articles/s41598-022-07897-8

6.6 Water runoff in urban environment



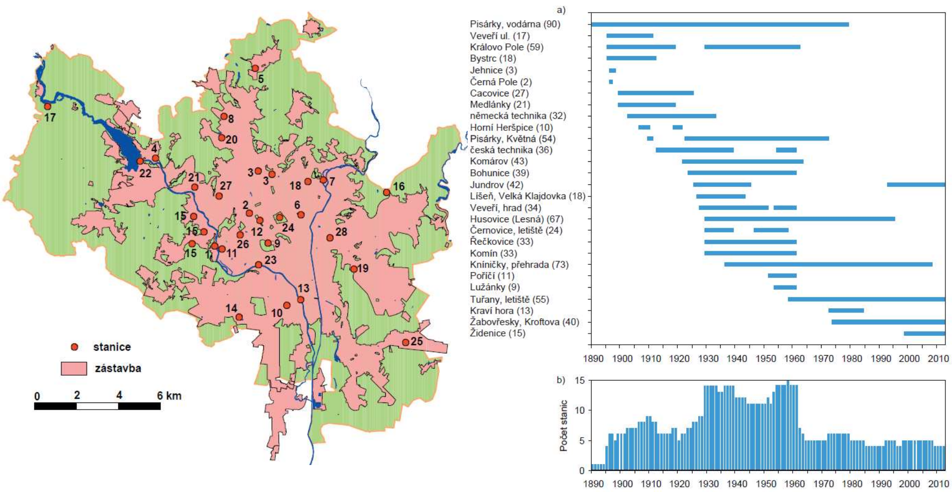
Source: https://www.melbournewater.com.au/sites/default/files/forested-urban-stormwater.jpg

Water runoff in urban environment



Before and after urbanisation hydrograph (adopted from Christopherson 1997)

6.7 Observational evidence (precipitation regime in Brno)

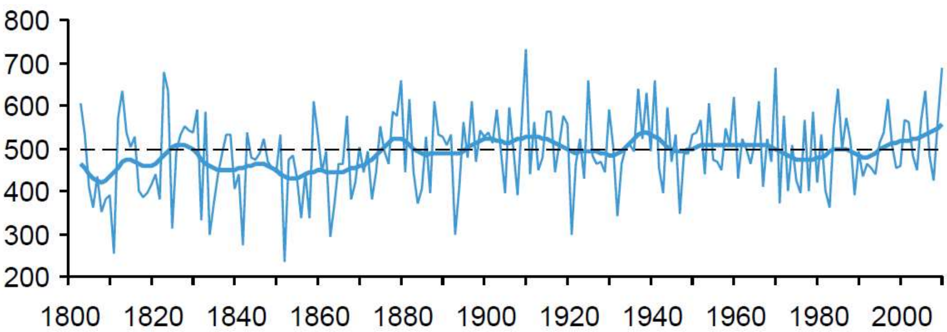


Network of stations in Brno area and its temporal development in the period 1890–2012: a) period of measurements; b) number of stations

One can characterize rain variability:

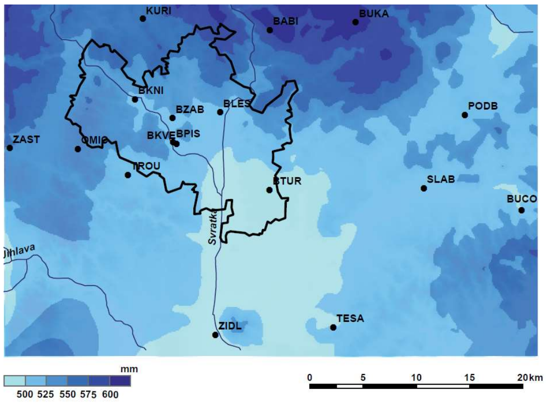
- in its amount (totals)
- in precipitation frequency
- in its intensity
- in its seasonal distribution

Long term variability of precipitation in Brno

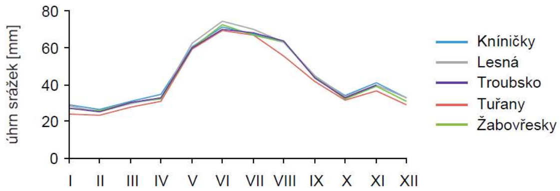


Fluctuation of mean annual precipitation totals in Brno in the period 1803–2010; annual values smoothed with Gaussian filter for 20 years are in bold and horizontal line is the mean for 1961–2010 reference period

Precipitation regime in Brno

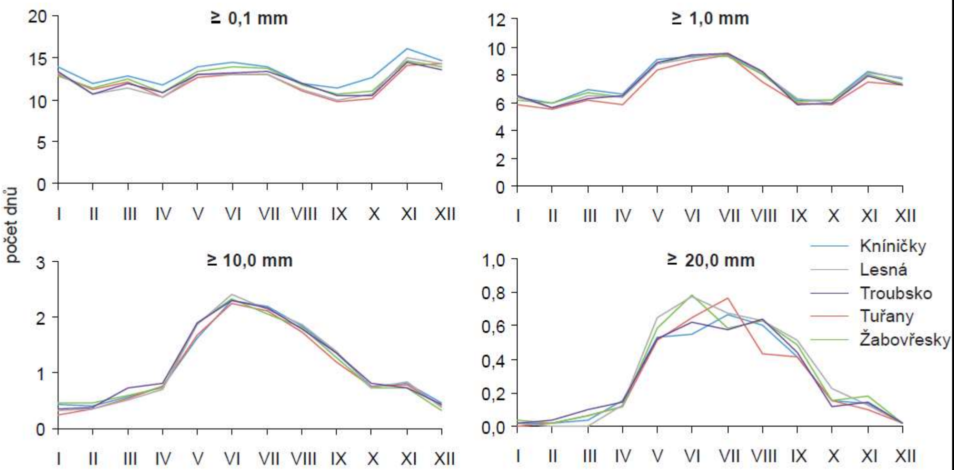


Spatial distribution of mean annual precipitation totals in Brno region in the period 1961–1990



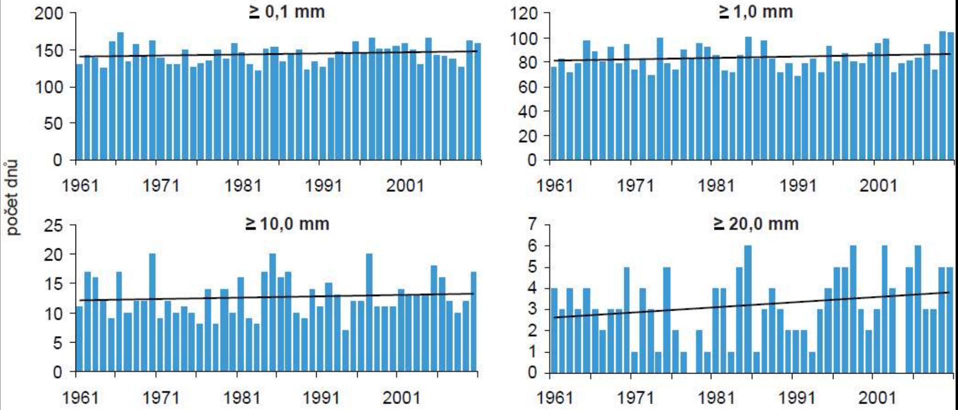
Comparison of mean annual variation of precipitation at selected stations in Brno in the period 1961–2010

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

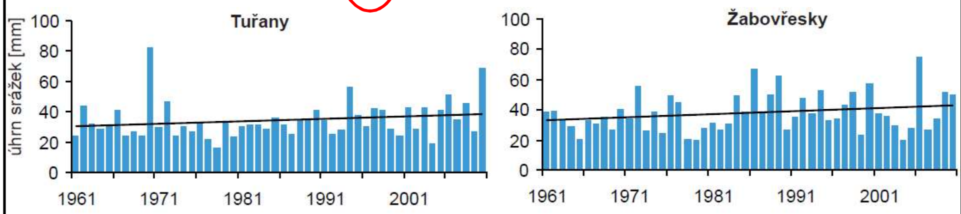


Variability in annual number of days with precipitation totals ≥ 0.1, 1.0, 10.0 and 20.0 mm including linear trends at Tuřany station in the period 1961–2010

Maximum daily precipitation totals

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

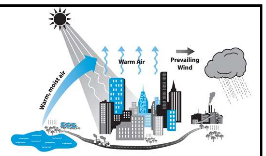
stanice	max. denní úhrn srážek	datum výskytu	doba opakování (roky)
Brno-Kníničky	88,5	15.6.2002	65,4
Brno-Tuřany	82,1	16.6.1970	145,7
Brno-Žabovřesky	74,9	7.8.2006	76,5
Troubsko	70,8	23.7.2010	46,2

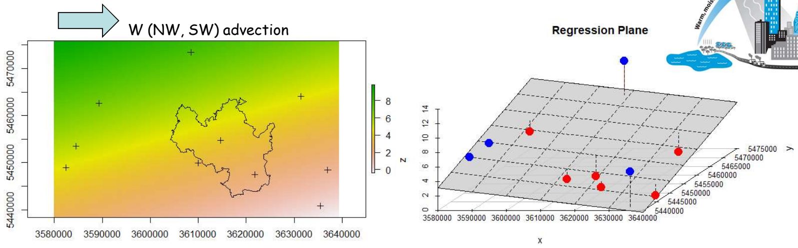


Variability of maximum daily precipitation totals including linear trends at two stations in Brno in the period 1961–2010

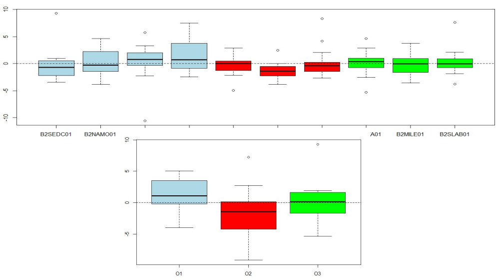
Conclusion: there are several signs that the precipitation regime become more extreme

Analysis of precipitation anomalies





Linear trend in daily rainfall totals (left) and positive (blue) and negative (red) deviations of daily rainfall totals from their linear trend (b) in the Brno area and its surroundings for W winds

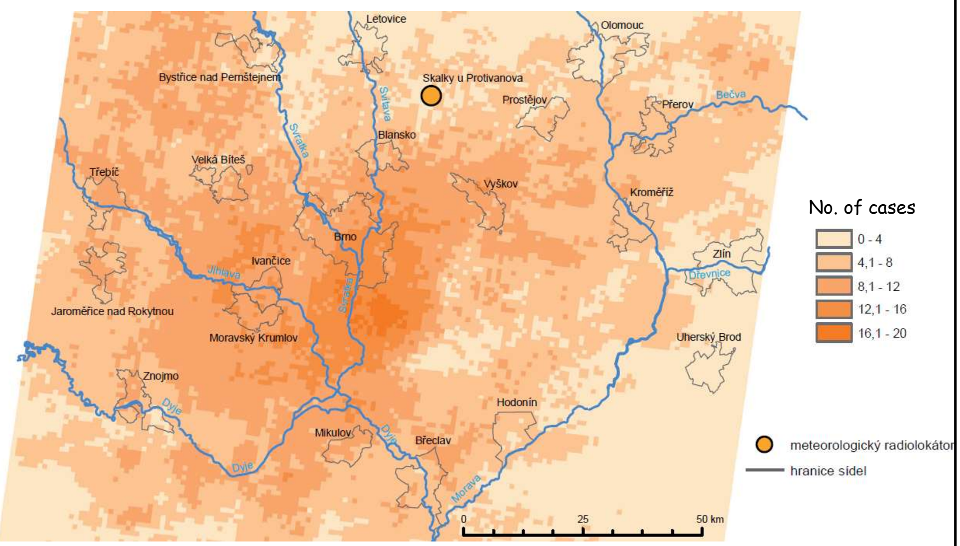


Conclusion: There is a signal indicating an increase in precipitation totals on the leeward side of the city of Brno, which may be related to the urban climate effect

Mean prec anomalies for individual stations and for three station groups

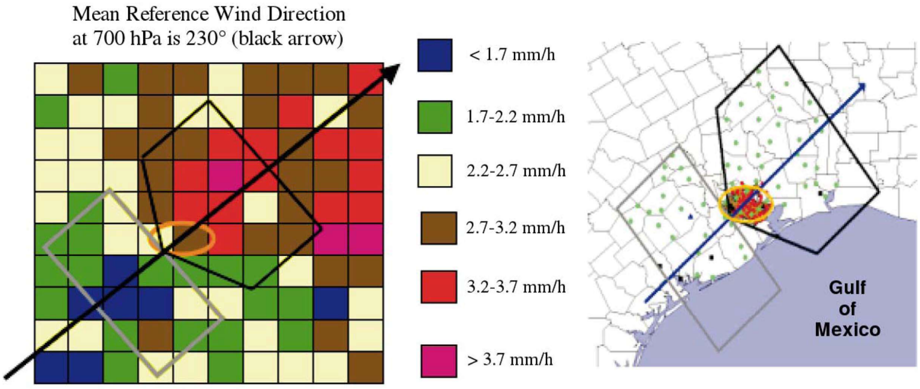
Urban Precipitation Radar Observations

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).]

6.8 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?