Satellites, Weather and Climate Module 42:

Anthropogenic climate change: Urban heat islands

Urban Heat Islands: Module goals

What are **Urban Heat Islands?**

- History
- Implications
- Characteristics
- Levels and Scales
- New concepts

http://vortex.accuweather.com

What is the **energy balance equation?**

- What are the individual terms?
- Can we do anything?

Are there **interactions with regional geography**?

What are the **large-scale weather factors**?

Which **neighborhood characteristics are factors**?

Introduction: Urban Heat Islands (UHIs)

Definition: *"Closed isotherms indicating an **area that is relatively warm**; most commonly associated areas of human disturbance such as **towns and cities**."*

History:

- **1819** British chemist Luke Howard examined *The Climate of London*
- Modern Era "Grandfathers": **Robert Bornstein, Tim Oke**

Implications:

- Human comfort (+/-)
- Snow and ice
- Growing season length
- Energy consumption (+/-)
- Ozone concentrations, formation rates
- Storm water temperatures, oxygen-levels

UHI basics: characteristics

Knowledge: Temperate, Mediterranean climates

Seasonality

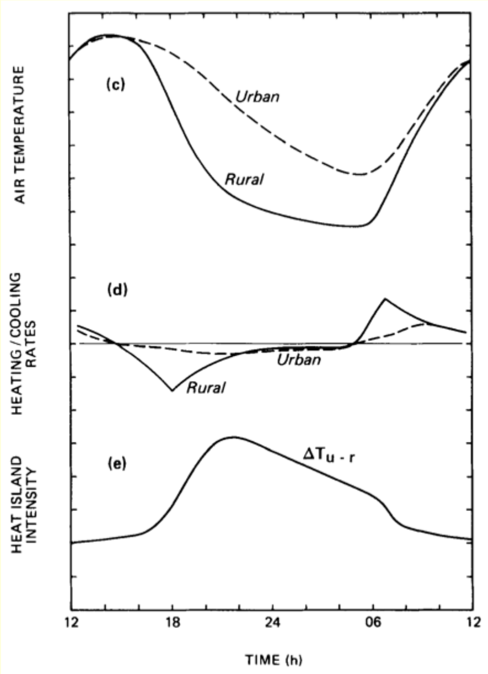
- *Temperate cities: seasonal cycle (Summer, Autumn)*
- *Tropical cities: dry season enchanced*

Urban Heat Island ***signal proportional*** *to city* ***population***

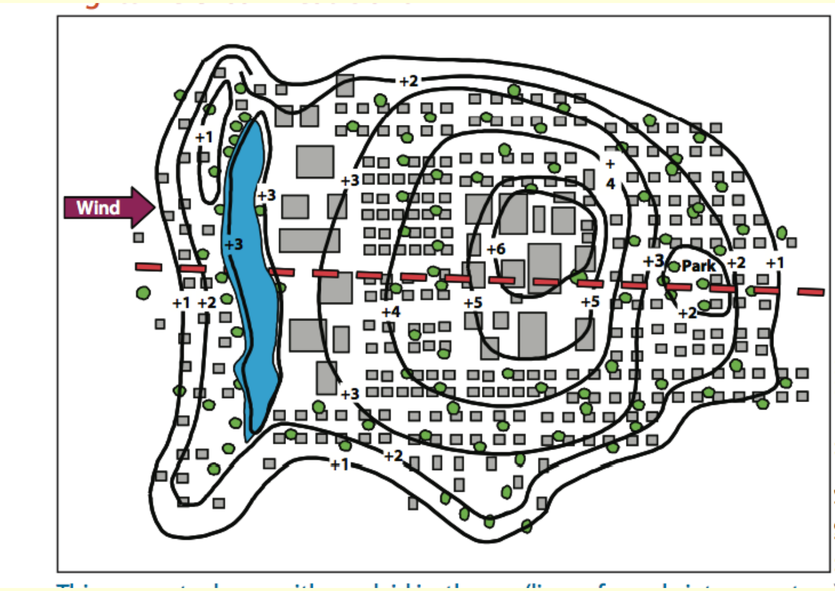
Time of Day: middle of the **night**

Misc. controls

- Weather
- Solar intensity
- Anthropogenic heat



Oke 1982

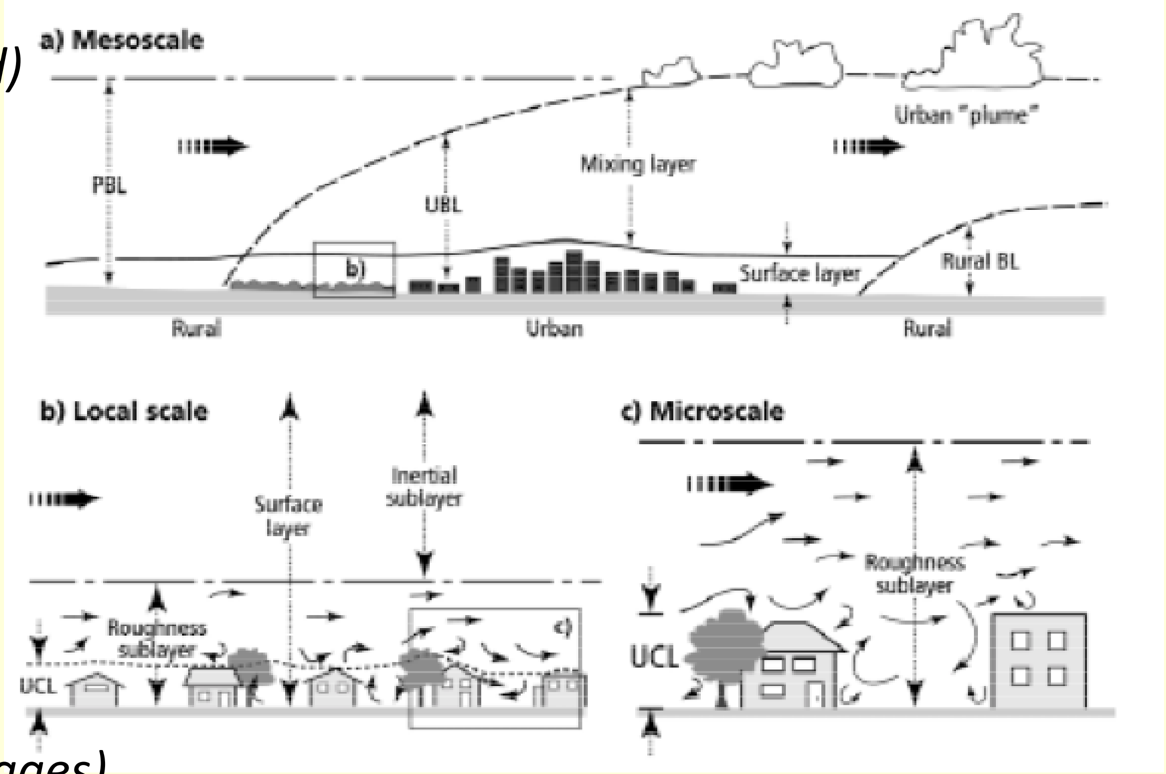


EPA: Reducing urban heat islands; originally from Voogt 2000

UHI basics: scales and (vertical) levels

Scale

- *Microscale (yard)*
- *Local (neighborhood)*
- *Mesoscale (city)*



Vertical level

- *Surface (thermal images)*
- *Urban canopy layer (mean height of buildings, trees)*
- *Urban boundary layer (vertical extent of urban influence)*

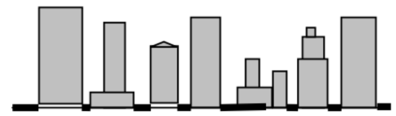
Modern concepts: urban climate zones

Old thought

- Rural vs urban

New thought

- Urban Climate Zone comparison

Urban Climate Zone, UCZ[1]	*Image*	*Rough-ness class*[2]	*Aspect ratio*[3]	*% Built (imperm-eable)*[4]
1. *Intensely developed urban with detached close-set high-rise buildings with cladding, e.g. downtown towers*		8	> 2	> 90
2. *Intensely developed high density urban with 2 – 5 storey, attached or very close-set buildings often of brick or stone, e.g. old city core*		7	1.0 – 2.5	> 85
3. *Highly developed, medium density urban with row or detached but close-set houses, stores & apartments e.g. urban housing*		7	0.5 – 1.5	70 - 85
4. *Highly developed, low or medium density urban with large low buildings & paved parking, e.g. shopping mall, warehouses*		5	0.05 – 0.2	70 - 95
5. *Medium development, low density suburban with 1 or 2 storey houses, e.g. suburban housing*		6	0.2 – 0.6, up to >1 with trees	35 - 65
6. *Mixed use with large buildings in open landscape, e.g. institutions such as hospital, university, airport*		5	0.1 – 0.5, depends on trees	< 40
7. *Semi-rural development, scattered houses in natural or agricultural area, e.g. farms, estates*		4	> 0.05, depends on trees	< 10

Key to image symbols: buildings; vegetation; impervious ground; pervious ground

[1] A simplified set of classes that includes aspects of the schemes of Auer (1978) and Ellefsen (1990/91) plus physical measures relating to wind, thermal and moisture controls (columns at right). Approximate correspondence between UCZ and Ellefsen's urban terrain zones is: 1(Dc1, Dc8), 2 (A1-A4, Dc2), 3 (A5, Dc3-5, Do2), 4 (Do1, Do4, Do5), 5 (Do3), 6 (Do6), 7 (none).

[2] Effective terrain roughness according to the Davenport classification (Davenport *et al.*, 2000); see Table 2.

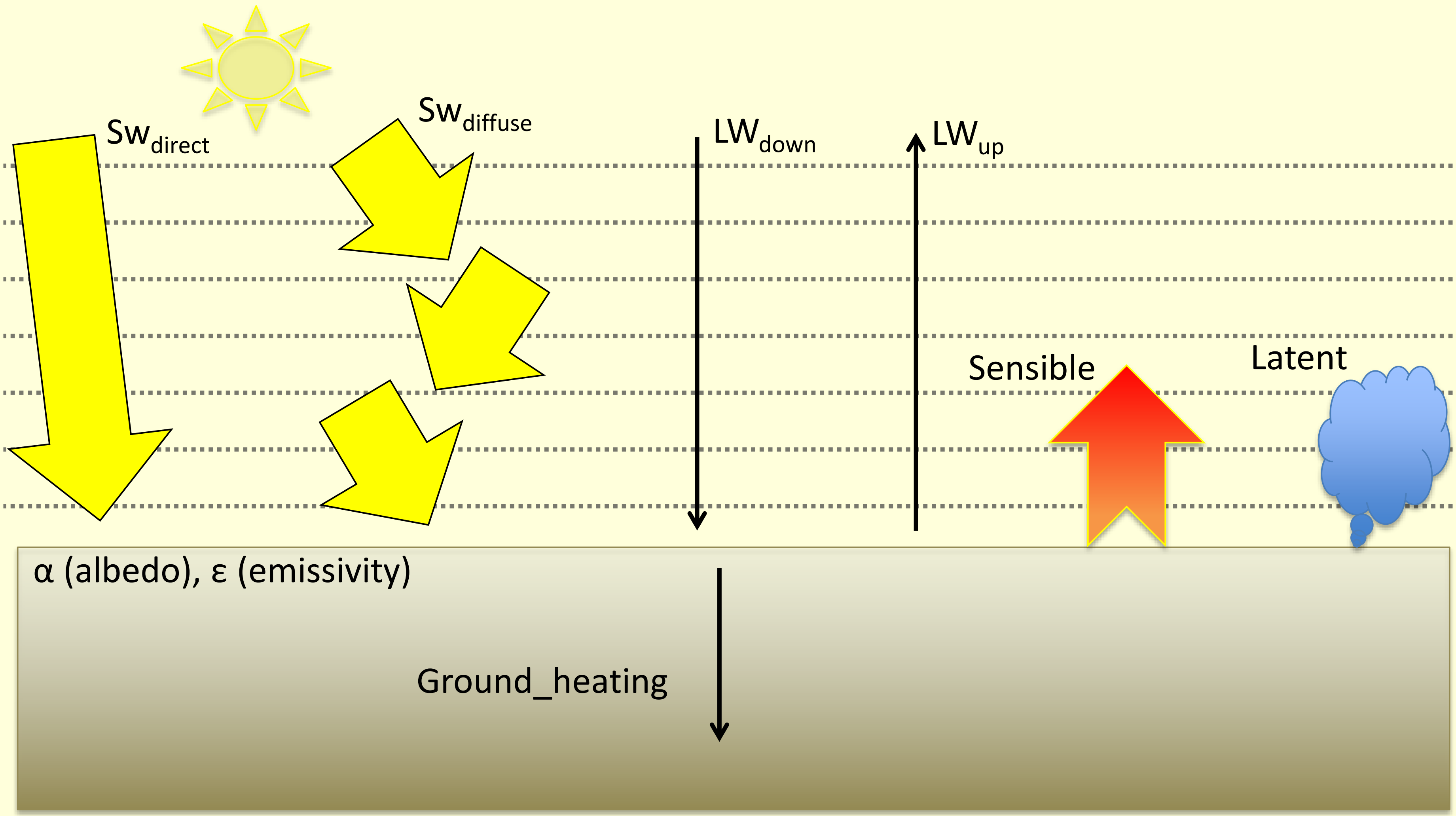
[3] Aspect ratio = z_H/W is average height of the main roughness elements (buildings, trees) divided by their average spacing, in the city centre this is the street canyon height/width. This measure is known to be related to flow regime types (Oke 1987) and thermal controls (solar shading and longwave screening) (Oke, 1981). Tall trees increase this measure significantly.

[4] Average proportion of ground plan covered by built features (buildings, roads, paved and other impervious areas) the rest of the area is occupied by pervious cover (green space, water and other natural surfaces). Permeability affects the moisture status of the ground and hence humidification and evaporative cooling potential.

Governing physics: surface energy balance

Surface energy balance:

$(1-\alpha)*(Sw_{direct}+Sw_{diffuse}) + \varepsilon*(LW_{down} - Lw_{up}) - Ground\_heating = Sensible + Latent$



How cities alter the equation: latent/sensible

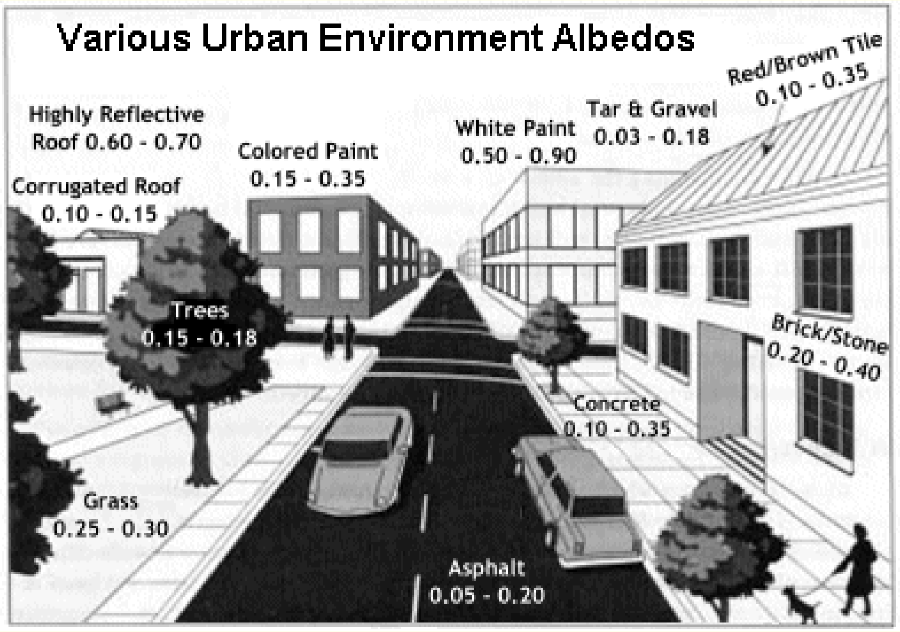
- Imperviousness surfaces: "*A ground cover type that is **never porous and typically man-made**.*"
  - Sidewalks, rooftops, parking lots and roads
  - City: 10-90% in a city, Rural: < 10%
- **Reduction in latent heat**
- Mitigation: Permeable surfaces, urban irrigation

How cities alter the equation: radiation interference

- Sky view factor: "*the **fraction of sky visible** from ground level*"
- Urban Canyon: *"**canyon-like environment of a street/alley** bordered by tall buildings on both sides"*
- **Reduction in upwards longwave radiation(night**)
- Reduction in downwards direct radiation (day)
- Mitigation: development guided by H:W

How cities alter the equation: albedo/emissivity

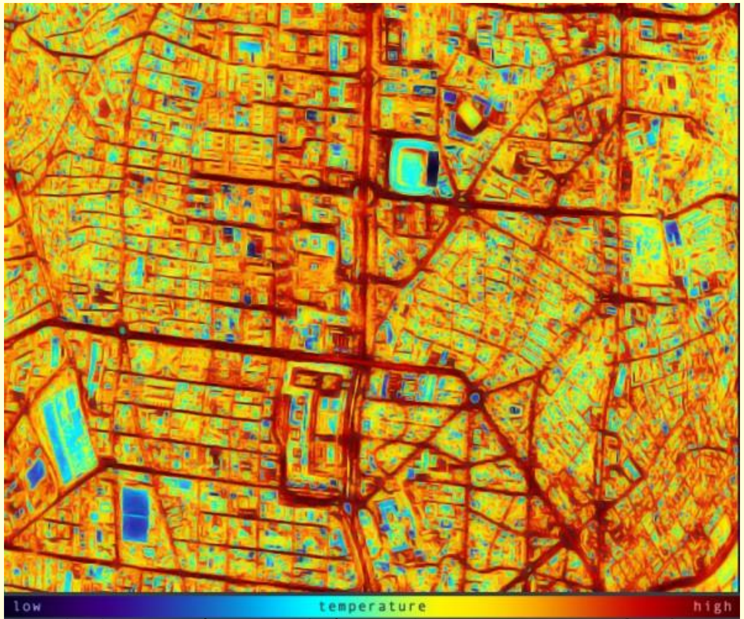
- Albedo: *“**ability to reflect** radiation”*
- Effective albedo: *“topographic features causing short wave **radiation trapping**”*
- Emissivity: *“effectiveness in **emitting/receiving energy as thermal radiation**”*
- Effect on equation:
  - **Albedo reductions**
  - **Effective albedo reductions**
  - **Emissivity increases** (except metal)



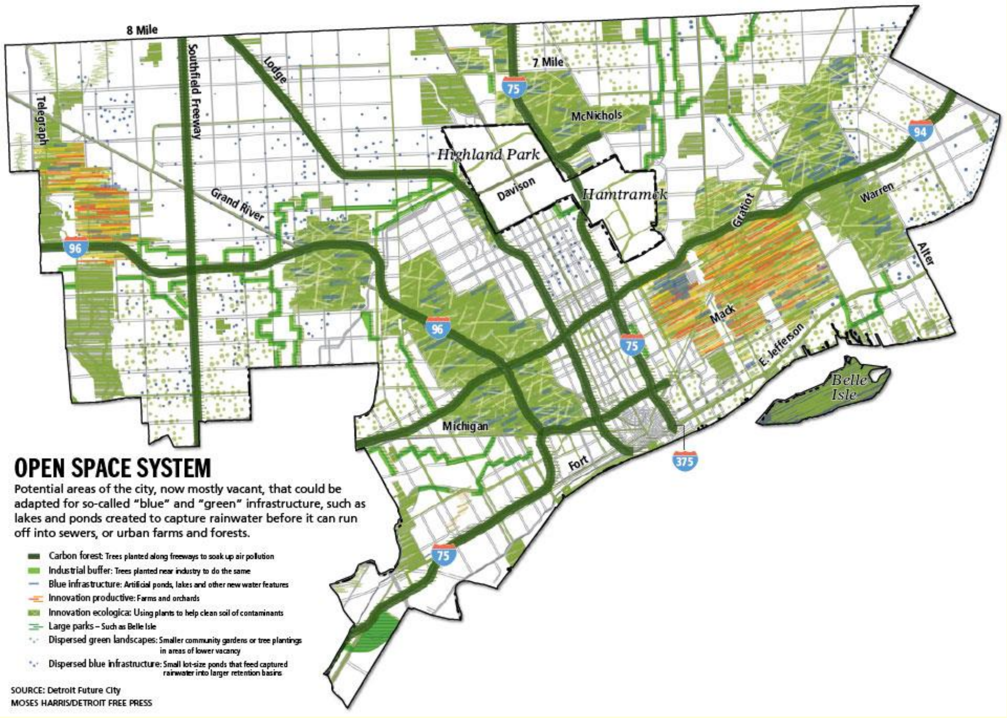
- Mitigation
  - Cool roofs
  - Urban greening
  - Cement (not asphalt)
  - Natural ground

How cities alter the equation: Absorption, storage

- Heat capacity: *"the ratio of the heat added to (or subtracted from) an object to the resulting temperature change."*
- Most building materials have higher heat capacities than rural materials
- Effect on surface energy balance
  - More effective at storing heat within their infrastructure
  - Release of heat overnight
- Mitigation:
  - building materials
  - Zoning changes



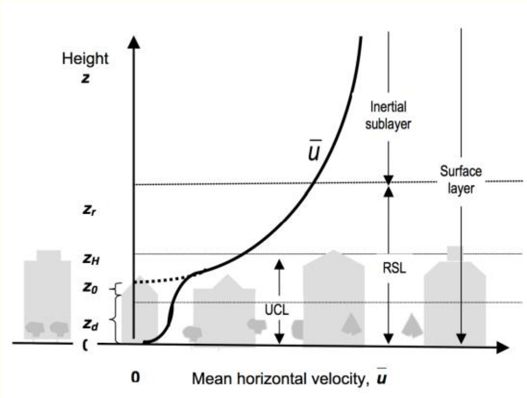
Madrid, Spain (overnight); Credits: University of Valencia

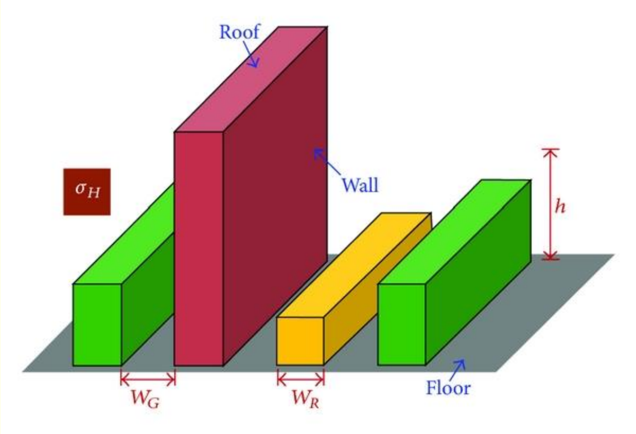


How cities alter the equation: Wind, convection

- Turbulent exchange: *"transfer rate of a property by turbulent eddies"*
- Aerodynamic roughness length: *"a measure of the capacity of the surface elements in absorbing momentum"*
- Wind: surface morphology creates **flow distortion**
- **Reduced turbulent exchange of heat, pollutants**

Cao doi 10.1155/2014/267683

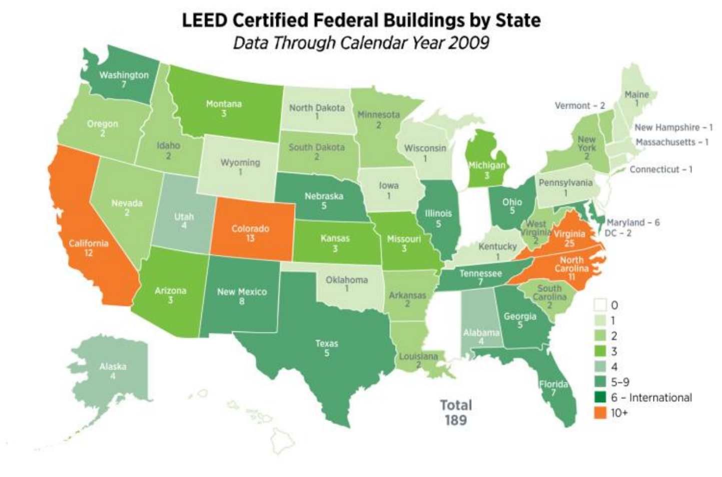




- Convection: *"Transfer of heat from one place to another by the movement of a fluid"*
- Aerodynamic roughness length influences convection
- Effect on energy balance
  - **Dry climates: less efficient than surroundings**
  - **Humid climates: more efficient than surroundings (Zhao et al. 2014)**

How cities alter the equation: Anthropogenic heat

- Anthropogenic heat: *“**heat from buildings, transportation, manufacturing,** lighting and human and animal metabolisms”*
- Depends on
  - latitude
  - time of year
  - population density
- Mitigation
  - Energy consumption of buildings
  - Heat – Anthropogenic Heat feedback
  - Bike usage
  - Recycling industrial heat



Mitigation technique example: Urban forests

Interesting solution to the energy equation: Urban oasis

- Oasis: “is an isolated area of vegetation in a desert”
- Cities **in dry regions** are more vegetated, moist
- Predominantly artificial watering
- Equation influenced
  - More latent
  - Convection reduced
- Daytime phenomena

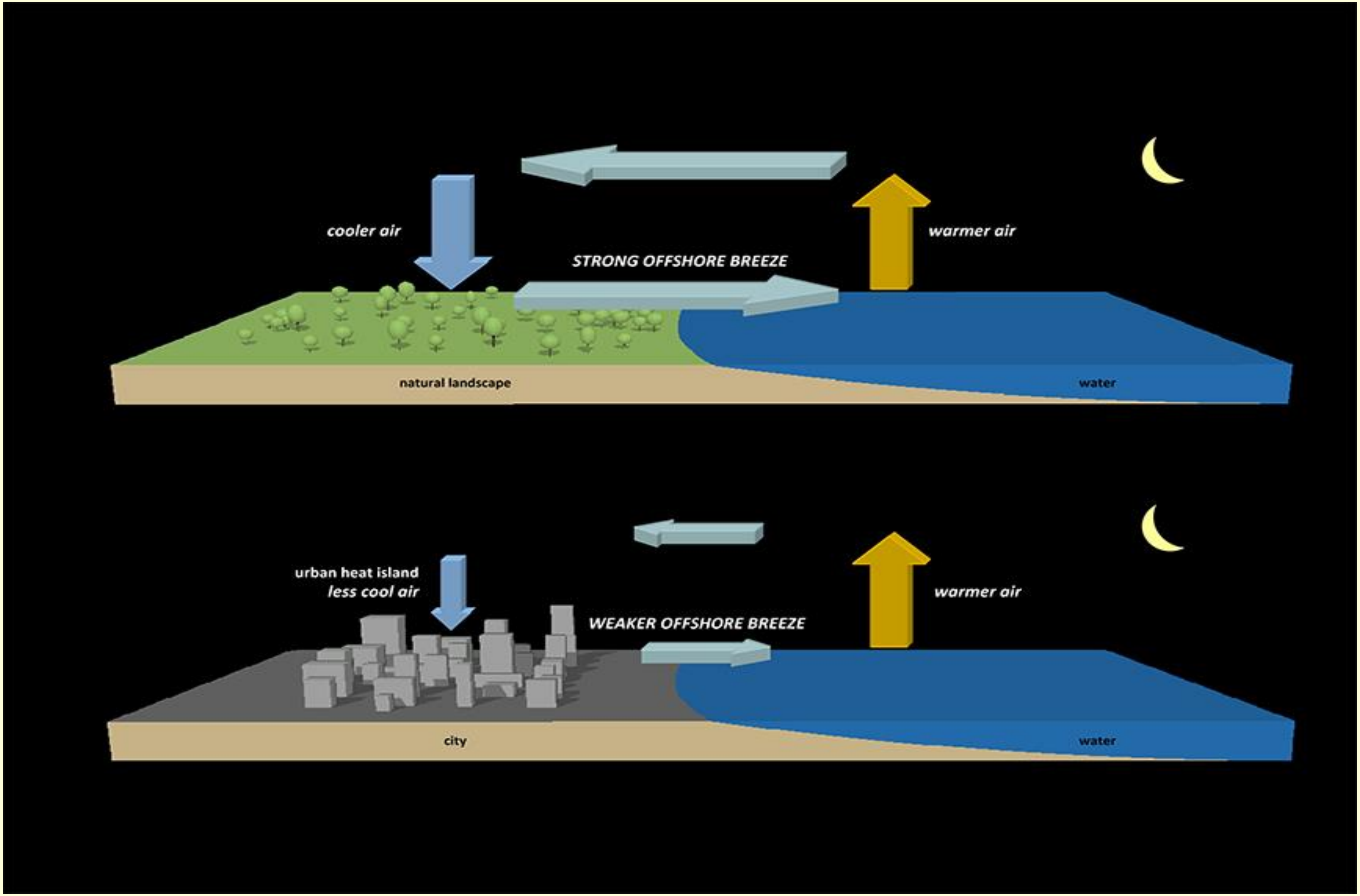
Regional geography influences: circulation changes

- Valley circulations
  - Break up inversions (Cao and Lin 2014)

- Mountains
  - Block wind from reaching a city
  - Create wind patterns that pass through a city

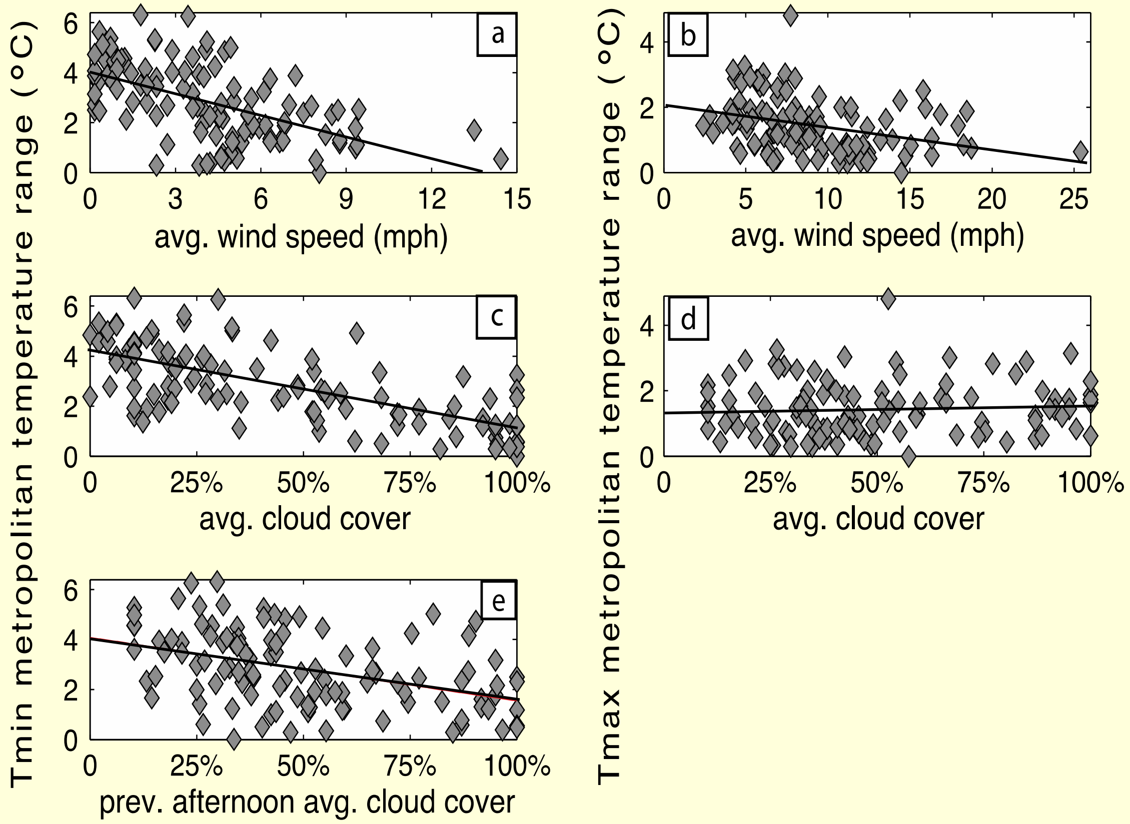
- Sea breeze/lake breezes**: little agreement**
  - Stronger daytime sea breeze circulation (Chen et al. 2010; Houston)
  - Slowed nighttime lake-breeze front (Keeler and Kristovich 2012; Chicago)
  - Accelerated nighttime lake-breeze front (Freitas et al. 2007; São Paulo, Brazil)
    - Stalls over center of city
    - Slowed front movement after city center
  - (day) Lake-breeze cools city (Oswald et al. 2012; Detroit)
  - (night) Land-breeze moves heat/pollution away (night)

Circulation changes: example



Large-scale controls: Favorable conditions

- Heat Island effect
- Wind
- Cloud cover
  - Reduces shortwave
  - Reduces longwave
  - Storage implications
  - Yesterday
- Surface pressure (high)
- Atmospheric moisture
- Low haze

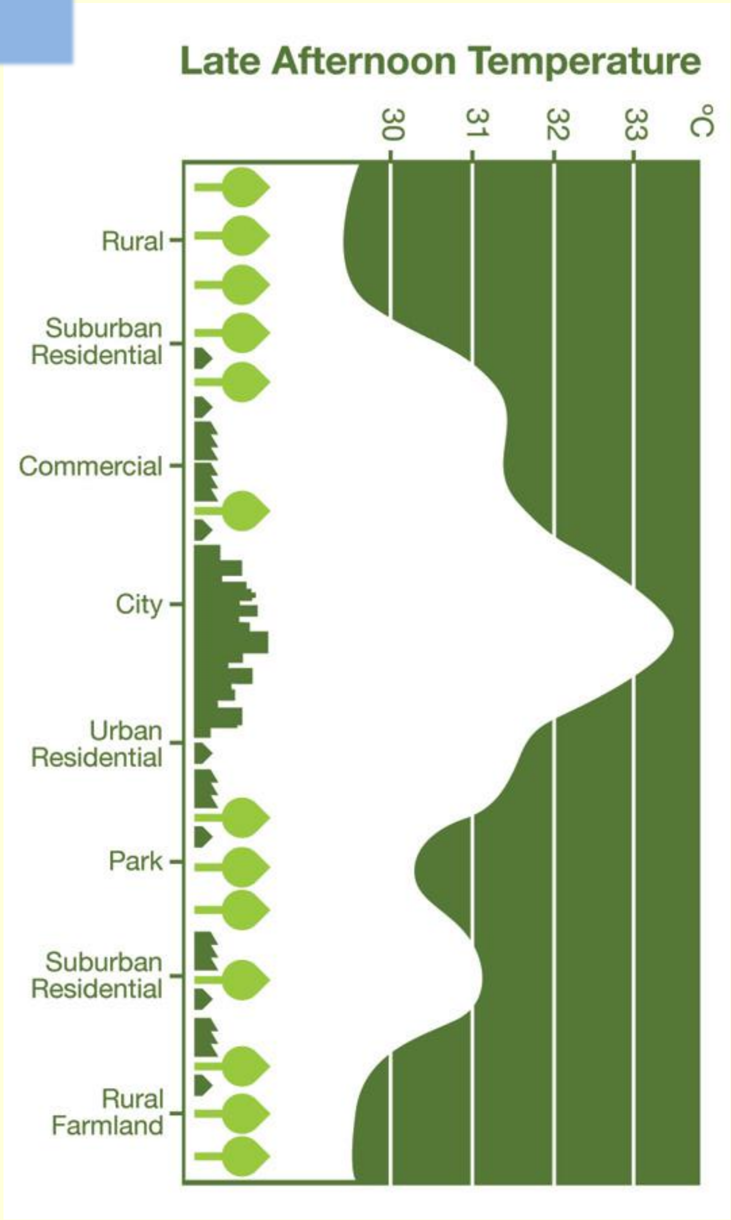


Detroit's range in temperature across a monitoring network as a function of (3) local airport observations. Oswald et al. (2012)

Neighborhood characteristics:

- **Intra-urban variability** of temperatures
- Measured
  - Mobile transects (vehicle, plane)
  - Dense in-situ observing network
  - Satellite imagery

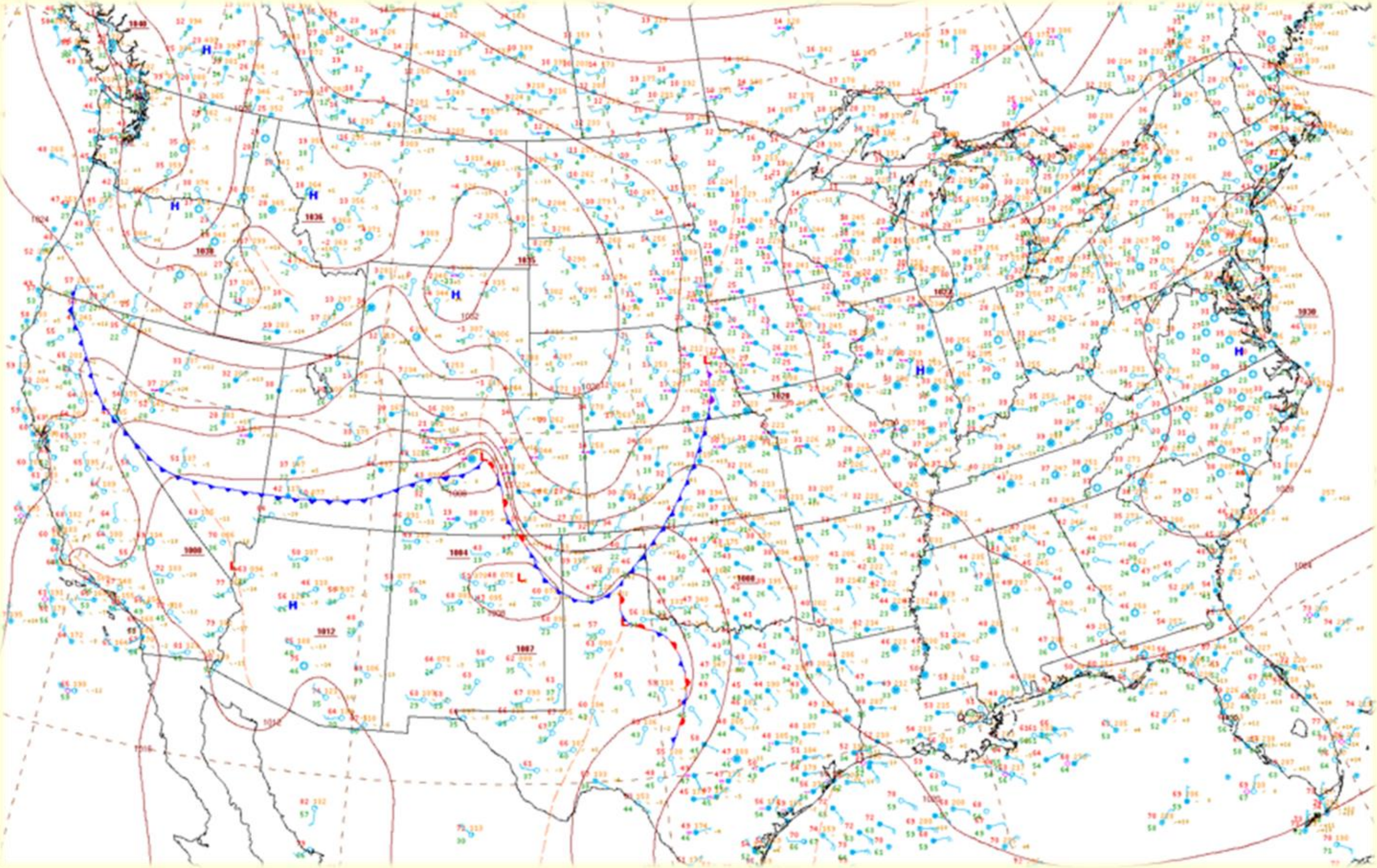
- **Characteristics**
  - Vegetative abundance
  - Percent imperviousness
  - Canopy cover (i.e. trees)
  - Building density, heights, types and uses
  - Road features
  - Sky view factor
  - Elevation
  - Socioeconomic factors: household income



Putting it all together: Weather Channel movie

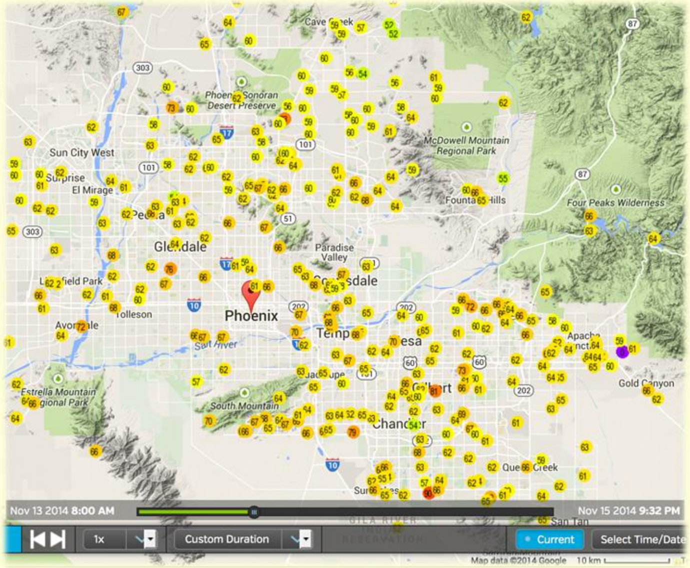
Activity: Weather Underground

- Find **locations** where you the urban heat island would be **strong or weak**
  - High pressure and low pressure (light winds, low cloud cover)
  - http://www.hpc.ncep.noaa.gov/sfc/lrgnamsfcwbg.gif



Activity: Weather Underground

- Go to Weather Underground
  - Find wundermap
  - http://www.wunderground.com/wundermap/
  - Look at big city in location(s)
  - Unselect radar and satellite images
  - Use calendar option (bottom-right) to past 2 calendar dates
  - Click “play”; can adjust speed; examine specific times
  - Patterns in the early AM or mid afternoon
  - Absence of patterns



- Once a pattern is found, explore why!
  - Neighborhood features
  - Can explore neighborhoods using Google Maps; particularly Streetview