favorable climatic conditions. However, the net carbon sequestration is much smaller in the Tropics than midlatitudes as in the Tropics, wood is used primarily as fuel (Bonan 2008).

3.5.4.2 Drylands

Drylands degrade across thresholds into less and less productive lands. Exiting this process needs external intervention (Verstraete et al. 2009). However, such measures require long time before becoming effective. During the intense Sahel drought, for instance, projects were launched in some areas to plant trees to increase precipitation. The long-lasting drought, the growing pressure for food, and the slow growth of trees, however, counteracted this measure as animals grazed the young trees.

The time involved makes it is difficult to assess whether measures to reverse degradations are effective. Long-term (>5 year) monitoring is required due to the high temporal variability of precipitation in drylands. Usually, dryland ecosystems are adapted well to short-term variability. If degradation exceeds a threshold that inhibits the system to recover spontaneously, degradation will continue (Verstraete et al. 2009). The abrupt increase of rainfall in the Sahel in 1994 may be explained by the enhanced warming of the land compared to the ocean that leads to an increased monsoonal landward flow and rainfall (Giannini et al. 2008).

An example of how afforestation, increased cultivation, and restrictions on grazing led to reversal of desertification is the Negev (Fig. 3.1). Here, October rains steeply and the rains of the rest of the rainy season appreciably increased since 1975 as compared to the 20 years before (Otterman et al. 1990). The area that receives 50 mm, the minimum precipitation needed for sufficient plant-available water, has increased. The increased vegetation cover intensified the dynamical convection processes and advection. Inversions capping the ABL penetrated higher due to the enhanced daytime convection. The strengthened advection provided moist air from the warm Mediterranean Sea and contributed to increased precipitation (Otterman et al. 1990).

3.5.5 Urbanization

Urbanization is an extreme case of LCC. Since 1950, the population living in cities has increased by a factor ten. In 2004, 1.2% of the Earth was urban land. Despite urban population grew strongest in the Tropics, most studies on urban effects have been performed for midlatitudes (Fig. 3.12).

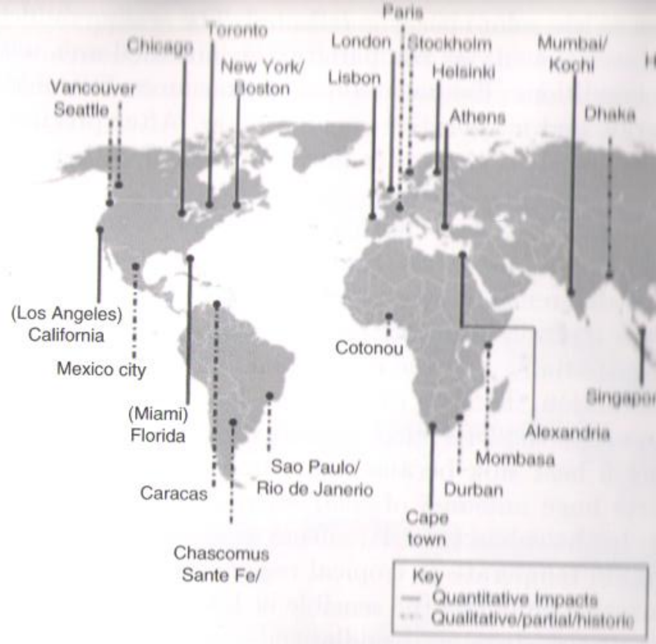

Figure 3.12. Geographical location of city for which major
performed (From Hunt and Watkiss 2011)

3.5.5.1 Urban Heat Island Effect

The main effects of cities on the airflow are throu
buildings due to pressure difference across roughness
ferential heating of urbanized surfaces, which produce
island (UHI) effect. To understand the origins of the
consider the surface-heat budget equation. Primary m
ate the UHI effect are the replacement of natural land
cial surfaces of different thermal properties (e.g., heat
diffusivity). The urban surfaces heat more intensely t
faces during the day, store the solar energy, and conv
heat. As sensible heat is transferred to the air, air te
to be 2–10 K higher in urban areas than in adjacent
consequences for stability. Anthropogenic heat release
adds to the UHI.

The albedo of urban land alters the reflection of inc
ation. In midlatitudes, the albedo of roofs, buildings, a
is typically lower than that of vegetation or bare soil. C

favorable climatic conditions. However, the net carbon sequestration is much smaller in the Tropics than midlatitudes as in the Tropics, wood is used primarily as fuel (Bonan 2008).

3.5.4.2 Drylands

Drylands degrade across thresholds into less and less productive lands. Exiting this process needs external intervention (Verstraete et al. 2009). However, such measures require long time before becoming effective. During the intense Sahel drought, for instance, projects were launched in some areas to plant trees to increase precipitation. The long-lasting drought, the growing pressure for food, and the slow growth of trees, however, counteracted this measure as animals grazed the young trees.

The time involved makes it is difficult to assess whether measures to reverse degradations are effective. Long-term (>5 year) monitoring is required due to the high temporal variability of precipitation in drylands. Usually, dryland ecosystems are adapted well to short-term variability. If degradation exceeds a threshold that inhibits the system to recover spontaneously, degradation will continue (Verstraete et al. 2009). The abrupt increase of rainfall in the Sahel in 1994 may be explained by the enhanced warming of the land compared to the ocean that leads to an increased monsoonal landward flow and rainfall (Giannini et al. 2008).

An example of how afforestation, increased cultivation, and restrictions on grazing led to reversal of desertification is the Negev (Fig. 3.1). Here, October rains steeply and the rains of the rest of the rainy season appreciably increased since 1975 as compared to the 20 years before (Otterman et al. 1990). The area that receives 50 mm, the minimum precipitation needed for sufficient plant-available water, has increased. The increased vegetation cover intensified the dynamical convection processes and advection. Inversions capping the ABL penetrated higher due to the enhanced daytime convection. The strengthened advection provided moist air from the warm Mediterranean Sea and contributed to increased precipitation (Otterman et al. 1990).

3.5.5 Urbanization

Urbanization is an extreme case of LCC. Since 1950, the population living in cities has increased by a factor ten. In 2004, 1.2% of the Earth was urban land. Despite urban population grew strongest in the Tropics, most studies on urban effects have been performed for midlatitudes (Fig. 3.12).

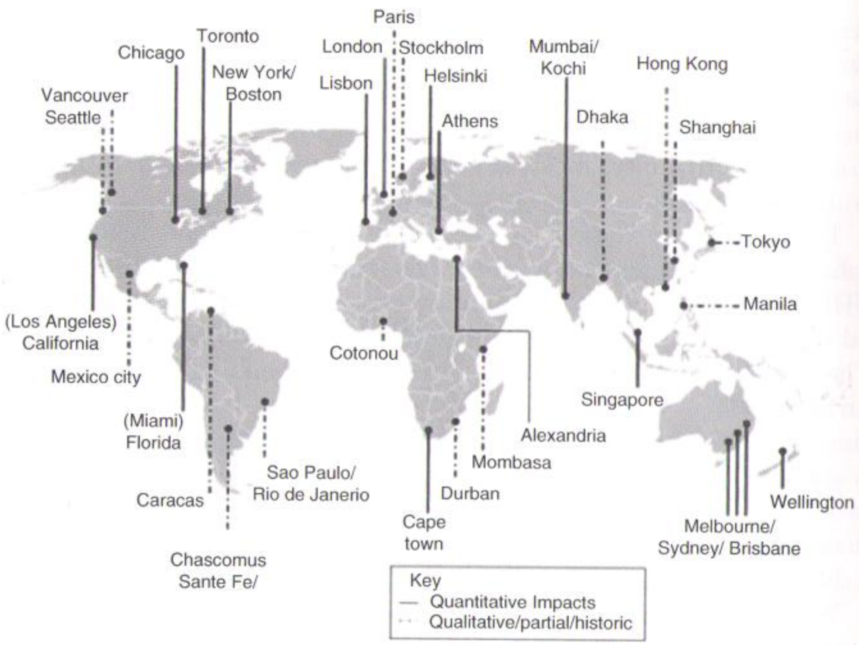

Figure 3.12. Geographical location of city for which major urban studies where performed (From Hunt and Watkiss 2011)

3.5.5.1 Urban Heat Island Effect

The main effects of cities on the airflow are through the drag from buildings due to pressure difference across roughness elements and differential heating of urbanized surfaces, which produces the urban heat island (UHI) effect. To understand the origins of the UHI, we have to consider the surface-heat budget equation. Primary mechanisms to create the UHI effect are the replacement of natural land surfaces by artificial surfaces of different thermal properties (e.g., heat capacity, thermal diffusivity). The urban surfaces heat more intensely than natural surfaces during the day, store the solar energy, and convert it to sensible heat. As sensible heat is transferred to the air, air temperature tends to be 2–10 K higher in urban areas than in adjacent rural areas with consequences for stability. Anthropogenic heat release from emissions adds to the UHI.

The albedo of urban land alters the reflection of incoming solar radiation. In midlatitudes, the albedo of roofs, buildings, and paved streets is typically lower than that of vegetation or bare soil. Consequently, the net energy increases as less solar energy is reflected. The sealing reduces evapotranspiration over the city as compared to an unsealed area with same atmospheric conditions. Evapotranpiration consumes less of the incoming solar energy, and evaporative cooling is low. After precipitation events in a city, most of the water goes into runoff rather than evapotranspiration.

The formation of an UHI effect, its magnitude, and related atmospheric responses depend on the large-scale forcing. The intensity of the UHI is given by the difference between the mean urban and mean rural temperature. It is typically proportional to the city size (Oke 1995). The intensity varies spatially over the city depending on the degree of surface sealing, ventilation, distance to the rural land, and climate region. In arid urban areas, the UHI effect is relatively weak. Here, a city is sometimes rather a heat sink because evapotranspiration from irrigated areas converts huge amounts of solar energy into latent rather than sensible heat. In the subarctic, UHI effects exist, but albedo plays a different role than in temperate or tropical regions.

Whether urbanization enhances the sensible or latent heat fluxes depends on where it occurs. In humid midlatitudes, urbanization shifts the Bowen ratio toward higher values. Here, urbanization reduces evapotranspiration and daytime relative humidity in the city and enhances the UHI effect. The slightly warmer air due to the UHI effect, however, may enhance evapotranspiration in the downwind of the city. Enhanced evapotranspiration and relative humidity were found for cities with water meadows, grassland, lakes, and/or lakes in their downwind region. In semiarid areas, the irrigation of the urban forest and lawns may lead to a shift toward lower Bowen ratios as compared to the adjacent nonirrigated land. Anthropogenic moisture releases from urban irrigation and/or as a by-product of combustion are important sources of enthalpy that result in cooling (Coleman et al. 2010).

The UHI intensity exhibits seasonal cycles and is modulated by cloudiness and wind conditions. The UHI effect has a distinct diurnal cycle with peaks in the late evening to early morning (Fig. 3.13). The positive heat anomaly is most evident during clear, calm nights. Obviously, the UHI intensity differs between weekdays and weekends/holidays. Fujibe (2010) investigated 29 years of hourly data from the Automated Meteorological Data Acquisition System network of Japan and found that on weekends/holidays, the UHI effect was about 0.2–0.25 K and 0.1–0.2 K lower at Tokyo and Osaka, respectively, and about 0.02 K lower at stations located in urban areas with population density of 300–1,000 km^{-2}. On the long term, the UHI effect relatively decreased and increased on Mondays and Fridays, respectively, by about 0.05–0.1 K/decade in Tokyo and about 0.02 K/decade at station
lation density of 100–1,000 km^{-2}. No significant trends in t
of the UHI effect existed between weekdays and weekends.

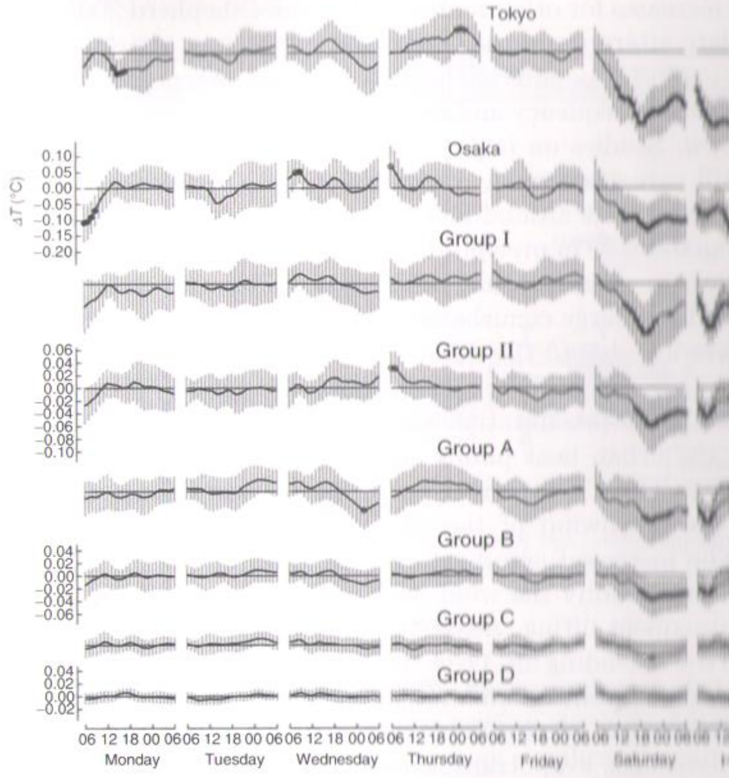

Figure 3.13. Average diurnal variation of the UHI (annual average,
of various population density on each day of the week. Open and closed
UHI effects being significant at the 5% and 1% levels, respectively.
panels, the dashed lines denote the results for Sundays only. Group
stations with population density ⩾3,000 km^{-2}, 1,000–3,000 km^{-2},
and 30–100 km^{-2}, respectively. The reference temperature to determin
of the UHI effect is from stations with population density <100 km
data collected from March 1979 to February 2008 (From Fujibe 2010)

3.5.5.2 Urban Impacts on Clouds and Precipitat

The pre- and METROMEX investigations suggested th
trigger or enhance the formation of convective clouds over a
hanced evapotranspiration under favorable large-scale con

gy increases as less solar energy is reflected. The sealing reduces
anspiration over the city as compared to an unsealed area with
mospheric conditions. Evapotranpiration consumes less of the
g solar energy, and evaporative cooling is low. After precipita-
nts in a city, most of the water goes into runoff rather than
anspiration.

formation of an UHI effect, its magnitude, and related atmo-
responses depend on the large-scale forcing. The intensity of the
given by the difference between the mean urban and mean ru-
perature. It is typically proportional to the city size (Oke 1995).
ensity varies spatially over the city depending on the degree of
sealing, ventilation, distance to the rural land, and climate re-
arid urban areas, the UHI effect is relatively weak. Here, a city
times rather a heat sink because evapotranspiration from irri-
reas converts huge amounts of solar energy into latent rather
nsible heat. In the subarctic, UHI effects exist, but albedo plays
nt role than in temperate or tropical regions.

her urbanization enhances the sensible or latent heat fluxes de-
n where it occurs. In humid midlatitudes, urbanization shifts
en ratio toward higher values. Here, urbanization reduces evap-
iration and daytime relative humidity in the city and enhances
I effect. The slightly warmer air due to the UHI effect, however,
nance evapotranspiration in the downwind of the city. Enhanced
anspiration and relative humidity were found for cities with wa-
dows, grassland, lakes, and/or lakes in their downwind region.
arid areas, the irrigation of the urban forest and lawns may lead
ft toward lower Bowen ratios as compared to the adjacent non-
d land. Anthropogenic moisture releases from urban irrigation
as a by-product of combustion are important sources of enthalpy
ult in cooling (Coleman et al. 2010).

UHI intensity exhibits seasonal cycles and is modulated by
ss and wind conditions. The UHI effect has a distinct diurnal cy-
peaks in the late evening to early morning (Fig. 3.13). The pos-
t anomaly is most evident during clear, calm nights. Obviously,
I intensity differs between weekdays and weekends/holidays.
2010) investigated 29 years of hourly data from the Automated
logical Data Acquisition System network of Japan and found
weekends/holidays, the UHI effect was about 0.2–0.25 K and
K lower at Tokyo and Osaka, respectively, and about 0.02 K
t stations located in urban areas with population density of
00 km^{-2}. On the long term, the UHI effect relatively decreased
reased on Mondays and Fridays, respectively, by about 0.05–

0.1 K/decade in Tokyo and about 0.02 K/decade at stations with population density of 100–1,000 km^{-2}. No significant trends in the differences of the UHI effect existed between weekdays and weekends.

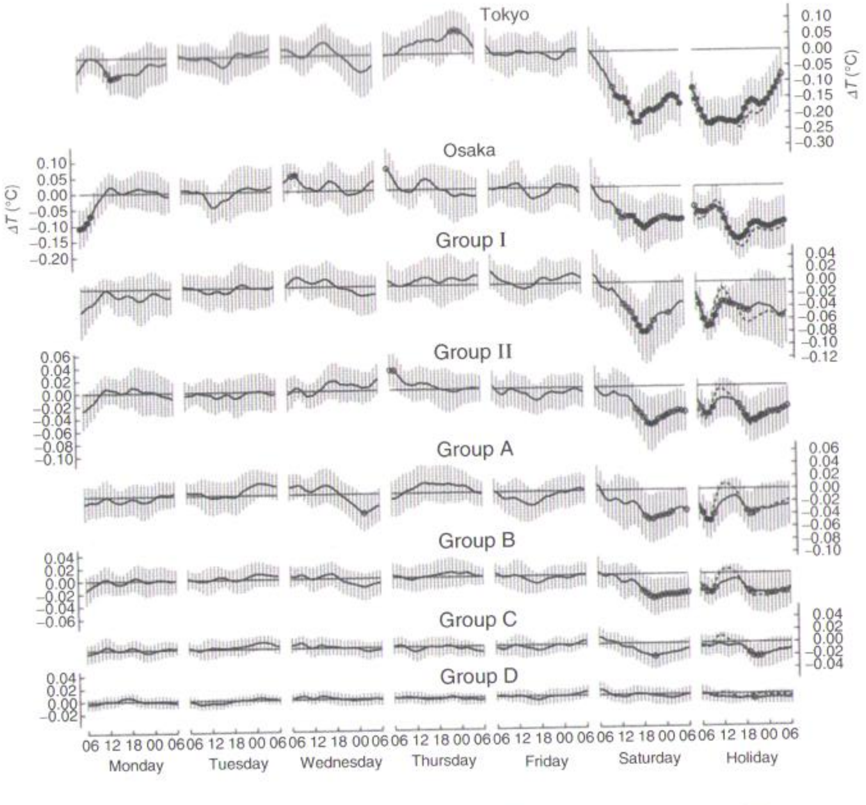

Figure 3.13. Average diurnal variation of the UHI (annual average, in K) at stations of various population density on each day of the week. Open and closed circles indicate UHI effects being significant at the 5% and 1% levels, respectively. In the holiday panels, the dashed lines denote the results for Sundays only. Groups A–D refer to stations with population density $\geqslant$3,000 km^{-2}, 1,000–3,000 km^{-2}, 100–3000 km^{-2}, and 30–100 km^{-2}, respectively. The reference temperature to determine the magnitude of the UHI effect is from stations with population density <100 km^{-2}. Plots base on data collected from March 1979 to February 2008 (From Fujibe 2010)

3.5.5.2 Urban Impacts on Clouds and Precipitations

The pre- and METROMEX investigations suggested that cities may trigger or enhance the formation of convective clouds over areas with enhanced evapotranspiration under favorable large-scale conditions. After

METROMEX, various studies extended the knowledge on urban impacts on precipitation. Changnon (1980), for instance, found that in the downwind of Chicago, summer precipitation increased about 0.4 mm on average from 1931–1976 due to urban growth. Observations show similar precipitation increases for other midlatitude cities (Shepherd 2005): The frequency of late-afternoon storms increased in Phoenix, Arizona, in response to the explosive population growth. Historical records for Mexico City show increased frequency and intensity of showers over the decades as the city grew. Studies on impacts of high-latitude cities on precipitation are still rare. Analyzing precipitation data from 1950 to 2002 for urban and rural sites around Fairbanks, Alaska, Mölders and Olson (2004) found an increase in precipitation due to the growth of Fairbanks. All studies have in common that urbanization increases precipitation amounts in the lee of large conurbations, and it reduces precipitation on the regional average due to the reduced regional-average evapotranspiration.

Urban areas affect precipitation variability by various mechanisms: Advection of the urban heat plume enhances the temperatures downwind of the city. The UHI-thermal perturbation destabilizes the ABL over and in the downwind of the city and promotes vertical lifting (Fig. 3.14). The increased aerodynamic roughness and surface heterogeneity of the city modify the wind field, and lead to low-level convergence with subsequent lifting. Advection of air from the adjacent rural areas replaces the ascending air. Over the city toward the downwind side, the vertical wind component can increase significantly. The water-vapor release associated with combustion humidifies the urban atmosphere. In humid midlatitudes, evapotranspiration over rural land exceeds that over the city leading to a moisture convergence. The large-scale flow and upward lifting of moist, relatively warmer air transport moist air toward the lee side of and into the lee of the city.

If the atmospheric conditions permit saturation to occur, the strong upward transport of moist air can increase the amounts of cloud particles and hydrometeors as compared to the clouds in the undisturbed landscape. Consequently, precipitation may form and/or increase in amount, intensity, and distribution (Changnon and Huff 1986). Over the lifetime of the clouds, more cloud and precipitating particles are formed over and in the lee of the cities than in rural areas. The enhanced moisture convergence and upward transport of water vapor over the city permit the air to reach higher, relatively colder levels. At subfreezing temperatures, this shifts precipitation formation in favor of the more efficient cold path involving riming and the Bergeron–Findeisen process.

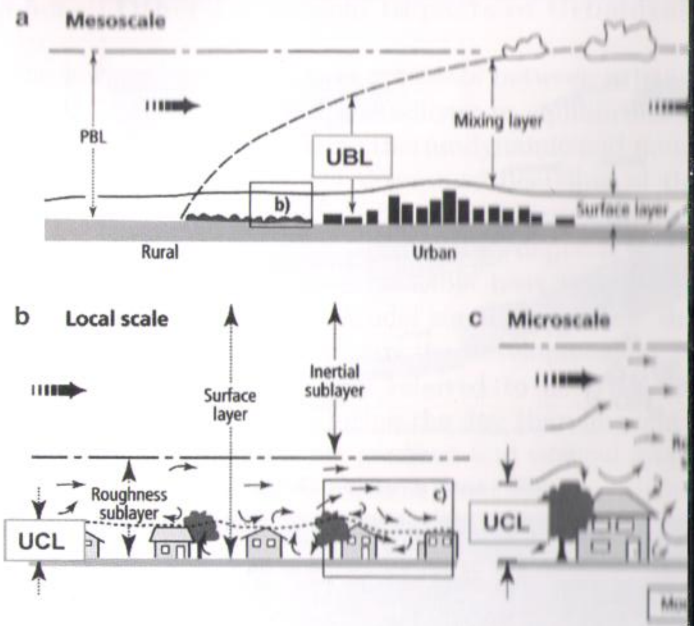

Figure 3.14. Schematic view of modifications of the lower atmo
environment as it occurs at various scales (Modified after Oke 19
2005)

For a city to affect significantly the precipitation di
major downwind, it must exceed a critical size. In midl
stance, urban growth of about 20% may significantly en
precipitation formation in the lee of cities of about 300
extent (e.g., Fig. 3.15). The same growth of small set
affects the atmosphere, except where small settlements
dominated by grassland (Mölders 1999a). In grasslan
ration enhances appreciably in the downwind of the g
during the warm seasons.

Anthropogenic heat and water-vapor release from i
sources, such as power plants, marginally affect precipit
mediate vicinity of the stacks due to altered buoyancy. W
of individual stacks is negligible most of the time in mi
sum of the anthropogenic heat release within an urba
tribute substantially to the UHI effect at high latitudes,
water release from combustion may notably affect atmos
and enhance precipitation in a city's downwind (e.g., Mö
2004).

X, various studies extended the knowledge on urban im-
cipitation. Changnon (1980), for instance, found that in the
Chicago, summer precipitation increased about 0.4 mm on
1931–1976 due to urban growth. Observations show similar
increases for other midlatitude cities (Shepherd 2005): The
late-afternoon storms increased in Phoenix, Arizona, in re-
explosive population growth. Historical records for Mexico
creased frequency and intensity of showers over the decades
grew. Studies on impacts of high-latitude cities on precip-
till rare. Analyzing precipitation data from 1950 to 2002
d rural sites around Fairbanks, Alaska, Mölders and Olson
an increase in precipitation due to the growth of Fairbanks.
ave in common that urbanization increases precipitation
he lee of large conurbations, and it reduces precipitation on
average due to the reduced regional-average evapotranspi-

as affect precipitation variability by various mechanisms:
f the urban heat plume enhances the temperatures down-
city. The UHI-thermal perturbation destabilizes the ABL
the downwind of the city and promotes vertical lifting
The increased aerodynamic roughness and surface hetero-
e city modify the wind field, and lead to low-level conver-
ubsequent lifting. Advection of air from the adjacent rural
s the ascending air. Over the city toward the downwind side,
vind component can increase significantly. The water-vapor
iated with combustion humidifies the urban atmosphere.
dlatitudes, evapotranspiration over rural land exceeds that
leading to a moisture convergence. The large-scale flow and
g of moist, relatively warmer air transport moist air toward
f and into the lee of the city.
ospheric conditions permit saturation to occur, the strong
sport of moist air can increase the amounts of cloud particles
eteors as compared to the clouds in the undisturbed land-
quently, precipitation may form and/or increase in amount,
d distribution (Changnon and Huff 1986). Over the lifetime
s, more cloud and precipitating particles are formed over
e of the cities than in rural areas. The enhanced moisture
and upward transport of water vapor over the city permit
ach higher, relatively colder levels. At subfreezing temper-
shifts precipitation formation in favor of the more efficient
volving riming and the Bergeron–Findeisen process.

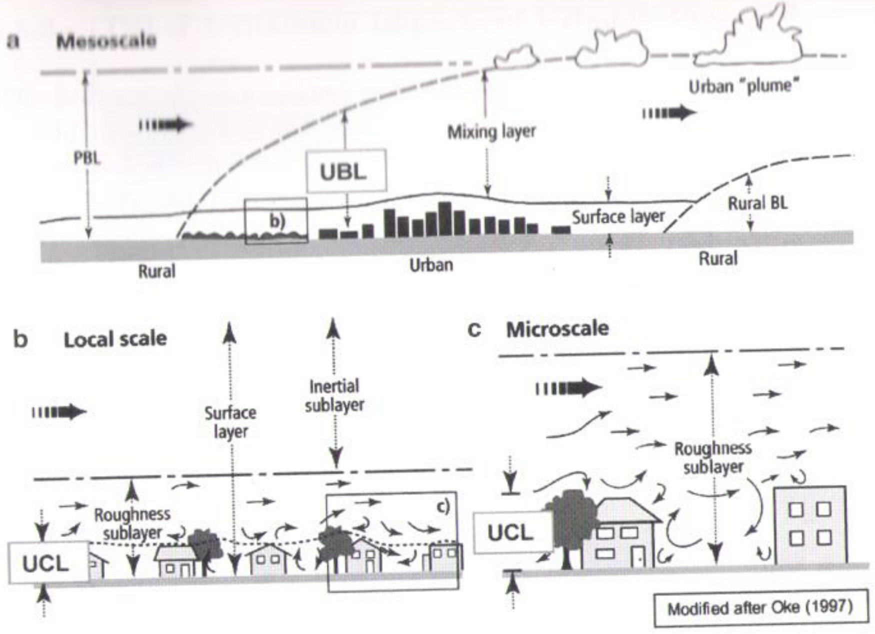

Figure 3.14. Schematic view of modifications of the lower atmosphere in an urban environment as it occurs at various scales (Modified after Oke 1995; from Shepherd 2005)

For a city to affect significantly the precipitation distribution in its major downwind, it must exceed a critical size. In midlatitudes, for instance, urban growth of about 20% may significantly enhance cloud and precipitation formation in the lee of cities of about 300 km^2 in original extent (e.g., Fig. 3.15). The same growth of small settlements hardly affects the atmosphere, except where small settlements grow in an area dominated by grassland (Mölders 1999a). In grassland, evapotranspiration enhances appreciably in the downwind of the grown settlement during the warm seasons.

Anthropogenic heat and water-vapor release from individual point sources, such as power plants, marginally affect precipitation in the immediate vicinity of the stacks due to altered buoyancy. While the impact of individual stacks is negligible most of the time in mid-latitudes, the sum of the anthropogenic heat release within an urban area can contribute substantially to the UHI effect at high latitudes. Anthropogenic water release from combustion may notably affect atmospheric humidity and enhance precipitation in a city's downwind (e.g., Mölders and Olson 2004).

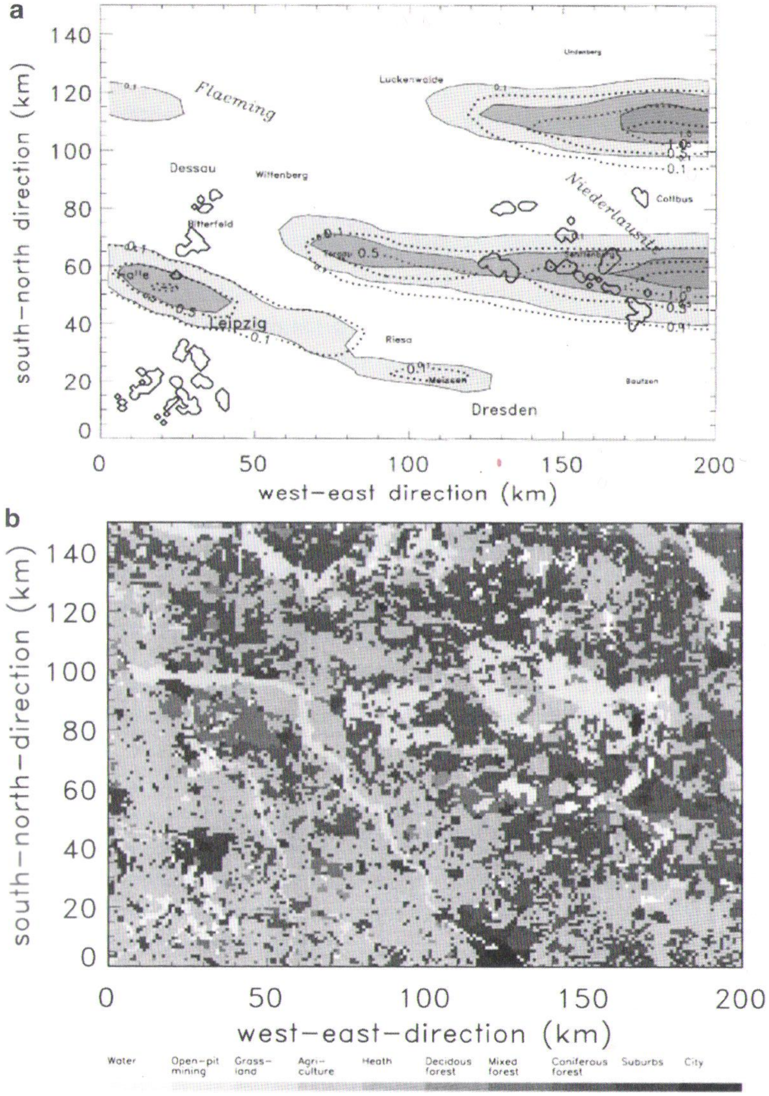

Figure 3.15. (**a**) Comparison of the 24-h accumulated precipitation (mm) as obtained for the reference landscape (**b**) and the landscape with a 20% increase in urban areas in Saxony, Germany, for a convective day in spring, assuming a geostrophic wind from 100° with 7.5 m/s at 3 km height. The names indicate locations of cities, the italic names of regions, and the solid black contours indicate open-pit mines (From Mölders 1999a)

3.5.5.3 Other Dynamical Impacts of Urbanization

The horizontal temperature gradients between urban and rural land can yield NCMC. The partial gradients in equilibrium temperature in combination with the overlying thermodynamic and moisture stratification dominate the upward or downward heat flux of thermally forced systems. Consequently, horizontal temperature gradients evolve that drive the NCMC. The urban circulation depends on the stability of the ABL, and the increase in sensible heat fluxes and roughness as compared to the rural land. Model simulations show that the UHI intensity and ABL stability govern the development of NCMC. Urban-induced NCMC are commonly referred to as UHI circulations. The UHI circulation is stronger during the day than at night because of the stronger urban–rural pressure gradient and vertical mixing during daytime hours. Urban-forced convection is not simply a night–early morning phenomenon.

Observations show that conurbations may delay frontal passages and/or bifurcate or divert precipitating systems (Loose and Bornstein 1977). The UHI effects may interact with and modify classical mesoscale circulations like land/sea breezes (Shepherd 2005) or mountain-valley breezes (Miao et al. 2009). Modifications of the local circulation systems have been modeled and observed, for instance, for Athens, Barcelona, Beijing, Chicago, Houston, Los Angeles, New York, and Paris, just to mention a few.

3.5.5.4 Trace Gas and Aerosol Release from Cities

Urban areas affect the atmosphere also by releasing moisture, trace gases, aerosols, and heat to the atmosphere. Traffic, industrial, and domestic fuel consumption are the major cause for urban air pollution. Thus, urbanization increases the urban emissions over a larger area. As cities grow, CO, NO_x, and particulate matter (PM) emissions, for instance, strongly increase with the increasing number of vehicles.

Airborne pollutants from large cities affect air quality, weather, and climate on the local to continental scale. Locally, the polluted air reduces incoming shortwave radiation with consequences for the energy budget. Urban-induced attenuation is typically less than 10%, but may reach up to 22% and 33% in much polluted megacities like Mexico City or Hong Kong (Kanda 2007).

Over the city and in its lee, the primary pollutants react and form secondary pollutants. The polluted urban air plume affects the natural

During summer nights, the UHI effect together with low wind speeds are the main reason for increased heat stress in mid- and low latitudes. The projected increase in ambient temperature together with (increased) UHI effects raise the risk for heat-stress-related health issues and reduce the quality of life (QOL). To mitigate this threat, measures to extend the emergency system and reduce the UHI effect have to be developed.

Parks and tree-covered neighborhoods can create "oasis effects" (Taha et al. 1991). Urban forests and parks reduce not only hydrocarbon concentrations, but also the UHI effect directly by shading the ground surface and indirectly by evapotranspiration. On average, air temperature decreases about 1 K per 10% canopy cover. Thus, neighborhoods with trees are about 2–4 K cooler than those without trees (e.g., Fig. 4.11). In Davis, California, for instance, air temperatures in an isolated orchard were 4.5 K lower than in the urban upwind (Taha et al. 1991).

Some cities already started efforts to reduce heat-stress due to UHI effect, urban growth, and climate change. The City of Chicago, for instance, plans to add approximately one million trees to their 4.1 million trees by 2020. Other cooling and energy-efficiency efforts persuaded include cool roofs, parks, and green roofs.

Studies suggest that white roofs can decrease urban daily maximum and minimum temperature by 0.6 and 0.3 K, respectively. Simulations using an urban canyon model coupled to a global climate model suggest that on average over all urban areas globally, installing white roofs may decrease the annual mean UHI effect by 33% (Oleson et al. 2010). The local effect of white roots depends on the season, location, and size of the urban area. At high latitudes in winter, for instance, an increased roof albedo affects marginally the UHI effect because roofs are snow-covered and incoming solar radiation is low. In low latitudes and midlatitude summers, white roofs help diminish the UHI effect and reduce emissions, as air conditioning needs less energy. In midlatitudes white roofs may lead to increased emissions from heating in winter.

Parking lots are sources of motor vehicle pollutants and have the character of small heat islands. In many European cities, homeowners installed "green parking lots" for their second vehicle. Green parking lots like green alleys are made of porous pavement often with about 10 cm in diameter small grass patches. These surfaces permit water to infiltrate into the soil instead of going into the sewer system. Due to evaporative cooling from the grass and open soil patches, green parking lots reduce the heat buildup.

Parks, urban forests, green parking lots and green roofs may require irrigation. Daytime Bowen ratios are related inversely to the irrigated area (Grimmond and Oke 1995). Thus, enhancing irrigation in urban

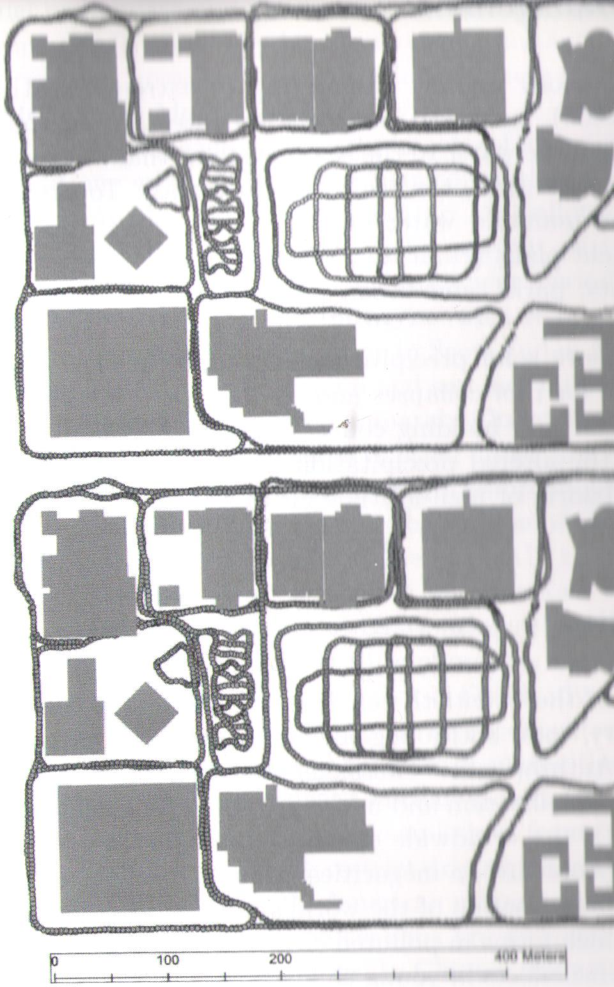

Figure 4.11. Temperatures from measurement drives from at 0.01 (*top*) and 2 m height (*bottom*) (From: Chow et al.

areas may reduce the UHI effect. Parks, urban fo
parking lots and green roofs mean LCC within
heterogeneity on the local scale. In addition to
and enhancing evapotranspiration, these measu
tation via secondary processes and have implied
management.

er nights, the UHI effect together with low wind speeds reason for increased heat stress in mid- and low latitudes. l increase in ambient temperature together with (increased) ise the risk for heat-stress-related health issues and reduce f life (QOL). To mitigate this threat, measures to extend y system and reduce the UHI effect have to be developed. tree-covered neighborhoods can create “oasis effects” (Taha Urban forests and parks reduce not only hydrocarbon con- ut also the UHI effect directly by shading the ground sur- rectly by evapotranspiration. On average, air temperature ut 1 K per 10% canopy cover. Thus, neighborhoods with t 2–4 K cooler than those without trees (e.g., Fig. 4.11). In rnia, for instance, air temperatures in an isolated orchard wer than in the urban upwind (Taha et al. 1991).

s already started efforts to reduce heat-stress due to UHI growth, and climate change. The City of Chicago, for in- to add approximately one million trees to their 4.1 million . Other cooling and energy-efficiency efforts persuaded in- ofs, parks, and green roofs.

ggest that white roofs can decrease urban daily maximum a temperature by 0.6 and 0.3 K, respectively. Simulations n canyon model coupled to a global climate model suggest ge over all urban areas globally, installing white roofs may annual mean UHI effect by 33% (Oleson et al. 2010). The white roots depends on the season, location, and size of the t high latitudes in winter, for instance, an increased roof marginally the UHI effect because roofs are snow-covered solar radiation is low. In low latitudes and midlatitude ite roofs help diminish the UHI effect and reduce emissions, oning needs less energy. In midlatitudes white roofs may ised emissions from heating in winter.

ts are sources of motor vehicle pollutants and have the small heat islands. In many European cities, homeowners en parking lots” for their second vehicle. Green parking n alleys are made of porous pavement often with about neter small grass patches. These surfaces permit water to the soil instead of going into the sewer system. Due to ooling from the grass and open soil patches, green parking e heat buildup.

an forests, green parking lots and green roofs may require ytime Bowen ratios are related inversely to the irrigated ond and Oke 1995). Thus, enhancing irrigation in urban

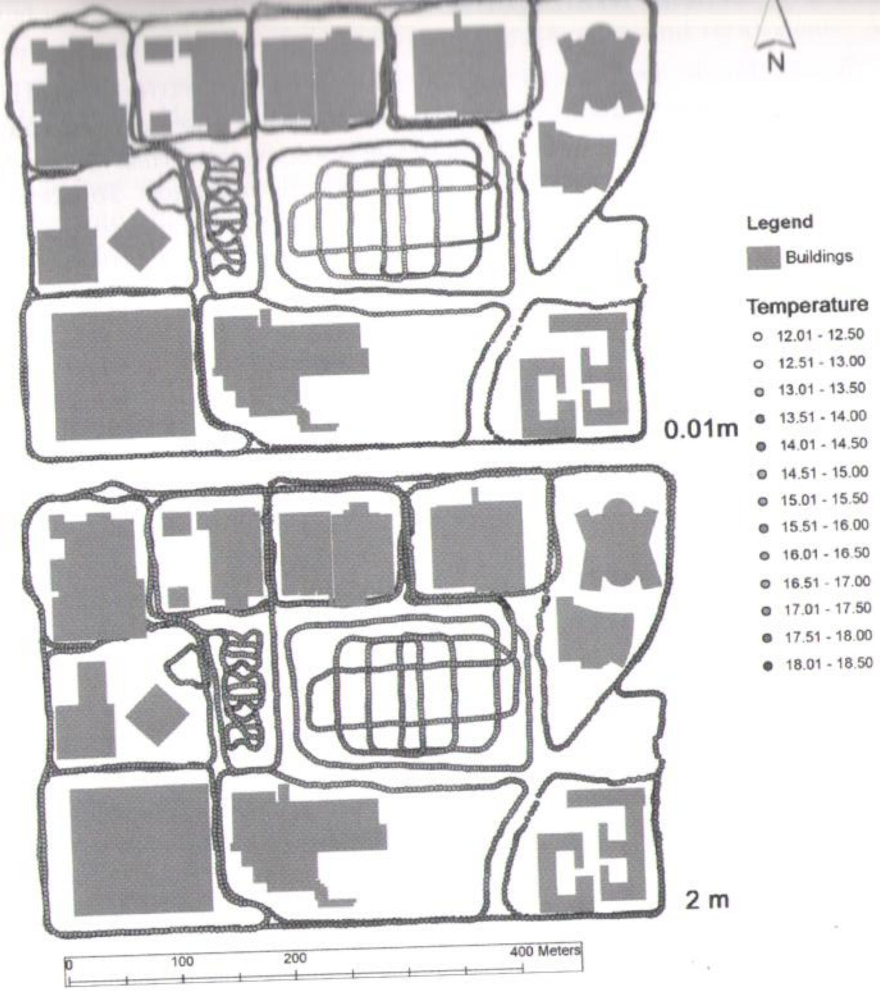

Figure 4.11. Temperatures from measurement drives from 0530–0630 LT as observed at 0.01 (*top*) and 2 m height (*bottom*) (From: Chow et al. 2011)

areas may reduce the UHI effect. Parks, urban forest, white roofs, green parking lots and green roofs mean LCC within the city and introduce heterogeneity on the local scale. In addition to reducing temperature and enhancing evapotranspiration, these measures may affect precipitation via secondary processes and have implied changes in stormwater management.

deling studies assessed the carbon debt and payback pe-
ıefit of biofuel and the time to pay back the up-front CO_2
end on the region, type of LCC, and agricultural manage-
; (Reijnders and Huijbregts 2008; Kim et al. 2009). Simu-
chinger et al. (2008) with a worldwide agricultural model
or GHG reductions of 86% excluding LCC, the up-front
in Brazil pay back in 4 years if sugarcane for ethanol pro-
wn on former tropical grazing land. If this grassland had
est before, the payback period lengthened to 45 years. In
ıels produced from corn on former grasslands increase the
s by 50%. Over 30 years, corn-based ethanol nearly dou-
emissions. The results by Kim et al. (2009) suggest that
eriod increases with the fraction of forest converted. Using
to expand biofuel cultivation enhances air temperatures
erting forest and grasslands for biofuel cultivations. Con-
g existing good cropland for food production will help to
m LCC (Searchinger et al. 2008).

; diesel by biofuel reduces the sulfur dioxide (SO_2), but
itrogen oxide (NO_x) emissions (Reijnders and Huijbregts
of biofuel reduces the particulate matter (PM) concen-
d and particle size. Smaller particles, however, have more
effects than larger particles (Pope et al. 1995). Further-
increase the soluble organic fraction and oxidation re-
ıfluence the nanostructure of diesel soot (Reijnders and
8).

s focused on CO_2 changes related to biofuel usage. How-
ange of one fuel by another fuel affects the emissions of
leased during the combustion. The LCC related to biofuel
only alter the physical states and the CO_2 concentra-
ther atmospheric species. The biogenic emissions of the
ions differ from those of the prior land-cover, especially
s are used. Soybeans or rapeseed, typical crops for bio-
ı, emit nitrous oxides (N_2O) (Reijnders and Huijbregts
ganisms fix N-compounds from fertilizer and release N_2O
Various studies suggest that N_2O emissions range be-
nd 5% of the fixed nitrogen added to a field. Typical
ice in German rapeseed and Brazilian soybean fields add
; of fixed nitrogen per km^2, respectively (Reijnders and
8). In Brazil, about 45% and 55% of the soybean harvest
ıd biofuel production, respectively. In Germany, about
ıpeseed harvest serves for biofuel production.

In addition to the up-front impacts, altered biogenic emissions and different emissions of biofuel, the harvest, refining, and distribution of biofuel affect the atmospheric composition. The practice to burn sugarcane for easier harvest, for instance, releases CH_4 and N_2O into the atmosphere. Corn- or sugarcane-based ethanol corrodes the traditional pipelines (`http://www.aaas.org/spp/cstc/briefs/biofuels/`) for which it has to be transported by trucks. This transport emits CO_2 that otherwise would not have been emitted. Biofuel burns differently than fossil fuel and may cause technical problems. The technical developments to overcome the problems may have again environmental impacts.

Several other challenges are related to LCC for biofuel cultivations. Experts predict that the large expansion of biofuel cultivations will reduce biodiversity. The monoculture going along with extensive biofuel production may cause soil erosion and increase runoff. The use of fertilizers may increase as some crops suitable for biofuel production need comparatively huge amounts of nutrients. Fertilization may negatively affect water and air quality. As corn production for biofuel expands into drier areas, irrigation becomes necessary. The additional irrigation may cool and moisten the atmosphere locally. The impact of the altered atmospheric composition on atmospheric chemistry and deposition into ecosystem is still a hot research topic.

4.5 Urbanization, Urban Areas, and Megacities

Projections with various GHG-scenarios suggest an increase of the frequency and length of heat waves (Barnett et al. 2005). Such climate change and variability challenge especially the urban population as they worsen the urban heat island (UHI)-related heat stress. A warmer climate in combination with enhanced emissions affects the chemical reaction rates with impacts on air quality. Changes in precipitation associated with a warmer climate affect urban runoff and may challenge the availability of high-quality water.

4.5.1 Urban Heat Island

Many megacities (e.g., Chicago, New York) are located in geographic regions for which climate projections indicate substantial increases of the number of days with temperatures exceeding 32.2 °C or even 37.8 °C.

examined the relationship between the decrease in emissions after Perestroika and precipitation. The time before Perestroika (1972–1988) was characterized by high and, the time thereafter (1989–2005) by, relatively lower emissions. The authors used daily precipitation data from 1971–2005 from one urban site in and three rural sites around Kraków, Poland. No trend in the precipitation totals were detected for 1971–2005. The precipitation totals of 1972–1988 differ significantly from those of 1989–2005 for only one of the rural sites in winter and for the Kraków site in fall. The improved air quality affected the spatial precipitation pattern mainly in spring and fall for daily-accumulated precipitation greater than 5 mm.

4.5.4 Urban Planning and Development

Urban planning and development affect where and which kind of LCC due to urbanization occur. The future may bring two different types of urbanization. Economic reasons may require more of the work force to live in (mega)cities. An aging population and increased demand for recreational zones along the coasts will lead to LCC for housing and recreational facilities (e.g., golf courses).

Recreational zones typically have urban forest, parks, and other green areas to keep a pleasant microclimate. Thus, the UHI effect remains low in recreational areas even in warm climate zones. The recreational urban areas may become local oases with relatively cooler and wetter conditions than the surroundings, given enough water is available to sustain the urban vegetation. In warm climates, emissions from domestic heating are rather low; traffic and generation of power for electricity and air conditioning are the major anthropogenic emission sources.

For many megacities in developing countries, no or hardly any planning related to the LCC exists. Megacities face environmental problems related to the UHI effect, air quality, and ventilation. Ventilation refers to local and regional wind systems handling the exchange of fresh and polluted air. Wind and subsequent ventilation conditions govern the climate and air quality of any city. For cities in complex terrain and/or at large lakes or the ocean, mesoscale circulations may be relevant for the ventilation and city's climate (Fehrenbach et al. 2001). The knowledge of local and/or mesoscale circulation systems can be used in local planning to improve the QOL and for hazard assessments. If the local wind system, for instance, may become very strong, it may pose the risk of hazards for high buildings in the affected area. The strength of

local wind systems determines the intensity of
tion paths into cities may advect clean or poll
nights with cold air production in the adjacen
low-latitude cities, advection of cold air reduce
latitude cities located in valleys, the drainage
inversion strength.

In some (growing) cities, environmental probl
bad due to direct and indirect couplings of ai
and local or mesoscale circulation systems (O
Spain, for instance, O_3 concentration can beco
rounding mountains and the sea breeze trap t
The nocturnal land breeze advects pollutants
Sea. The next day's sea breeze then advects
time, daytime pollution levels raise.

The paths for clean air and/or cool air adve
fied for growing (mega)cities. Authorities have
emission sources are inserted into these ventila
sources exit in the ventilation paths, emission-r
to be taken. Growing cities with reduced ventilat
frequent temperature inversions are extremely re
In these cities, emissions should be reduced as f

Structural properties like aerodynamic rough
displacement, effective building heights, and dens
affect local atmospheric conditions. New const
paths have to be avoided when they increase su
act as flow obstacles. Flow obstacles and high su
nocturnal drainage flows. If ventilation paths a
building structures, measures may be necessary

Since city centers, parks, and suburban, com
areas interact differently with the ABL, local clim
parts of a city. The natural and anthropogenic
these parts of a city as well. Thus, ensuring a
surfaces may reduce the UHI effect that otherwi
in response to the growing (mega)city.

The climate of growing megacities depends s
planning or the lack thereof. Any urban plannin
of huge amounts of data from various sources (e.g.
emission, topography, soil, and meteorological da
local relationships (Hunt and Watkiss 2011). Plann
identified and/or designed. The huge amount of d
may make the planning cumbersome. Some of th

preci stance, examined the rela-
betwe fter Perestroika and precip-
The time before Perestroika (1972–1988) was characterized by
, the time thereafter (1989–2005) by, relatively lower emissions.
iors used daily precipitation data from 1971–2005 from one ur-
in and three rural sites around Kraków, Poland. No trend in
pitation totals were detected for 1971–2005. The precipitation
1972–1988 differ significantly from those of 1989–2005 for only
e rural sites in winter and for the Kraków site in fall. The im-
r quality affected the spatial precipitation pattern mainly in
d fall for daily-accumulated precipitation greater than 5 mm.

Urban Planning and Development

planning and development affect where and which kind of LCC
banization occur. The future may bring two different types of
ion. Economic reasons may require more of the work force
(mega)cities. An aging population and increased demand for
al zones along the coasts will lead to LCC for housing and
al facilities (e.g., golf courses).
ional zones typically have urban forest, parks, and other green
eep a pleasant microclimate. Thus, the UHI effect remains
reational areas even in warm climate zones. The recreational
as may become local oases with relatively cooler and wetter
than the surroundings, given enough water is available to
urban vegetation. In warm climates, emissions from domestic
e rather low; traffic and generation of power for electricity and
oning are the major anthropogenic emission sources.
y megacities in developing countries, no or hardly any plan-
d to the LCC exists. Megacities face environmental problems
the UHI effect, air quality, and ventilation. Ventilation refers
d regional wind systems handling the exchange of fresh and
r. Wind and subsequent ventilation conditions govern the cli-
air quality of any city. For cities in complex terrain and/or
kes or the ocean, mesoscale circulations may be relevant for
tion and city's climate (Fehrenbach et al. 2001). The knowl-
al and/or mesoscale circulation systems can be used in local
improve the QOL and for hazard assessments. If the local
m, for instance, may become very strong, it may pose the
rds for high buildings in the affected area. The strength of

local wind systems determines the intensity of the UHI effect. Ventilation paths into cities may advect clean or polluted air especially during nights with cold air production in the adjacent rural area. In mid- and low-latitude cities, advection of cold air reduces the UHI effect. In high-latitude cities located in valleys, the drainage of cold air may enhance inversion strength.

In some (growing) cities, environmental problems become particularly bad due to direct and indirect couplings of air pollution, UHI effects, and local or mesoscale circulation systems (Oke 1995). In Barcelona, Spain, for instance, O_3 concentration can become very high as the surrounding mountains and the sea breeze trap the pollution in the city. The nocturnal land breeze advects pollutants onto the Mediterranean Sea. The next day's sea breeze then advects aged polluted air. Over time, daytime pollution levels raise.

The paths for clean air and/or cool air advection have to be identified for growing (mega)cities. Authorities have to ensure that no major emission sources are inserted into these ventilation paths. If emission sources exit in the ventilation paths, emission-reduction measures have to be taken. Growing cities with reduced ventilation, high emissions, and frequent temperature inversions are extremely receptive to air pollution. In these cities, emissions should be reduced as far as possible.

Structural properties like aerodynamic roughness length, zero-point displacement, effective building heights, and density of the urban canopy affect local atmospheric conditions. New constructions in ventilation paths have to be avoided when they increase surface roughness and/or act as flow obstacles. Flow obstacles and high surface roughness weaken nocturnal drainage flows. If ventilation paths are in areas with dense building structures, measures may be necessary to improve ventilation.

Since city centers, parks, and suburban, commercial, and industrial areas interact differently with the ABL, local climates differ among these parts of a city. The natural and anthropogenic emissions differ among these parts of a city as well. Thus, ensuring a mix of different urban surfaces may reduce the UHI effect that otherwise would occur locally in response to the growing (mega)city.

The climate of growing megacities depends strongly on intelligent planning or the lack thereof. Any urban planning requires the analysis of huge amounts of data from various sources (e.g., land-use, land-cover, emission, topography, soil, and meteorological data) and knowledge of local relationships (Hunt and Watkiss 2011). Planning criteria have to be identified and/or designed. The huge amount of data and relationships may make the planning cumbersome. Some of the data interpretation may also be nonobjective. Thus, decisions may be irreproducible for similar cases when officers change.

Fehrenbach et al. (2001) suggested an automatic tool that provides a knowledge-based classification for planning objectives. The conceptual model relies on spatially distributed data of land-cover and topography from a Geographic Information System (GIS). The model uses conceptual relationships concerning land-cover and ventilation, the dominant controls of local climate and air quality and a knowledge-based classification scheme for climate analysis to identify automatically critical areas with respect to ventilation, air quality, and thermal effects. The model uses three different information layers to classify each $100 \times 100\,\mathrm{m}^2$ grid element. It assigns zero or one planning objective per problem section to each grid element. Critical areas typically have a combination of three different planning objectives. Uncritical areas are not associated with any objective. The model provides reproducible maps of urban climate and air quality that can be evaluated by meteorological and air chemistry measurements.

This conceptual model is objective and provides a high degree of transparency. Therefore, maps created by the model are well suited for urban and regional planners in their initial planning. These maps cannot replace the legally required environmental impact assessment studies. However, they make preparing and designing the network for the meteorological and air chemistry measurements and identifying cases for regulatory photochemical modeling more cost efficient (Fehrenbach et al. 2001).

4.6 Detecting Land-Cover Changes in Observations

As discussed in Chap. 3, impacts of LCC on local climate are difficult to detect in measurements. Typically, long-term monitoring data are taken over extended patches of grass or bare soil. Thus, the data rather represent the advected response to upwind LCC than a change at the site. Association of a change in the microclimate at a site requires additional knowledge. It has to be excluded that relocation of the site caused the change. Changes in site location mean a different latitude and/or longitude and potentially different elevation and exposure to dominant major flow patterns (e.g., drainage flows, mesoscale circulations, emission sources). These changes may affect the measured air and dewpoint temperature, their minimum and maximum values, wind speed and direction, and concentrations. Consequently, even if the new

---

and old locati
change due to

Other diffic
ence to report
derreporting.
observers cha
paper records
tainty makes
with LCC in

Sampling o
to assess the
works for the
tection of LC
and limitation
quire develop
clusions.

The recent
it even more
PaiMazumder
design may af
$50 \times 50\,\mathrm{km}^2$ i
and 2007 usin
using this dat
perature, and
"truth." They
encompassed
taken WRF-g
they projecte
called "real"
the real netwo
culturally use
of the 41 netw
the "reference
values. Their
100-sites-netw
distribution o
the 30 random
tributed sites
and spatial va
tation average
High-density
convective pre