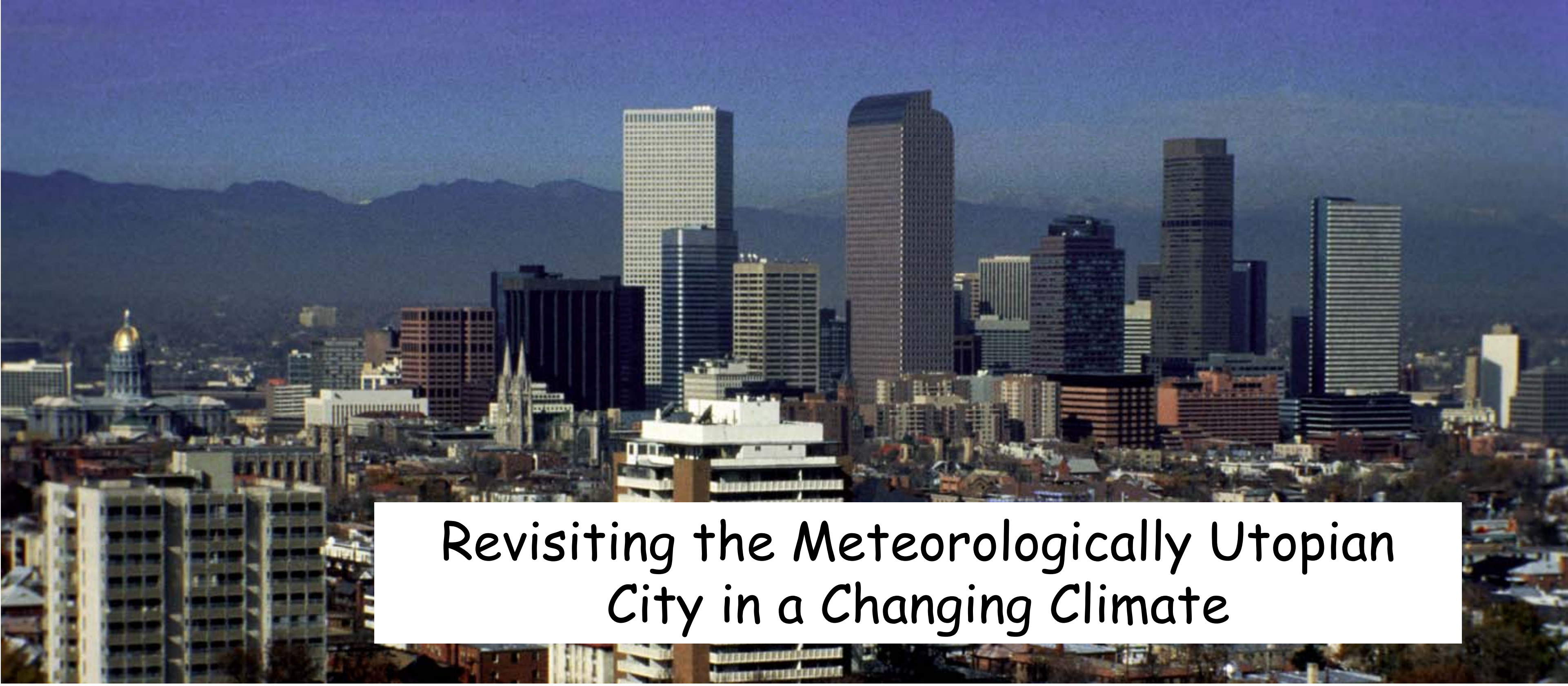

Revisiting the Meteorologically Utopian City in a Changing Climate

Gordon Bonan
National Center for Atmospheric Research
Boulder, Colorado

Institute of Urban and Regional Development and Department of City and Regional Planning
University of California-Berkeley, Berkeley, CA
15 November 2007

A scientist's perspective

Landsberg discussed the urban climate and the role of science in urban planning

Numerous conferences in the 1970s and 1980s sponsored by the World Meteorological Organization on urban climate and urban planning

the meteorologically utopian city[1,2,3]

Helmut Landsberg
Institute for Fluid Dynamics and Applied Physics
University of Maryland
College Park, Md. 20742

Abstract

Despite the problems of our decaying cities, there will be an increasing need for greater urbanization for some time to come. Granted the necessity for the existence of towns, how should they be built and function? Widely divergent views have come from architects, engineers, economists, political scientists, and real estate developers. To this chorus of intellectual bricklayers, the meteorologist is a johnny-come-lately. The meteorological requirements to be considered in the optimal design of towns are discussed in this article.

The cities, once the pride of nations, are decaying. Were it not for historic sites in some, or centers of communication and commerce in others, their doom as slum sites would be sealed. Admittedly, there are half-hearted endeavors toward urban renewals and some attempts to build new towns, but is this enough? There are inescapable estimates that in this country between 20 and 30 million more people will have to be housed by the end of the century. There are other reasonable projections that new technology will permit, by that time, all the nation's crops to be raised with 3% of the work force. That will further intensify the flight from farm to town. All in all, there will be a dire need for more urban settlement. If one looks abroad, the problems are not different, and perhaps in some countries even more aggravated.

There have been innumerable proposals on how to get out of the dilemma. Some experiments have been undertaken, but there is much resignation and a tendency to let things develop, in a random fashion, into chaos. The problems are political and organizational, physical and fiscal, historical and sociological, ethnic and geographical, industrial and economic. Yet it is obvious that many of the historical reasons for towns have vanished. Where it was once advantageous to band together for defense behind walls and towers, this is an invitation to disaster in the nuclear age. Where once the only means of communication were the face-to-face meetings or letters that took weeks to arrive from any distance, global space can now be spanned with the speed of light. If personal presence is necessary, distances that took days to overcome are now in reach within hours. And often the last stretch of a few miles between an airport and the urban center in rush hour traffic is as agonizingly slow as in the horse-and-buggy age.

The question is therefore: Why towns, and if towns, what kind of towns? Let me admit at once that towns have a *raison d'être* as convenient centers of communications, as hubs and transit points of traffic, as agglomerations of sufficient population to support cultural, educational, and sports enterprises as well as large stores. Thus the only major question remaining is, how should a town be built and function? This question will be answered quite differently by persons of different background and indeed, widely divergent views have been expressed by architects, traffic engineers, economists, political scientists, and real estate developers, with some attempts by planners—more recently aided by systems analysts, with the now inevitable but not infallible computer—to integrate all this into an optimal design.

In this chorus of intellectual bricklayers, the meteorologist is a johnny-come-lately. We may ask ourselves: Do we have anything worthwhile to contribute? In this audience, this may be a rhetorical question, but not elsewhere. Let me attempt an answer here. It will be given with an avowedly meteorological bias. In fact, my approach will be one that meteorologists and perhaps others should take more often: in the light of the known facts, to arrive at an optimal design and then compromise with other realities later. Indeed, I have often felt we should use this system too in designing meteorological networks, rather than let other factors dictate to us where we should take our observations; but that is another question. Obviously this approach is utopian—hence the title of my talk. However, there are some sound meteorological principles that must begin to penetrate the planning process. Currently, while the ravages of "Agnes" of June 1972 are still fresh in our minds, it is appropriate to start with the problem of floods. If a town is planned for a river or creek valley, or being redeveloped along such water bodies, the flood plains that our geological colleagues can readily map are

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[1] Address before the American Meteorological Society Conference on Urban Environment, Philadelphia, Pa. 1 November 1972.

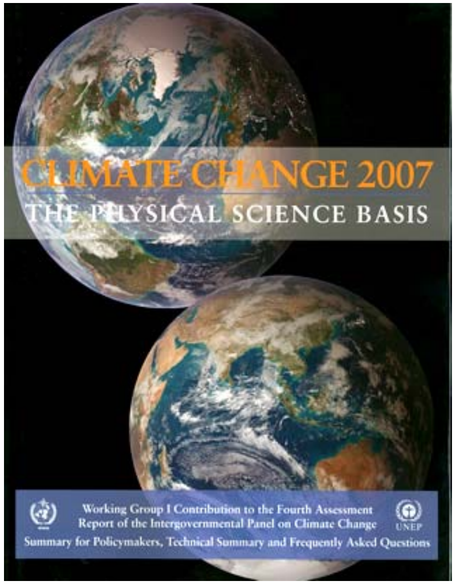
[2] Publication No. 77 of Graduate Program in Meteorology.

[3] Based on work supported by NSF Grant GR-29304X.

Landsberg (1973) Bulletin American Meteorological Society 54:86-89

Climate of the 20th century

The IPCC released its 4th assessment report in 2007. This influential report has greatly changed the scientific debate about climate change.



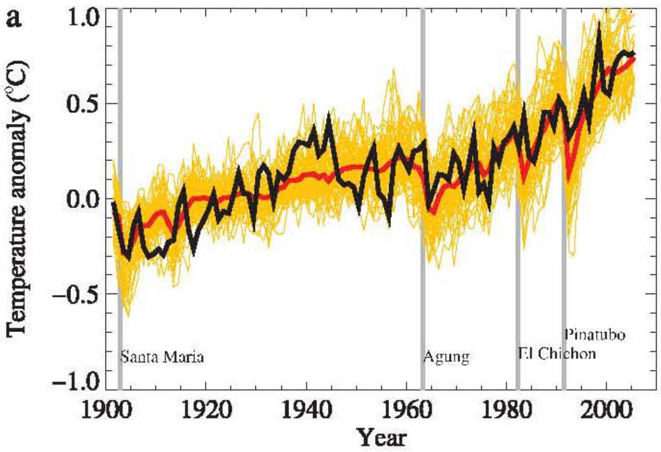
CLIMATE CHANGE 2007
THE PHYSICAL SCIENCE BASIS

Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change
Summary for Policymakers, Technical Summary and Frequently Asked Questions
UNEP

It is *extremely unlikely* (<5%) that the global pattern of warming during the past half century can be explained without external forcing, and *very unlikely* that it is due to known natural external causes alone.

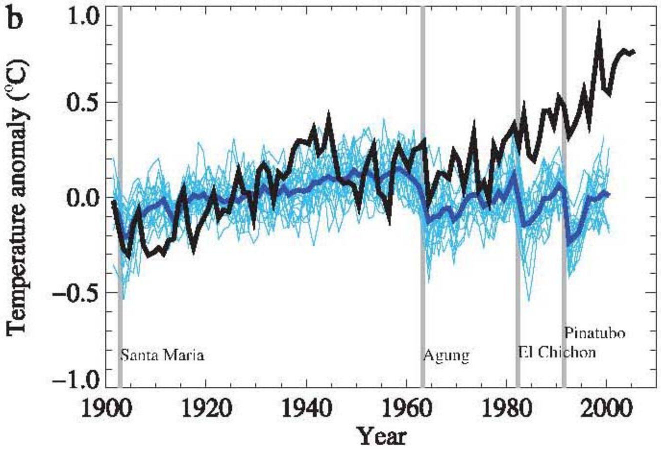
Hegerl et al. (2007) in *Climate Change 2007: The Physical Science Basis,* Solomon et al., Eds., 663-745

Anthropogenic and natural forcings



Anthropogenic forcings
Greenhouse gases
Sulfate aerosols
Black carbon aerosols
Ozone

Natural forcings only



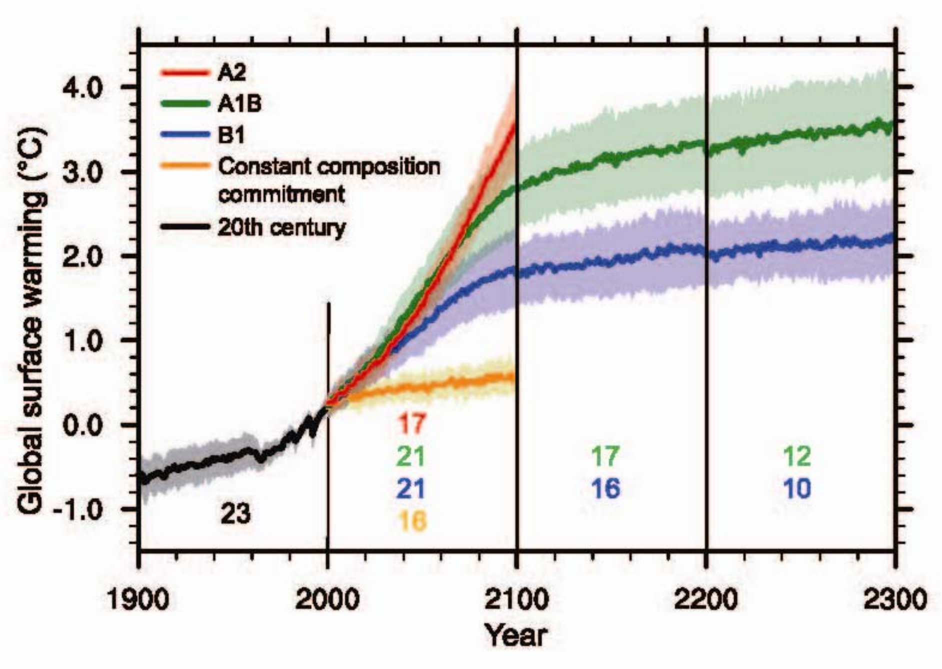
Natural forcings
Solar variability
Volcanic aerosols

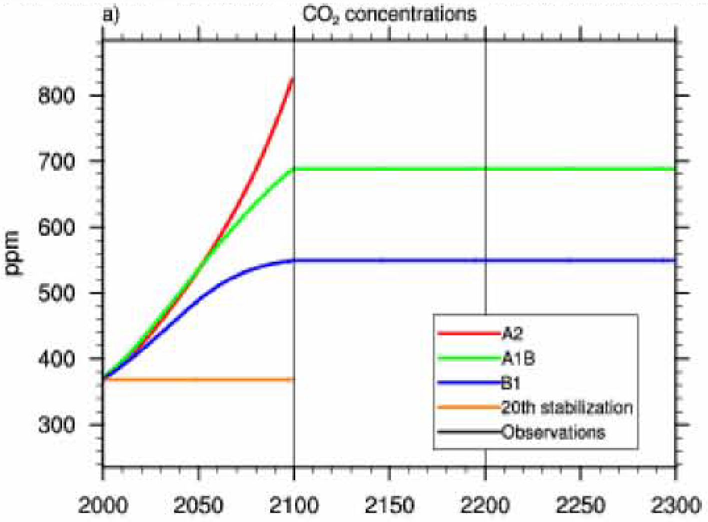
Climate of the 21st century

Multi-model mean surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1

Multi-model mean warming and uncertainty for 2090 to 2099 relative to 1980 to 1999:

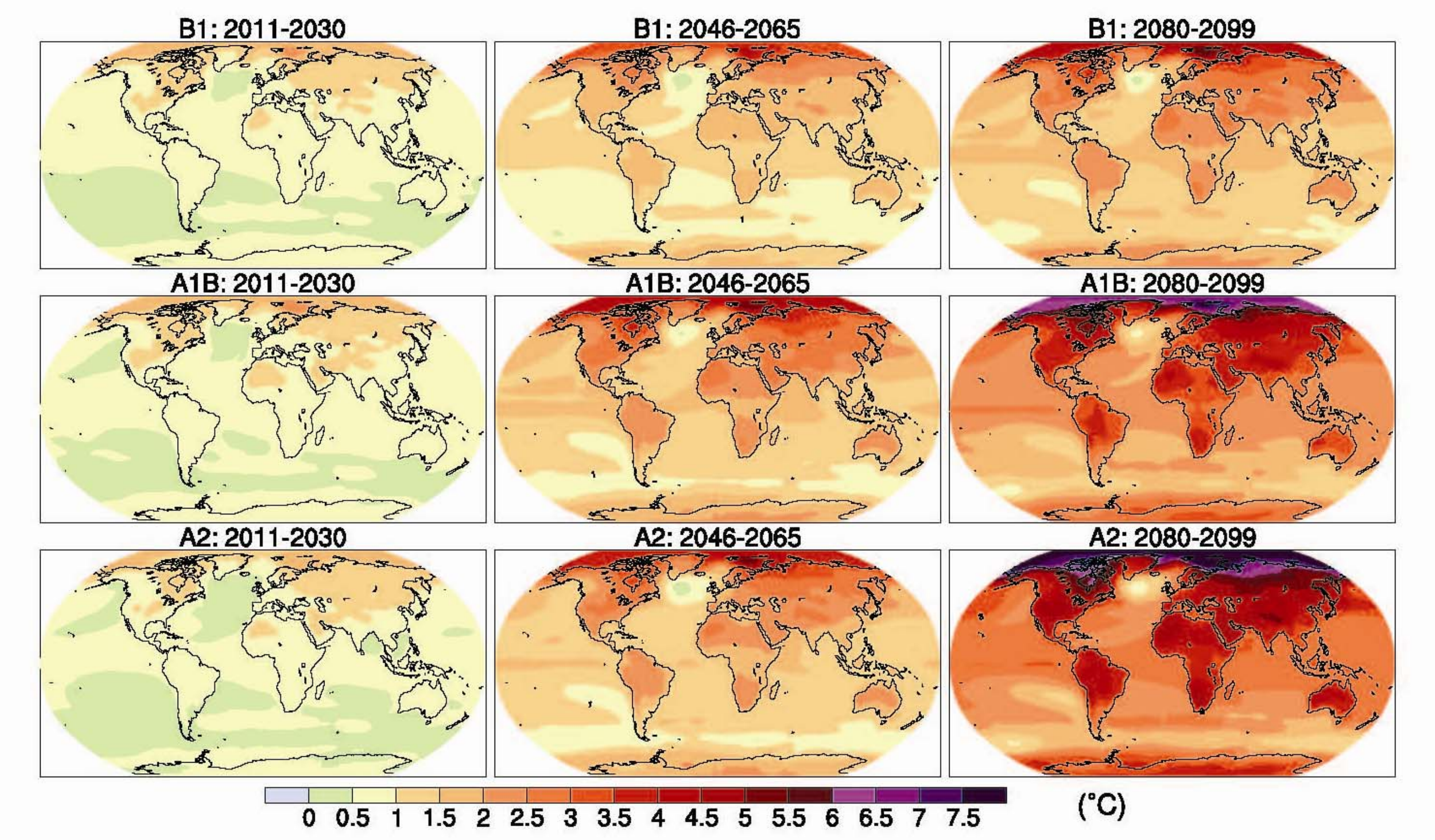
A2: +3.4°C (2.0°C to 5.4°C)
A1B: +2.8°C (1.7°C to 4.4°C)
B1: +1.8°C (1.1°Cto 2.9°C)





Meehl et al. (2007) in *Climate Change 2007: The Physical Science Basis,* Solomon et al., Eds., 747-845

Climate change mitigation



Multi-model mean of annual mean surface warming (surface air temperature change, °C) for the scenarios B1, A1B, and A2. Anomalies are relative to the average of the period 1980 to 1999.

Science has changed…from will climate change…to how to mitigate warming – carbon cycle, biofuels, carbon plantations, land use

Meehl et al. (2007) in *Climate Change 2007: The Physical Science Basis,* Solomon et al., Eds., 747-845

Energy fluxes

Net solar radiation + Net longwave radiation = Sensible heat + Latent heat + Soil heat

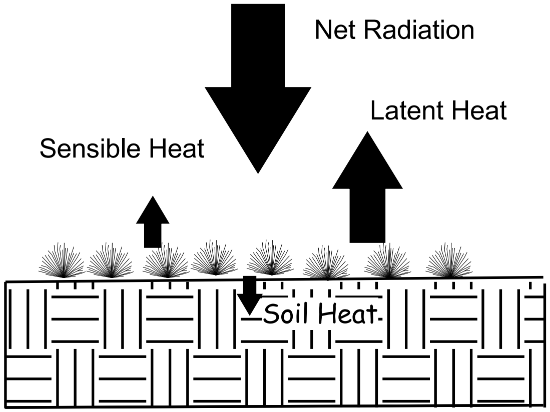
Net solar radiation = $(1-r)S\downarrow$
r = albedo, defined as fraction of incoming solar radiation reflected

Net longwave radiation = $\varepsilon L\downarrow - \varepsilon\sigma T^4$
All material emits radiation in proportion to its absolute temperature raised to the fourth power

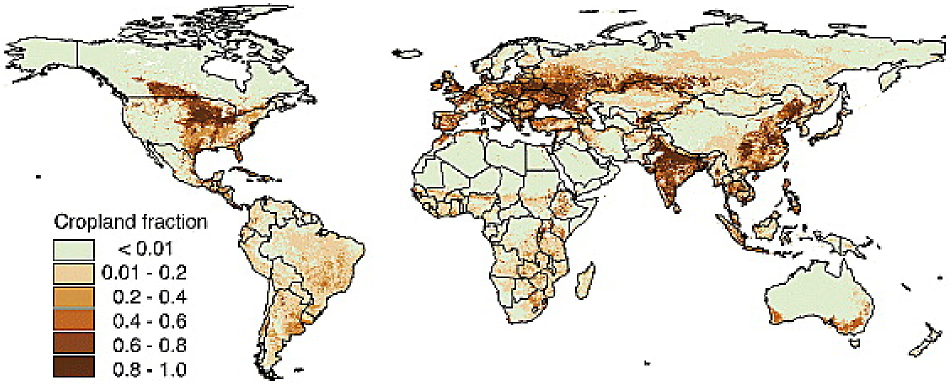
Sensible heat - Movement of air transports heat. A common example is the the cooling of a breeze on a hot summer day.

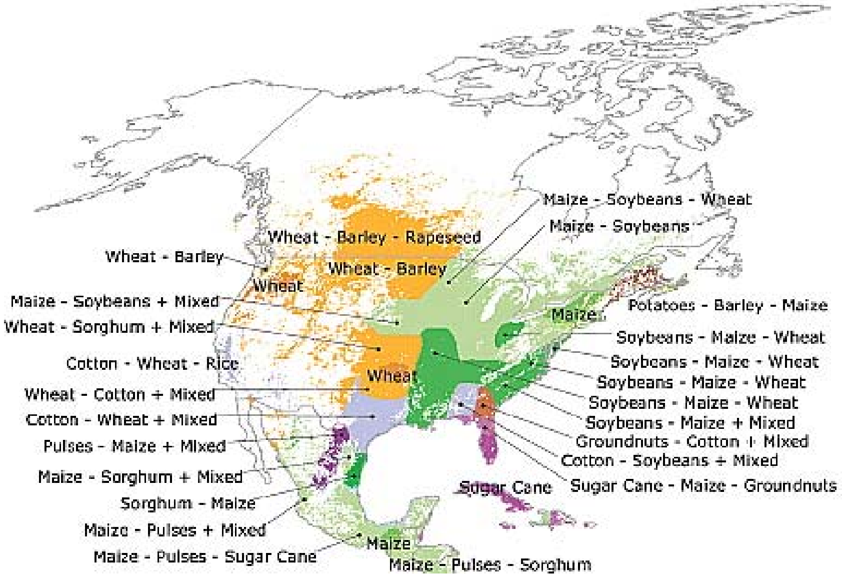
Latent heat - Energy is required to change the phase of water from liquid at the surface to vapor in air. This cools the evaporating surface. Heat loss is why a person may feel cold on a hot summer day when wet but hot after being dried with a towel.

Soil heat - Heat is exchanged with the underlying soil through conduction - the transfer of heat along a temperature gradient from high temperature to low temperature due to direct contact. The heat felt when touching a hot mug of coffee is an example of conduction.



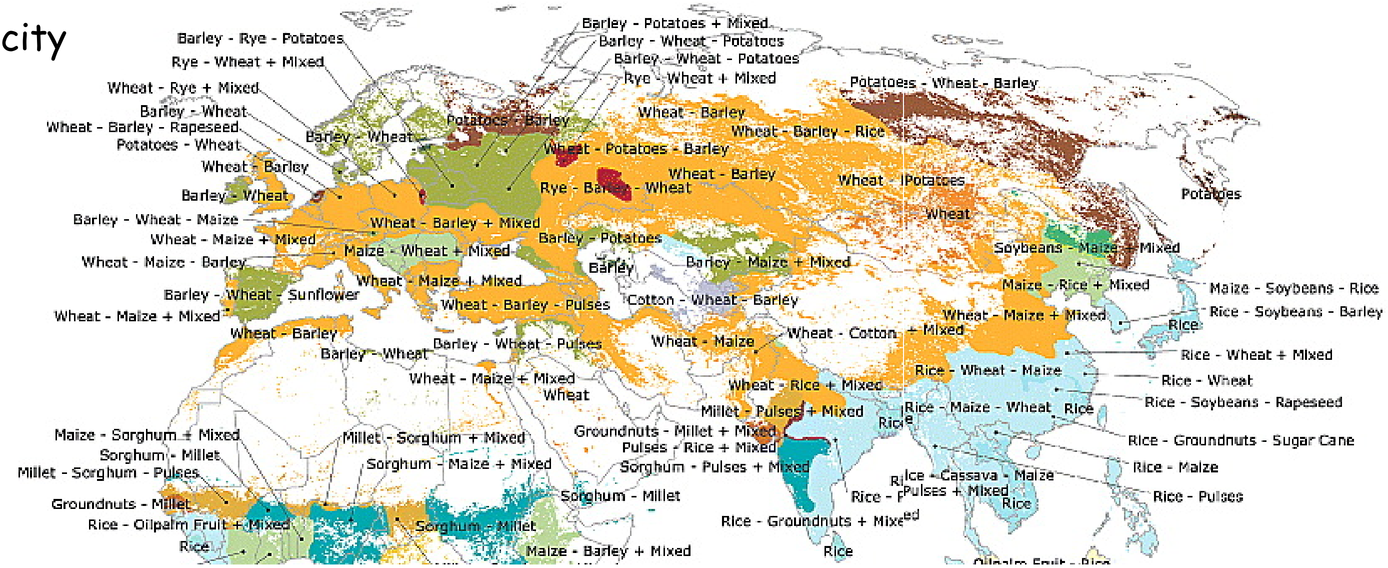
Anthropogenic land use





Agroecosytems

- ☐ Albedo
- ☐ Bowen ratio
- ☐ Infiltration/runoff
- ☐ Soil water holding capacity
- ☐ Atmospheric CO_2
- ☐ Nitrogen cycle
- ☐ Dust



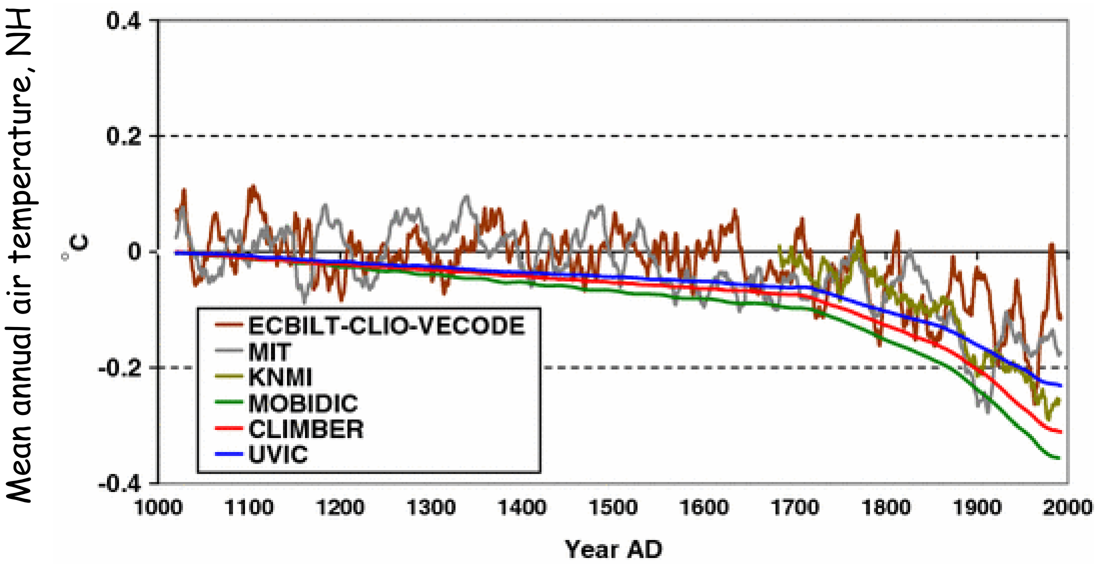
Leff et al. (2004) GBC, 18, GB1009, doi:10.1029/2003GB002108

Historical land use forcing of climate

The emerging consensus is that land cover change in middle latitudes has cooled the Northern Hemisphere (primarily because of higher surface albedo)

Comparison of 6 earth system models of intermediate complexity forced with historical land cover change, 1000-1992

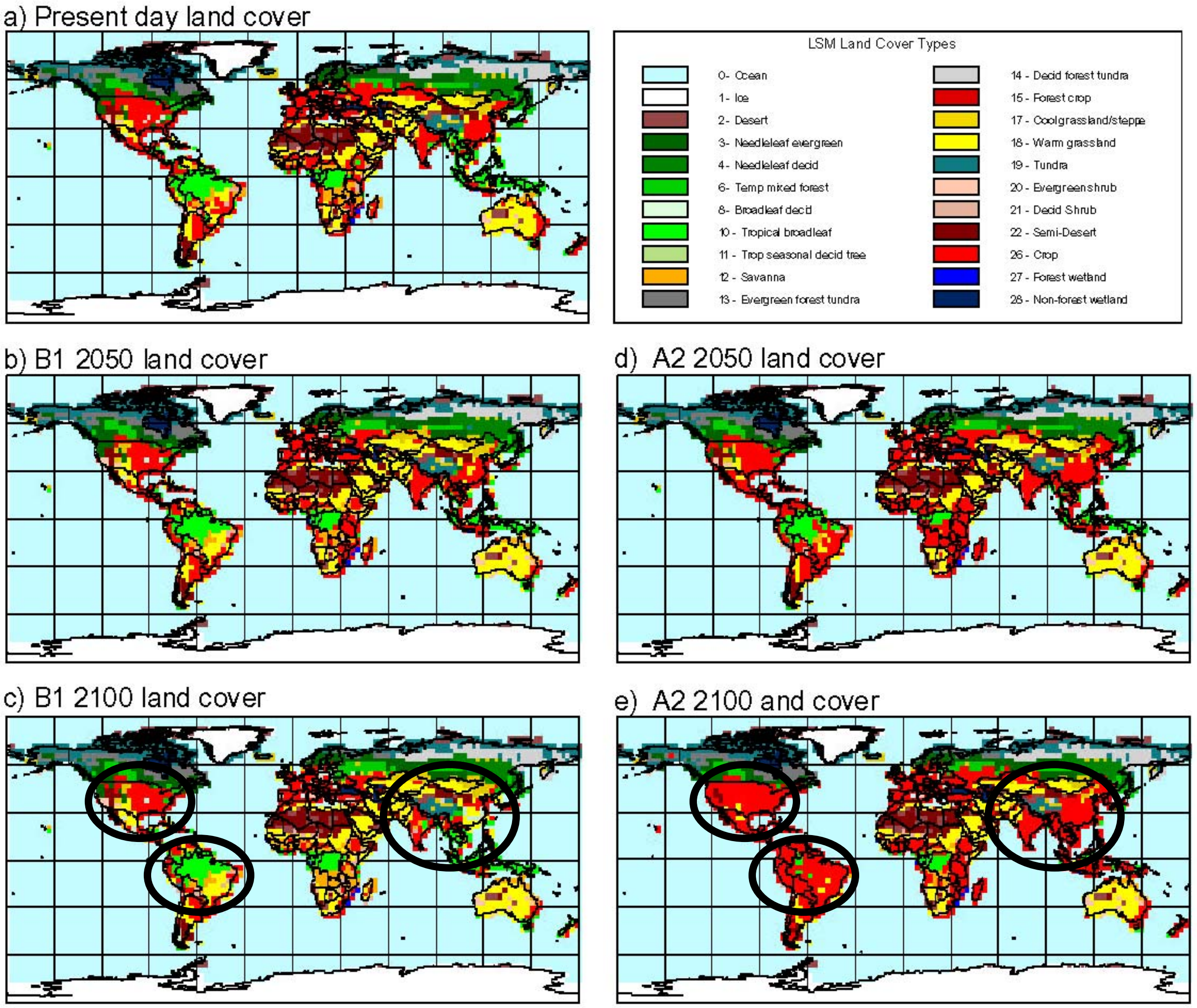
Northern Hemisphere annual mean temperature decreases by 0.19 to 0.36 °C relative to the pre-industrial era



Brovkin et al. (2006) Climate Dynamics 26:587-600

Future land cover change as a climate forcing

Future IPCC SRES Land Cover Scenarios for NCAR LSM/PCM



Feddema et al. (2005) Science 310:1674-1678

A2 – Widespread agricultural expansion with most land suitable for agriculture used for farming by 2100 to support a large global population

B1 - Loss of farmland and net reforestation due to declining global population and farm abandonment in the latter part of the century

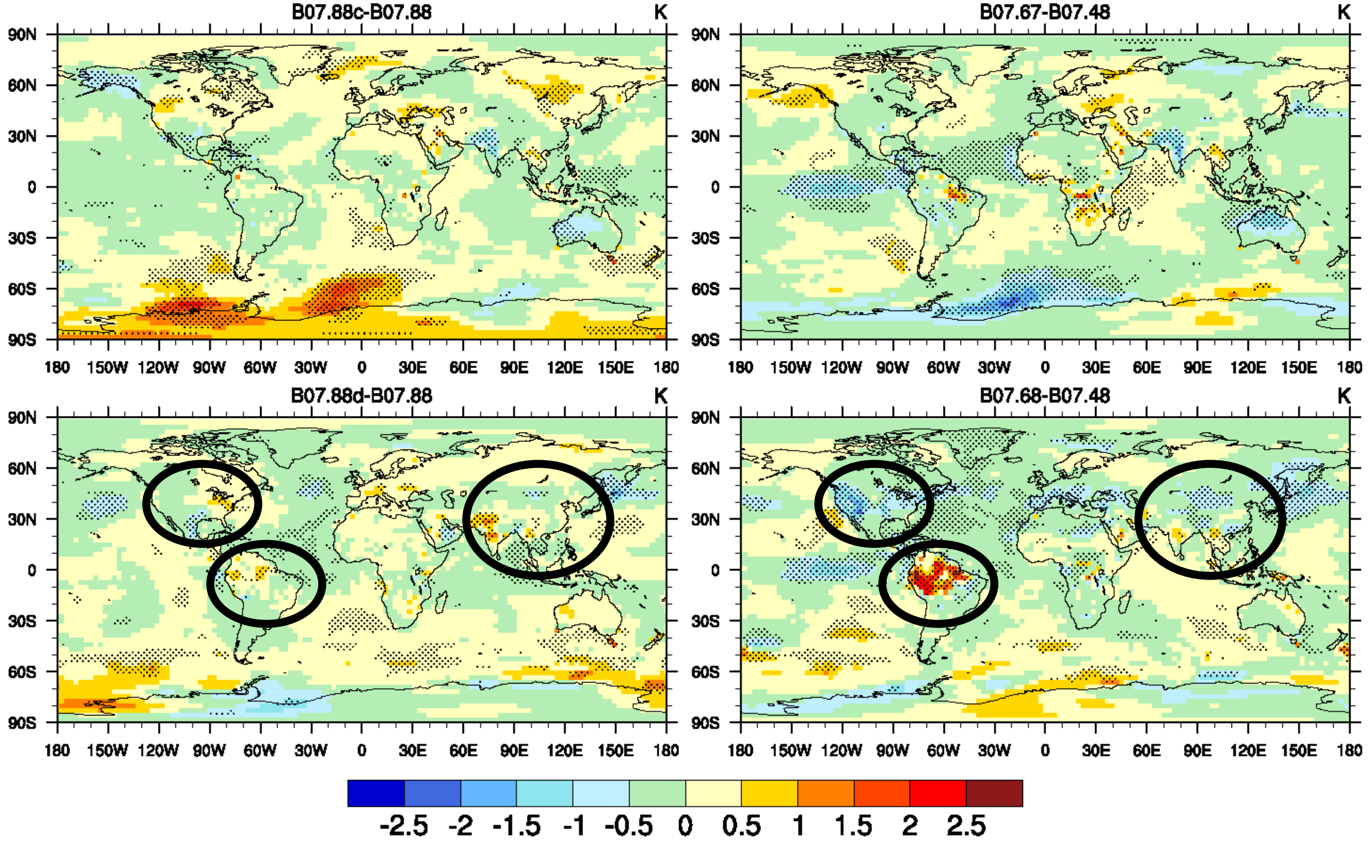
Future land cover change as a climate forcing

Land use choices affect climate

SRES B1 **JJA reference height temperature** SRES A2

2050

2100



Climate simulations with changing land cover. Figures show the effect of land cover on temperature for the months June-August.

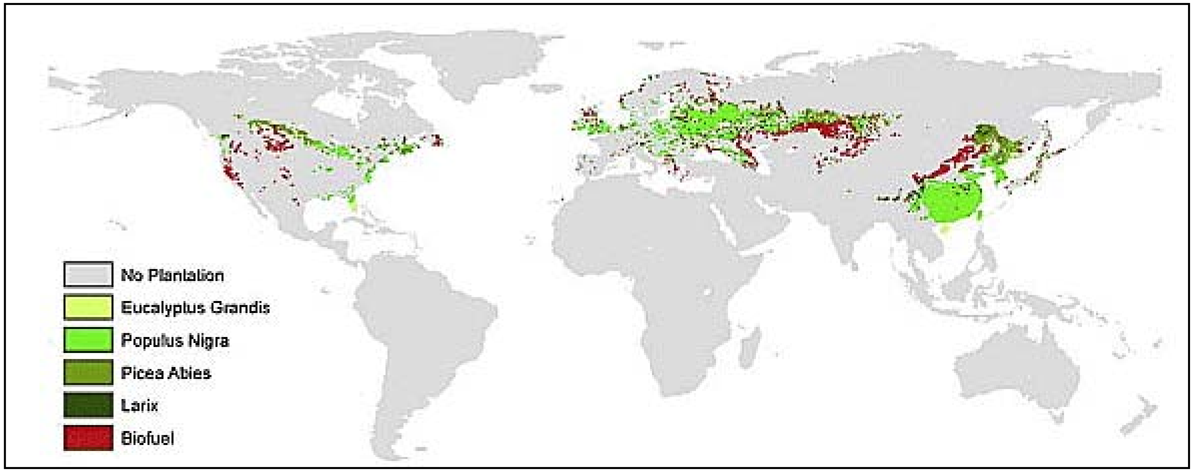
(SRES land cover + SRES atmospheric forcing) - SRES atmospheric forcing

Feddema et al. (2005) Science 310:1674-1678

Land management policies to mitigate climate change

Reforestation might be chosen as an option for the enhancement of terrestrial carbon sequestration or biofuel plantations may be used as a substitute for fossil fuels

2100 land management, IPCC A1b scenario



Carbon plantations and biofuel plantations reduce atmospheric CO_2, leading to cooling

Carbon plantations have lower albedo than biofuels, leading to warming

Green = carbon plantations
Green + red = biofuel plantations

Excess agricultural land converted to carbon storage or biofuels

Schaeffer et al. (2006) GBC, 20, GB2020, doi:10.1029/2005GB002581

Urban design to mitigate climate warming

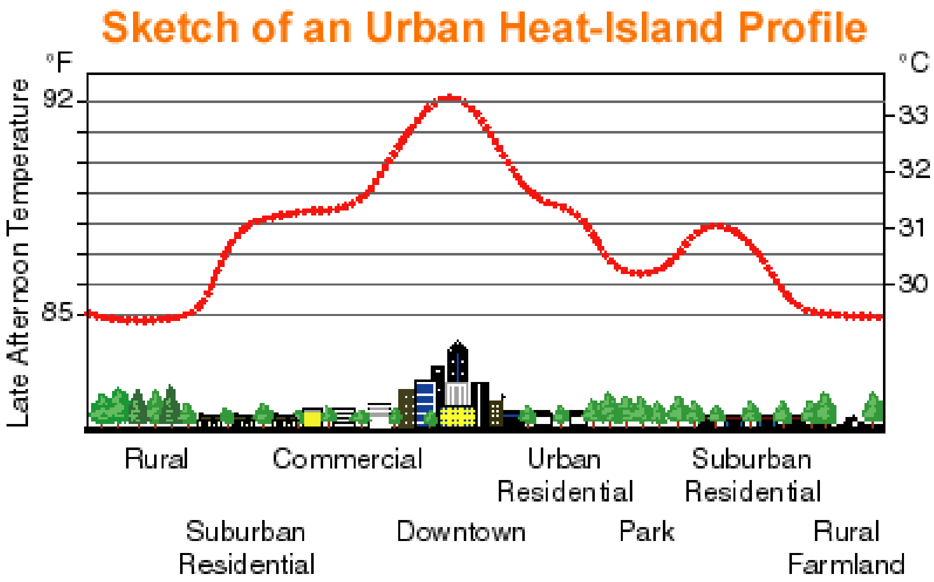
Urban parks

Rooftop gardens

White roofs

Green parking lots

Urban heat island

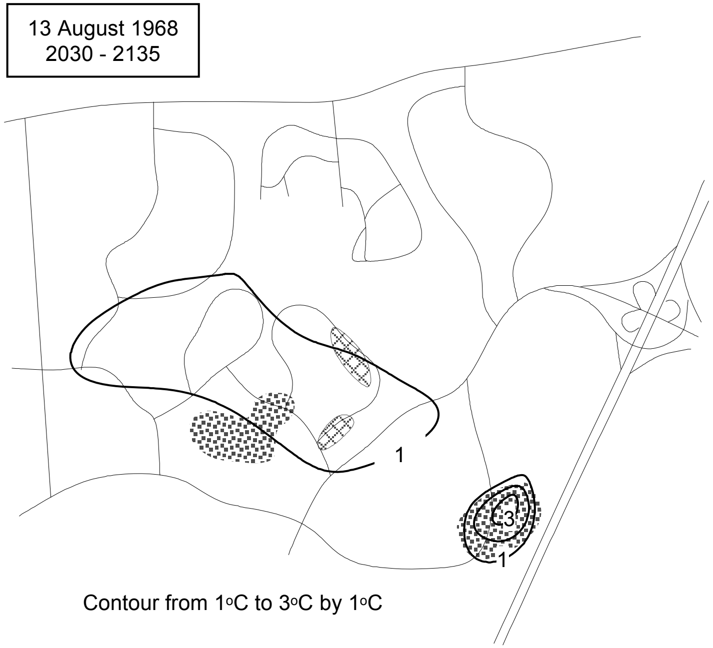


The urban heat island was first recognized in London in 1820 with Luke Howard's observation "night is 3.7°F (2.1°C) warmer…in the city than in the country"

Landsberg (1981) The Urban Climate (Academic Press)

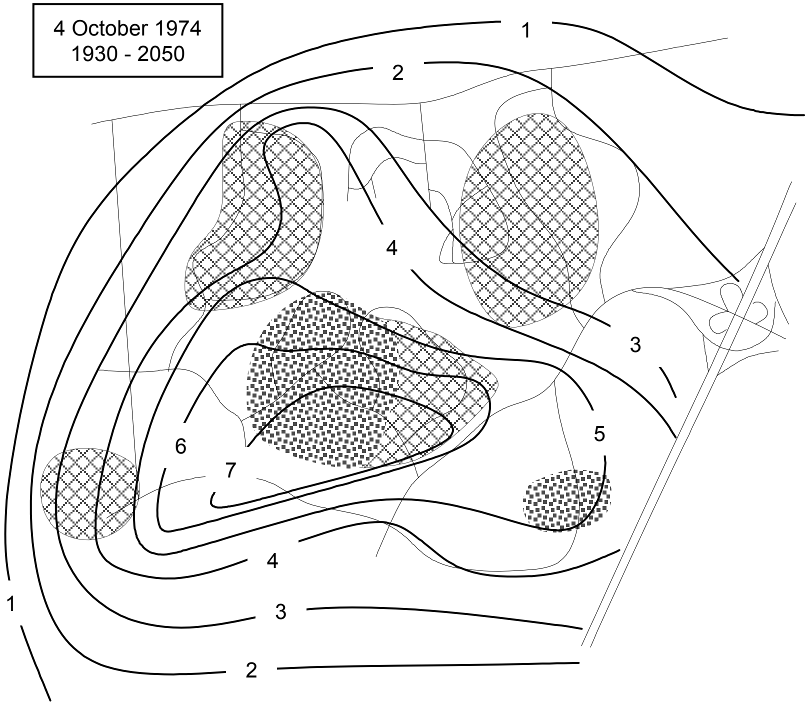
Columbia, Maryland

1968, population 1000

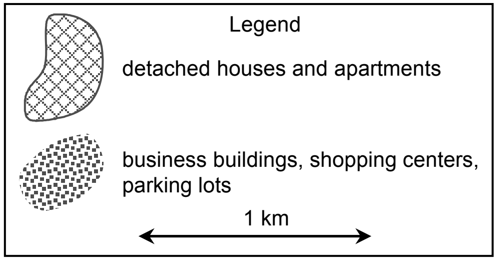


Contour from 1°C to 3°C by 1°C

1974, population 20 000



Contour from 1°C to 7°C by 1°C

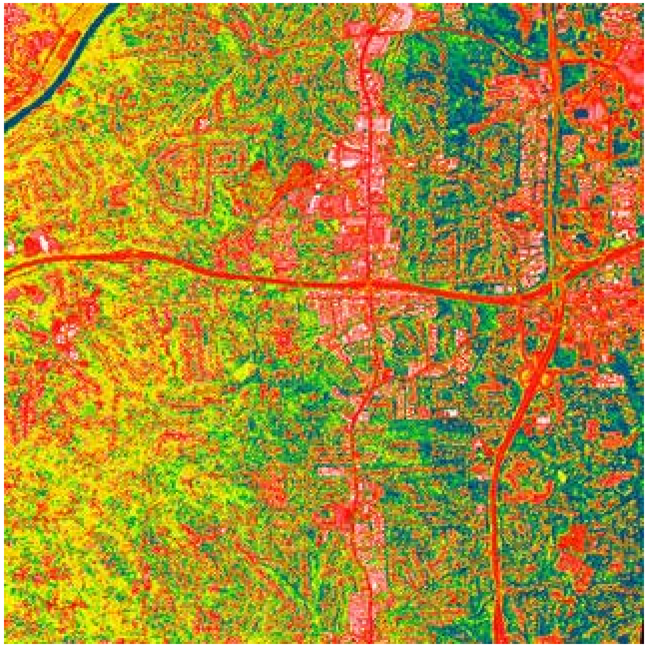


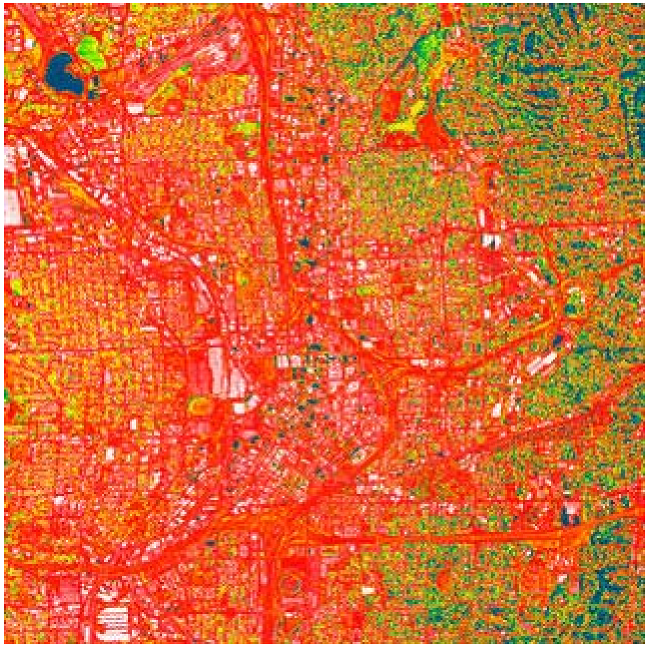
1968: Maximum warming compared with surrounding rural area was 1 °C. A small business center was a local heat island of up to 3 °C

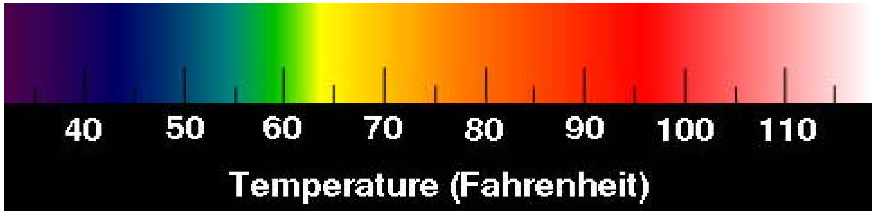
1974: Most of the town was more than 2 °C warmer than the surrounding rural land. A central commercial and residential district was 5-7 °C warmer

Landsberg & Maisel (1972) Bound.-Layer Meteor. 2:365-370
Landsberg (1979) Urban Ecology 4:53-81

Atlanta, Georgia


Suburban Atlanta daytime thermal


Urban Atlanta daytime thermal



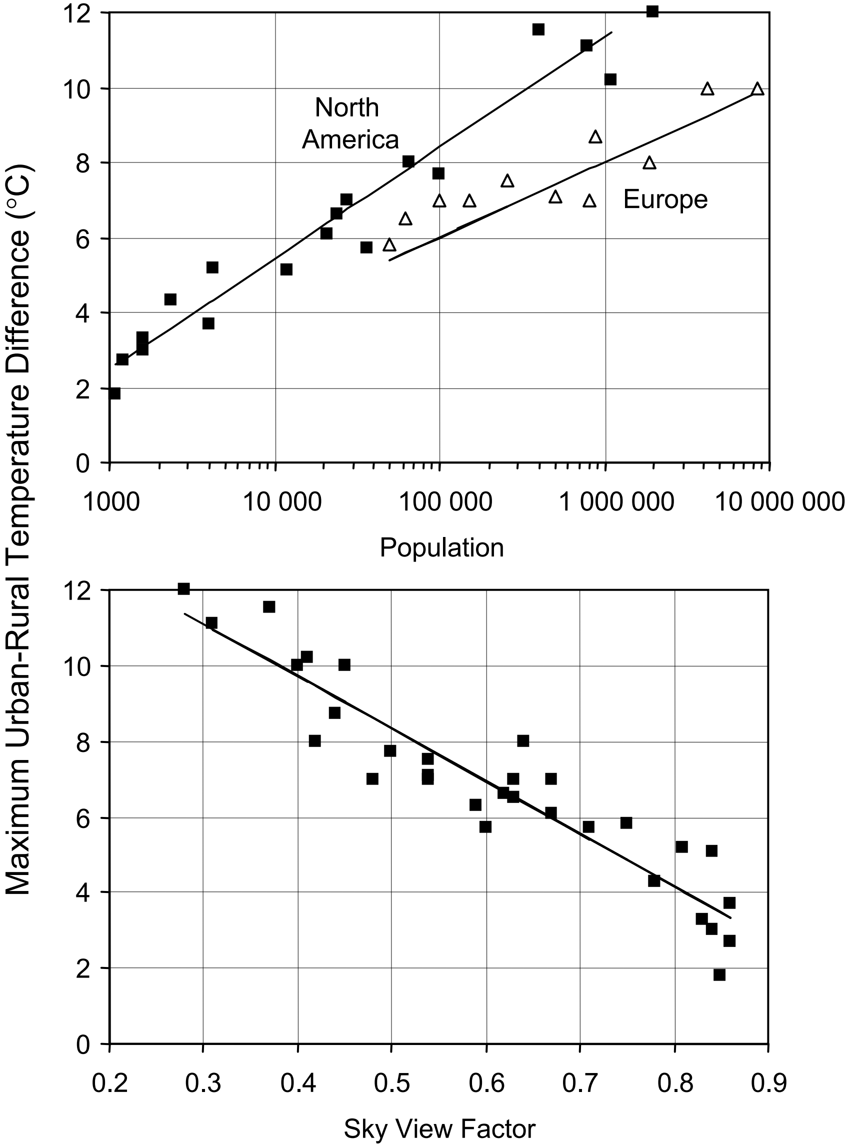
Trees and parks appear as blue, green, or yellow. Buildings, streets and other urban surfaces appear as red.

Urban Atlanta is warmer than suburban Atlanta.

NASA/Goddard Space Flight Center
Scientific Visualization Studio

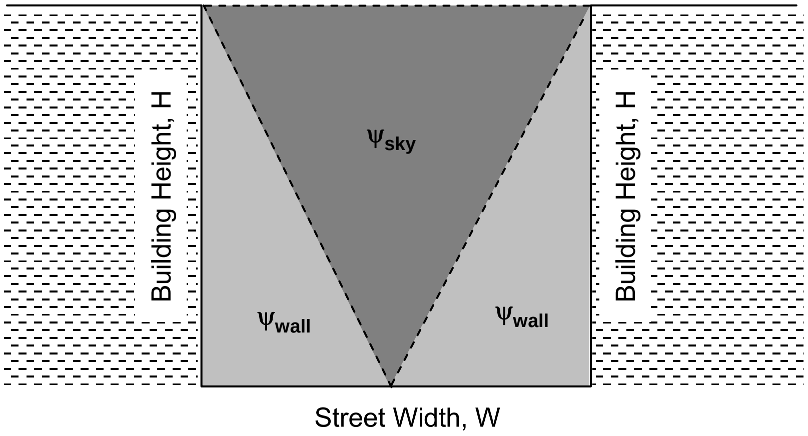
Maximum heat island

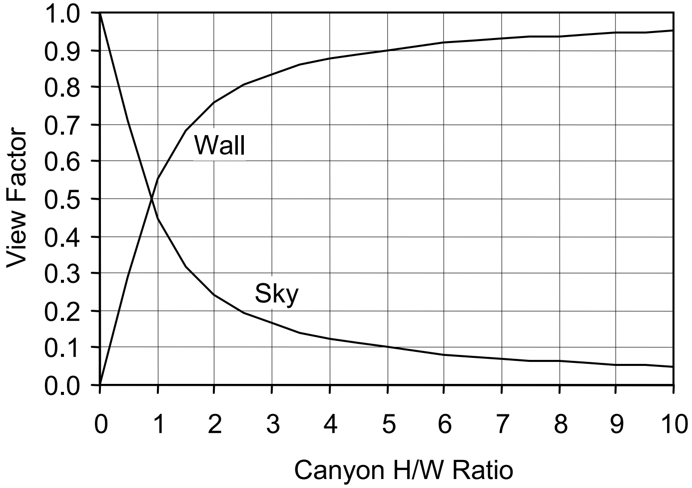
Maximum instantaneous $\Delta T_{u\text{-}r}$ at any time of the year. The average heat island is much less.



Oke (1981) J. Climatol. 1:237-254

View factors



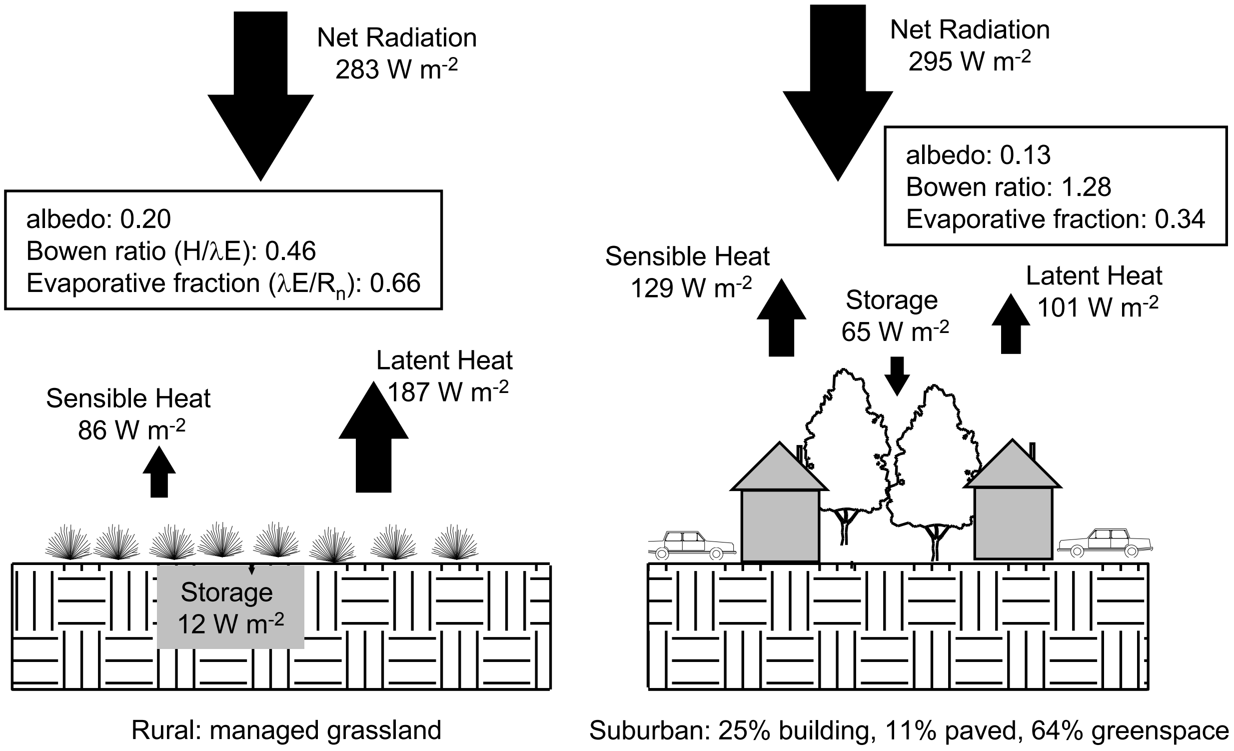


As H/W increases, a point in the street "sees" proportionally less of the sky and more of the wall. More of the longwave radiation emitted by urban surfaces is trapped in the canyon.

Bonan (2008) Ecological Climatology. 2nd edition (Cambridge Univ. Press)

Surface energy fluxes, Vancouver, B.C.

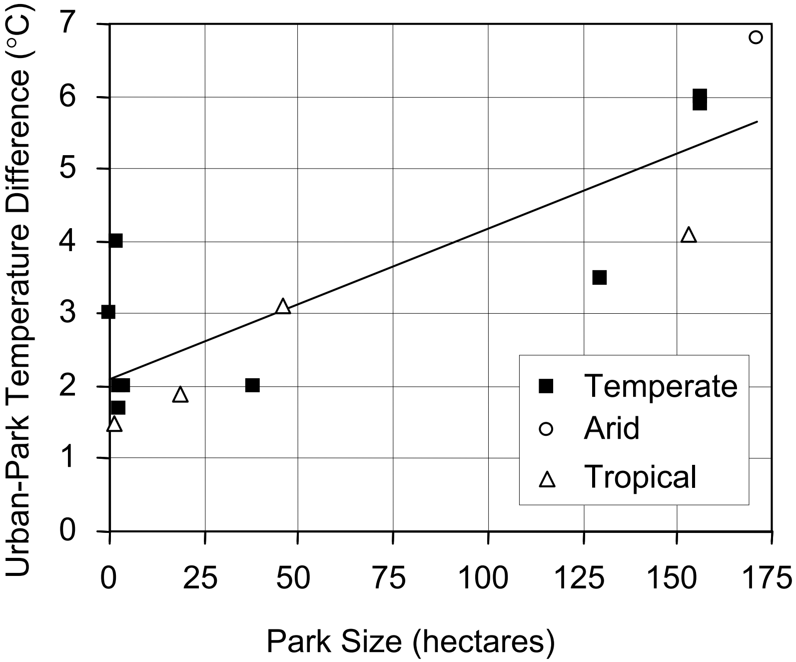
an average summer day



Cities have lower albedo, less latent heat flux, greater sensible heat flux, and greater heat storage compared with rural locations

Cleugh & Oke (1986) Bound.-Layer Meteor. 36:351-369

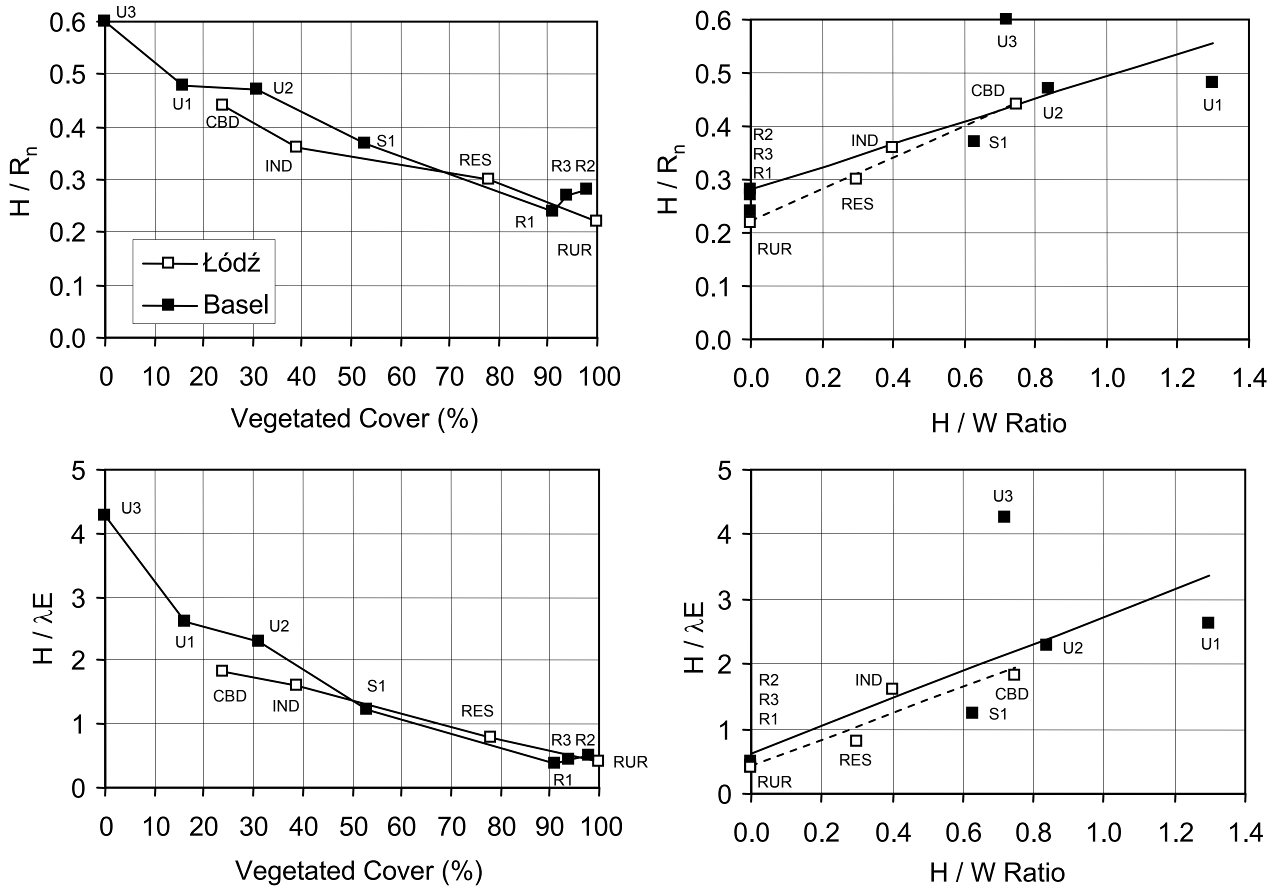
Urban parks cool climate



Cooling effect of parks increases with park size

Upmanis et al. (1998) Int. J. Climatol. 18:681-700

Urban parks cool climate

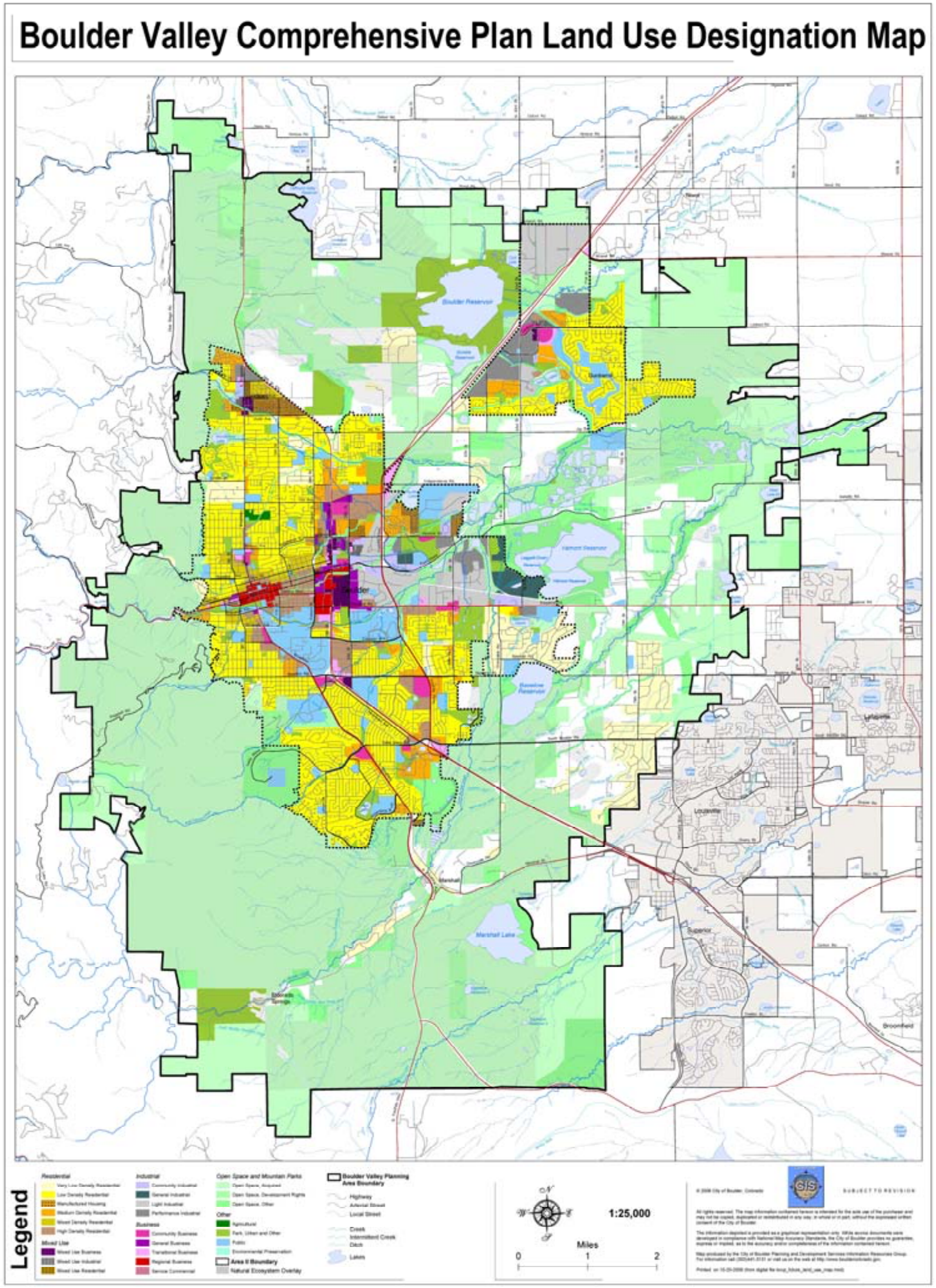


Ratio of sensible heat to net radiation (H/R_n, top) and Bowen ratio ($H/\lambda E$, bottom) in relation to vegetation cover (left) and H/W (right) for four sites in Łódź, Poland, and seven sites in Basel, Switzerland

Sensible heat flux decreases with more greenspace and increases with greater H/W

Christen & Vogt (2004) Int. J. Climatol. 24:1395-1421
Offerle et al. (2006) J. Appl. Meteor. Climatol. 45, 125-136

Scale - city planning



Residential

- 🟨 Very Low Density Residential
- 🟨 Low Density Residential
- ▩ Manufactured Housing
- 🟧 Medium Density Residential
- 🟨 Mixed Density Residential
- 🟫 High Density Residential

Mixed Use

- ▥ Mixed Use Business
- ▥ Mixed Use Industrial
- ▥ Mixed Use Residential

Industrial

- 🟪 Community Industrial
- ⬛ General Industrial
- ⬜ Light Industrial
- ⬛ Performance Industrial

Business

- 🟪 Community Business
- 🟪 General Business
- 🟪 Transitional Business
- 🟥 Regional Business
- 🟥 Service Commercial

Open Space and Mountain Parks

- 🟩 Open Space, Acquired
- 🟩 Open Space, Development Rights
- 🟩 Open Space, Other

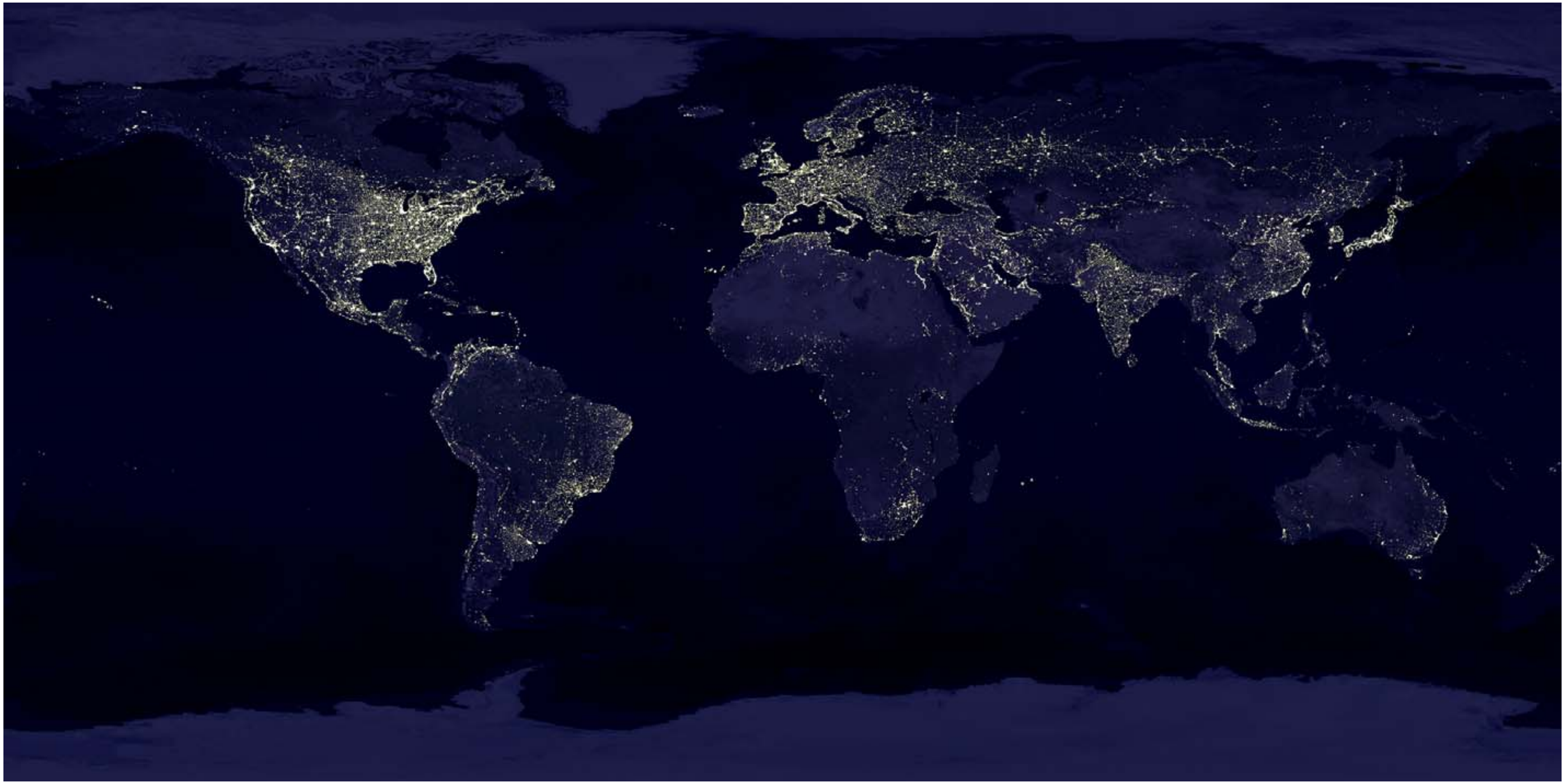
Other

- 🟩 Agricultural
- 🟩 Park, Urban and Other
- 🟦 Public
- 🟦 Environmental Preservation
- ⬚ **Area II Boundary**
- ▨ Natural Ecosystem Overlay

Scale – residential subdivision

Scale – global climate model

Urban areas as seen by satellite in nighttime lights of the world



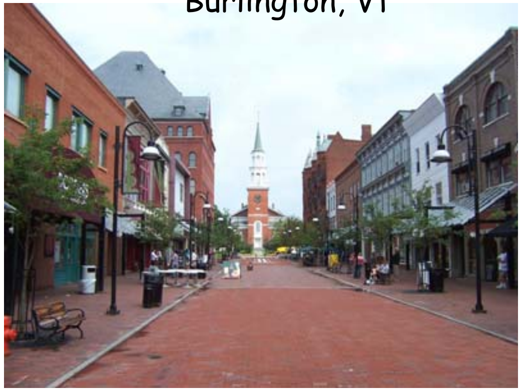
Diversity of city form


New York City


Mexico City

Suburban Colorado

Burlington, Vt



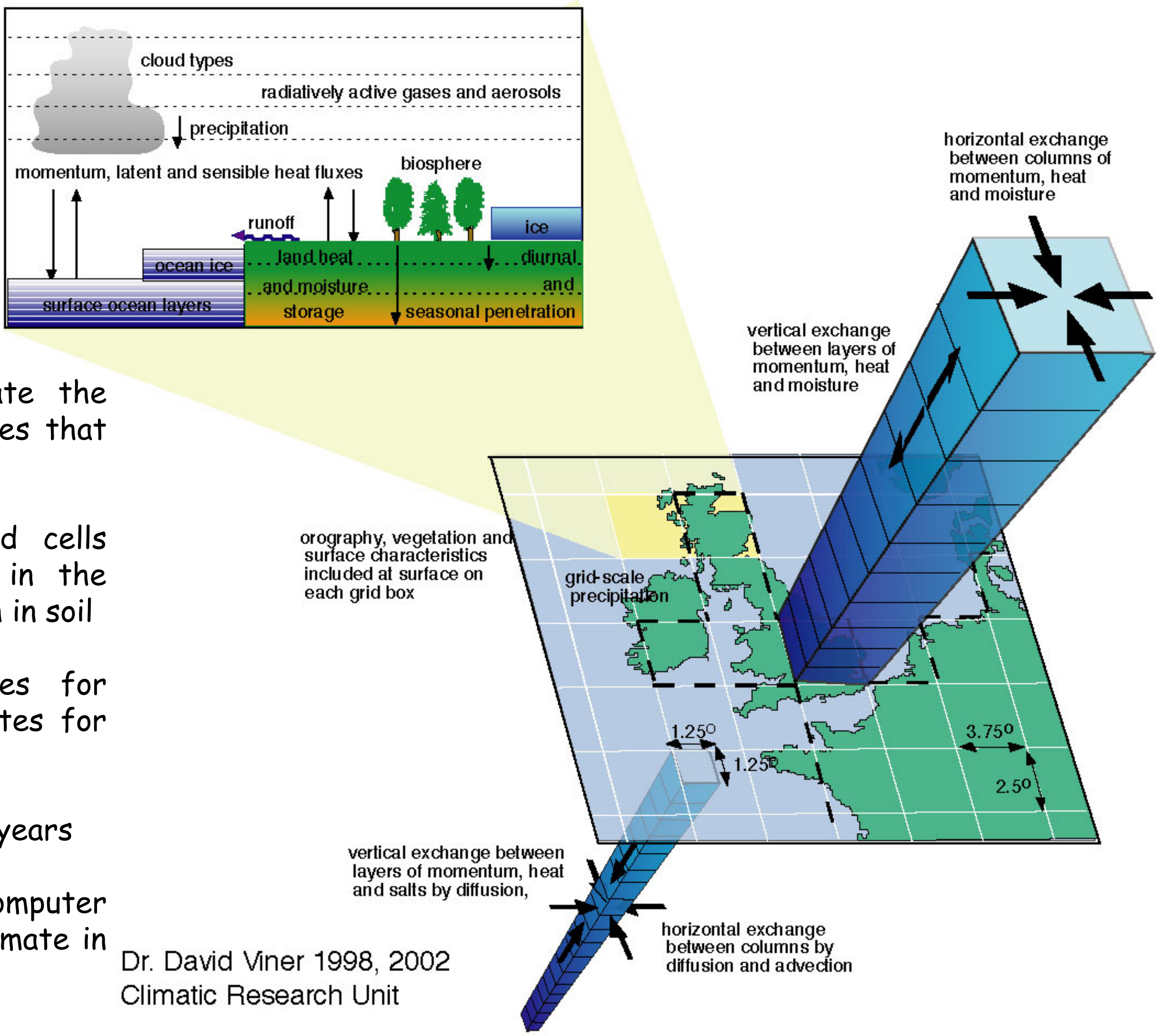

Denver Tech Center


Cairo


Calcutta


Village, China

Coupled land-atmosphere-ocean-sea ice climate system



Dr. David Viner 1998, 2002
Climatic Research Unit

Uses mathematical equations to simulate the physical, chemical, and biological processes that drive Earth's climate

Discretizes the planet into model grid cells defined by longitude, latitude, height in the atmosphere, depth in the ocean, and depth in soil

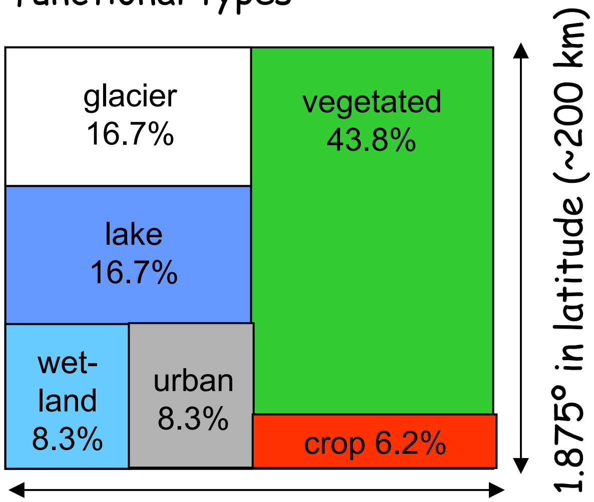
Equations are solved every 20-minutes for atmosphere and land and every 60-minutes for ocean and sea ice

Typical simulation: several hundred model years

What emerges from trillions of computer calculations is a picture of the world's climate in all its complexity

Representing the land surface

Subgrid land cover and plant functional types



2.5° in longitude (~200 km)

CLM represents a model grid cell as a mosaic of up to 6 primary land cover types. Vegetated land is further represented as a mosaic of several plant functional types





Bonan et al. (2002) G BC 16(2), 1021, doi:10.1029/2000GB001360

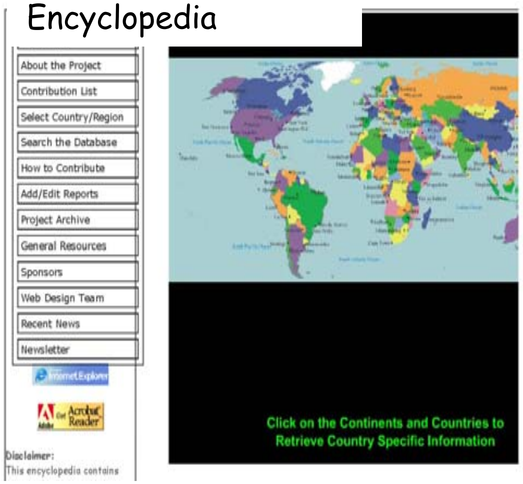
Urban land classes

Urban Class	H/W ratio	Vegetative fraction	Density (U.S. example)
CBD/ Industrial	3+	< 0.1	~ > 800 people/km^2
High density	1 - 3	~ 0.33	~ 400 - 800 people/km^2
Low density /suburban	~ 0.5	~ 0.75	~ 250 - 400 people/km^2

Model input data
Fractional area of city
Building height
H/W ratio
Roof fraction
Vegetated fraction
Building materials

Building materials

World Housing Encyclopedia



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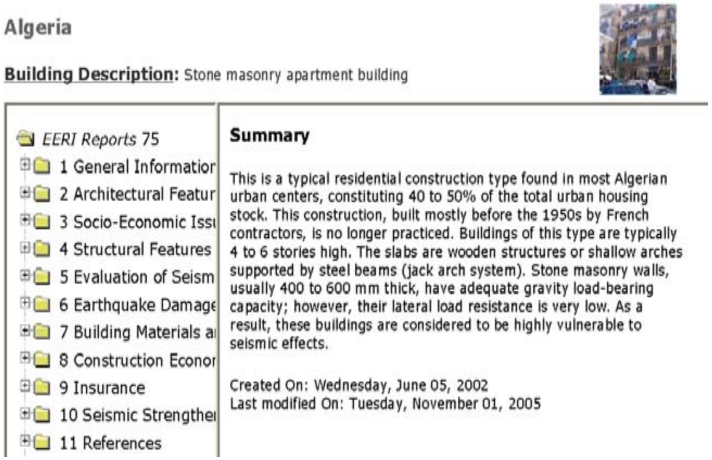
This encyclopedia contains

Click on the Continents and Countries to Retrieve Country Specific Information



Algeria

Building Description: Stone masonry apartment building

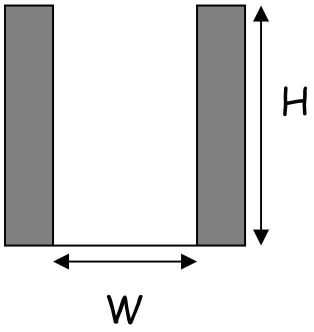
Summary

This is a typical residential construction type found in most Algerian urban centers, constituting 40 to 50% of the total urban housing stock. This construction, built mostly before the 1950s by French contractors, is no longer practiced. Buildings of this type are typically 4 to 6 stories high. The slabs are wooden structures or shallow arches supported by steel beams (jack arch system). Stone masonry walls, usually 400 to 600 mm thick, have adequate gravity load-bearing capacity; however, their lateral load resistance is very low. As a result, these buildings are considered to be highly vulnerable to seismic effects.

Created On: Wednesday, June 05, 2002
Last modified On: Tuesday, November 01, 2005

Urban canyon, H/W

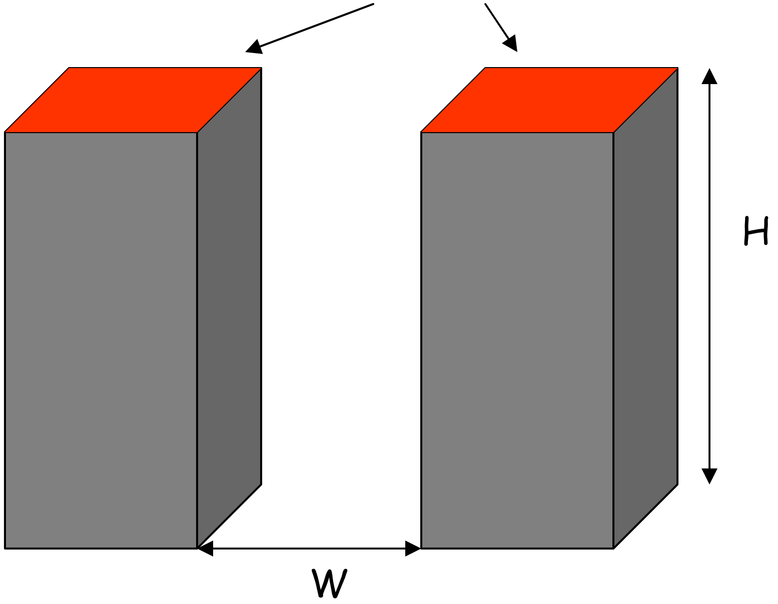
City and residential streets can be characterized by an idealized “canyon” defined by building height H and street width W



Roof area, W_{roof}

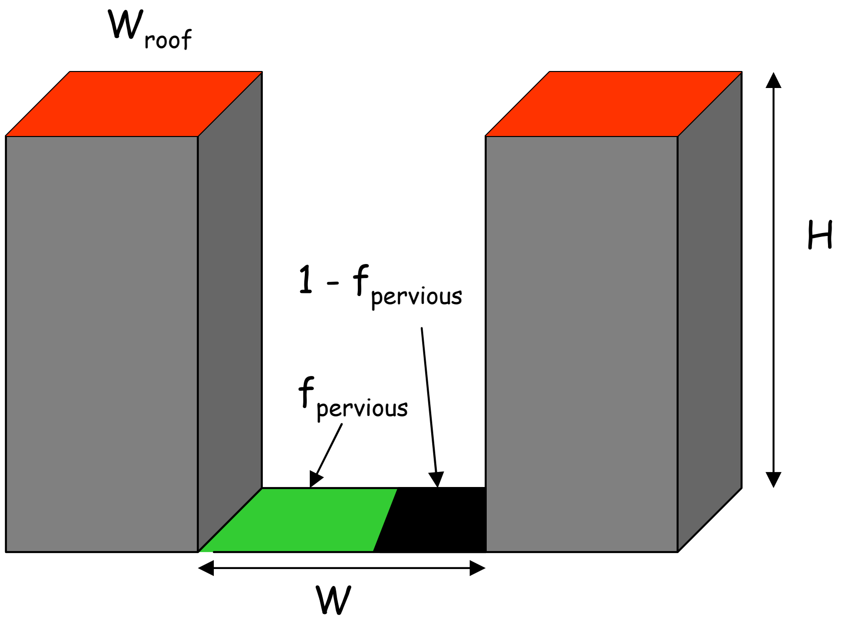
A substantial surface area is covered by roofs

Fraction of city covered by roofs, $0 \leq W_{roof} \leq 1$



$1 - W_{roof}$ is the fractional area of the urban canyon

Urban parks, $f_{pervious}$



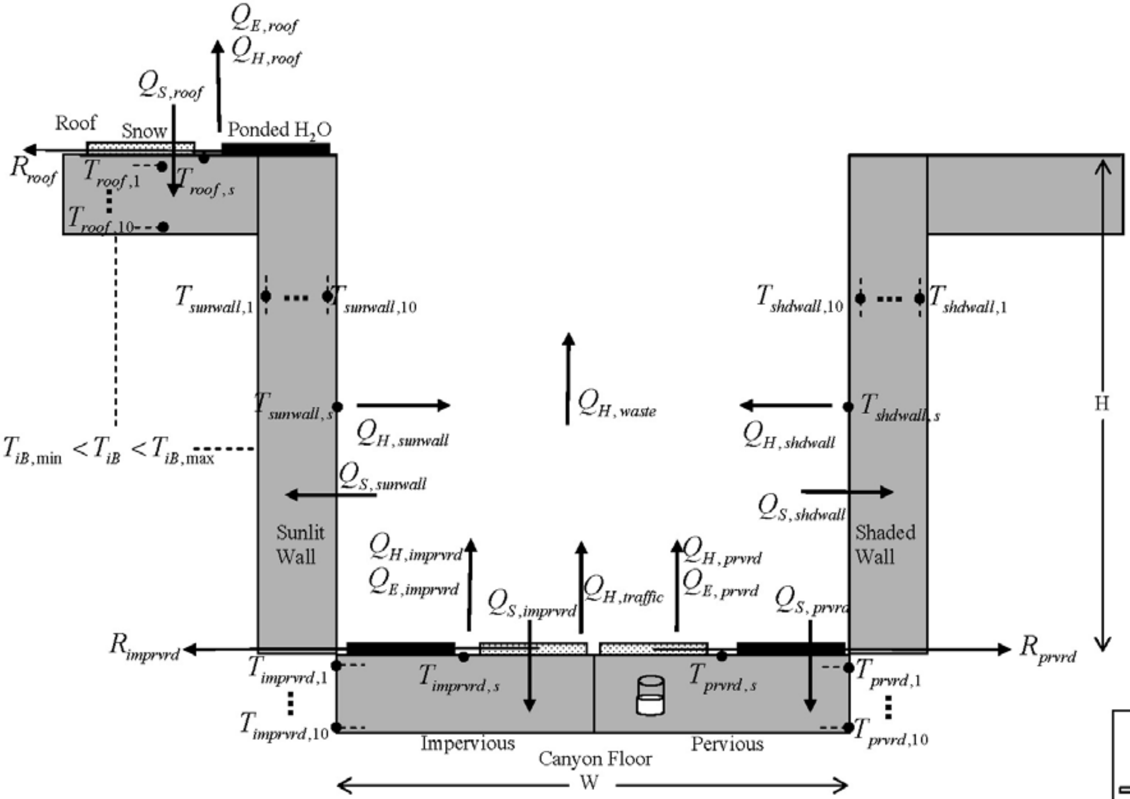
Impervious area = $1 - f_{pervious}$

Building materials

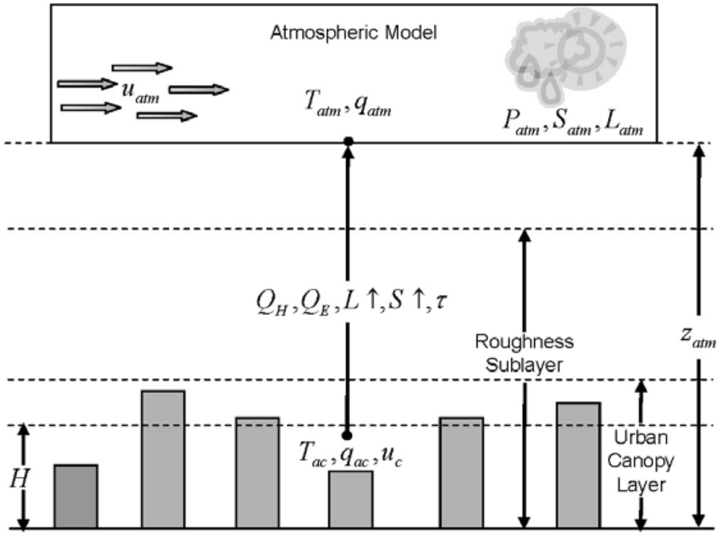
Thermal properties
Roof thermal conductivity, heat capacity
Wall thermal conductivity, heat capacity
Road thermal conductivity, heat capacity
Soil thermal conductivity, heat capacity

Radiative properties
Roof albedo, emissivity
Wall albedo, emissivity
Road albedo, emissivity
Soil albedo, emissivity

Urban-atmosphere coupling

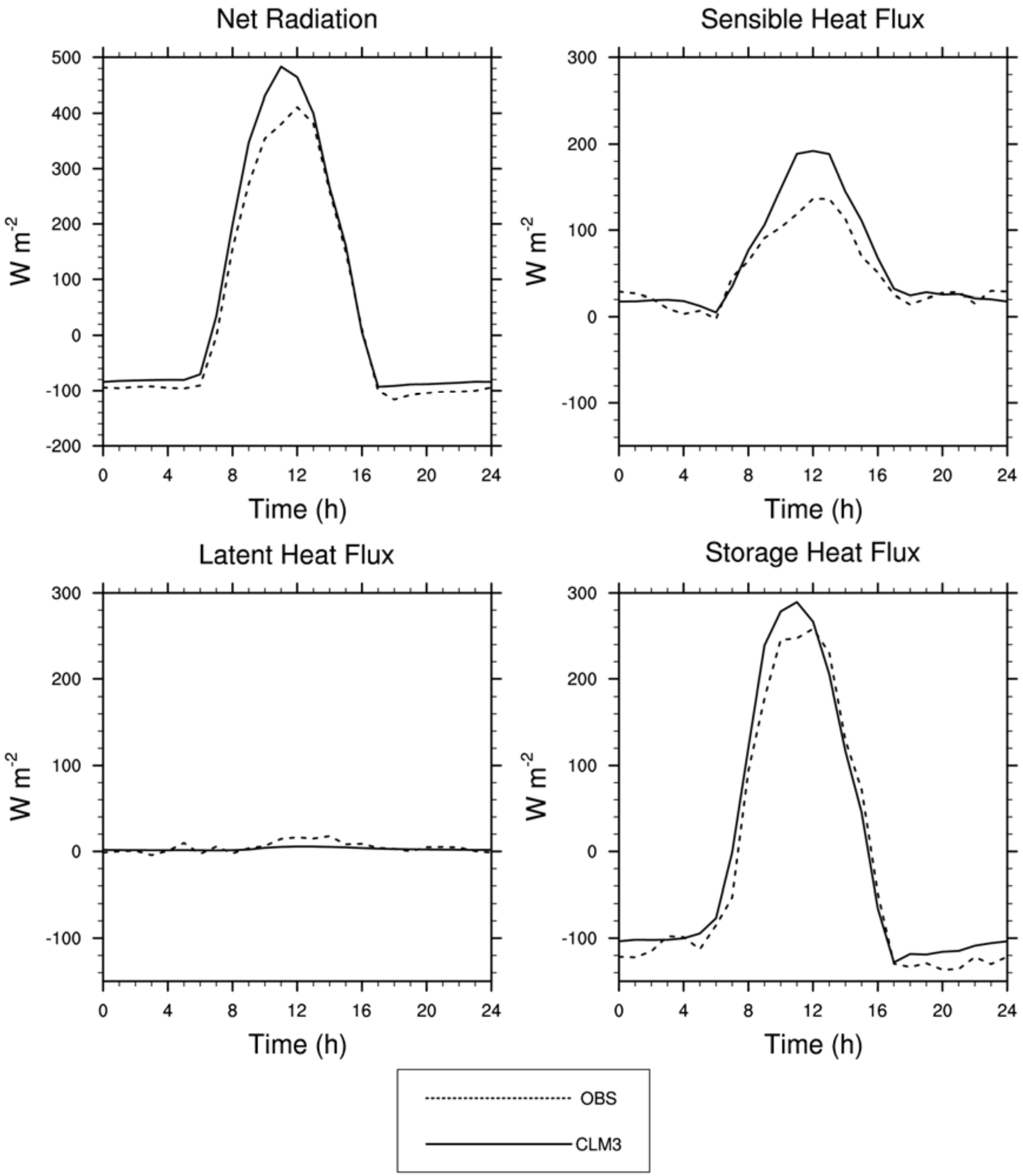


Energy fluxes are modeled for an idealized urban canyon. These fluxes affect atmospheric temperature, humidity, wind, radiation, and precipitation, which in turn determine energy fluxes



Oleson et al. (2008) J. Appl. Meteor. Climatol., in press

Simulated energy balance



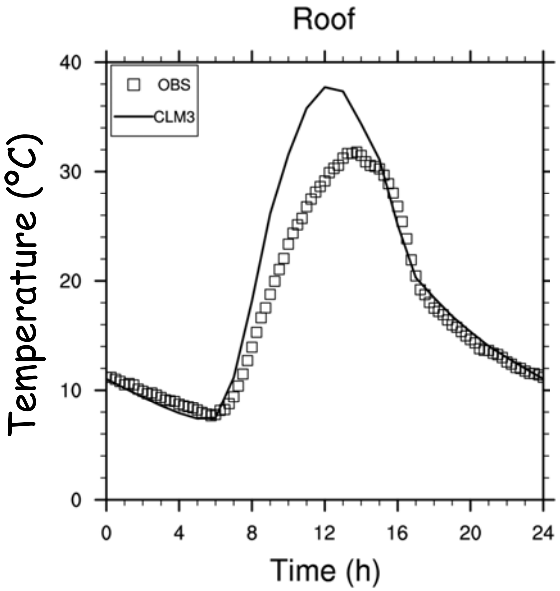
Average diurnal cycle of simulated and observed heat fluxes for the Mexico City site (Me93) for Dec 2-7, 1993

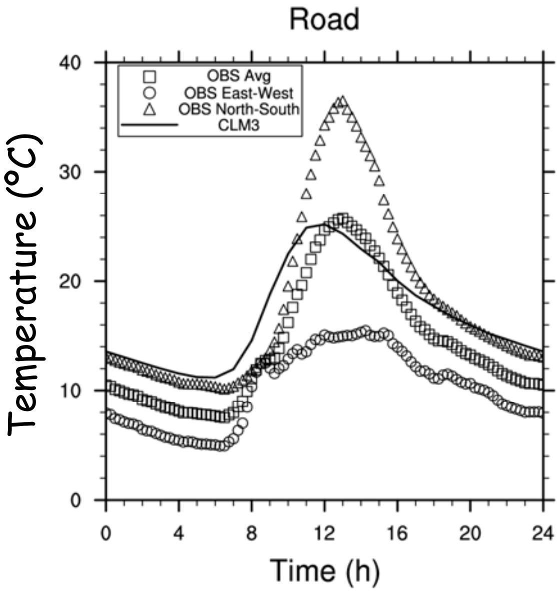
Key features

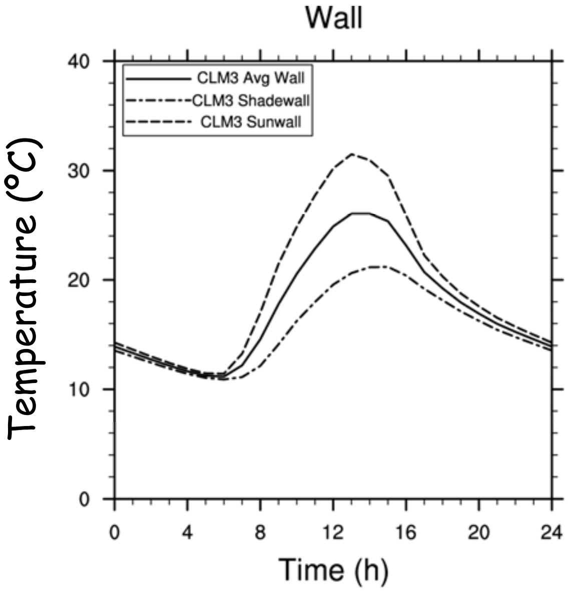
- Diurnal cycle is well represented
- Simulated net radiation is too high (model ignores pollution), which drives high sensible heat
- Negligible latent heat flux
- Large storage heat flux

Oleson et al. (2008) J. Appl. Meteor. Climatol., in press

Simulated temperatures



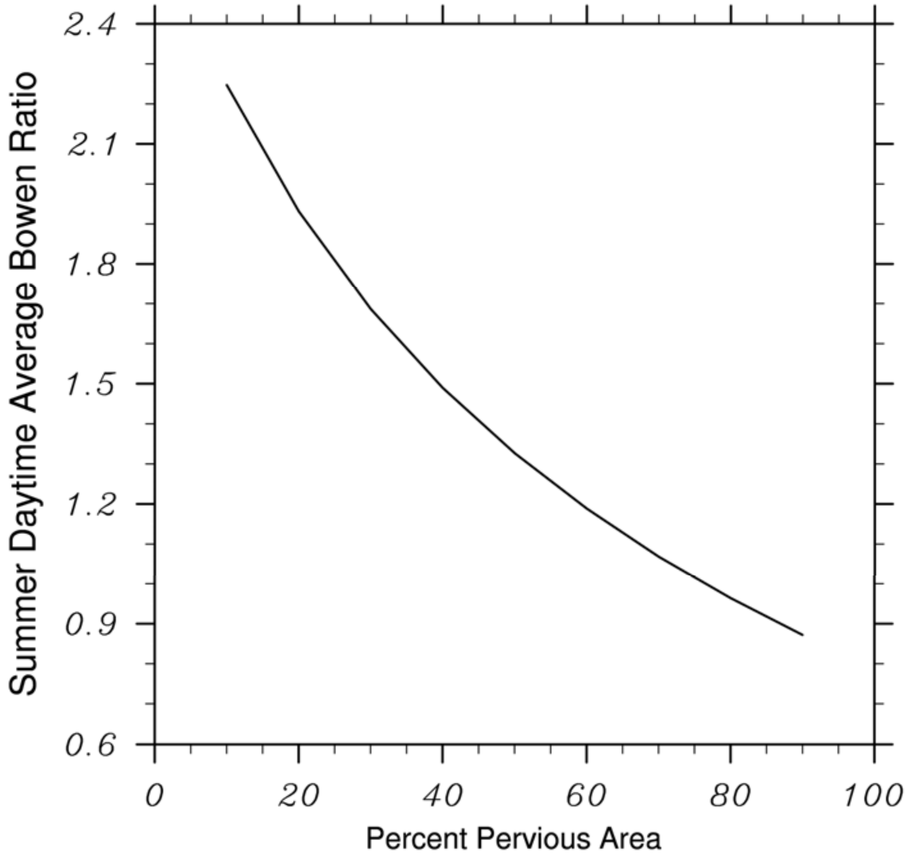




Average diurnal cycle of simulated and observed surface temperatures for the Mexico City site (Me93) for Dec 2-7, 1993

Oleson et al. (2008) J. Appl. Meteor. Climatol., in press

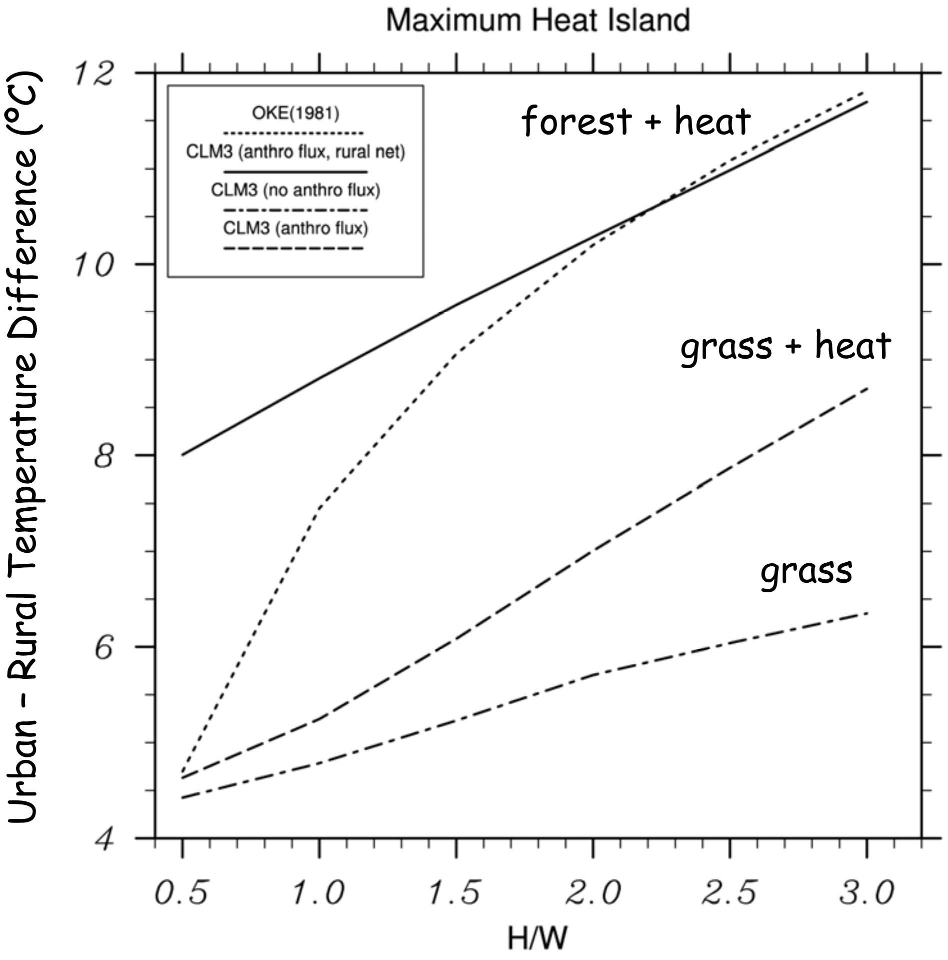
Vegetation cools the city



Simulated summer (June-August) daytime average Bowen ratio ($H/\lambda E$) as a function of percent pervious area for a mid-latitude North American city with H/W = 0.5

Oleson et al. (2008) J. Appl. Meteor. Climatol., in press

Simulated urban heat island



Maximum heat island for a North American mid-latitude city

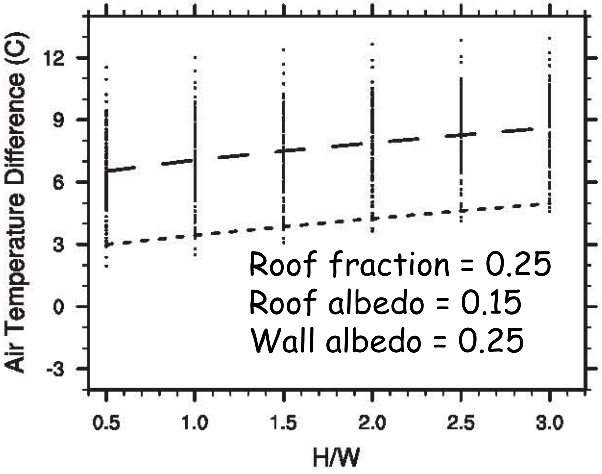
Model results are shown for no anthropogenic heat flux, with anthropogenic flux, and with anthropogenic flux and rural site modeled as forest

Simulated heat island is sensitive to specification of anthropogenic heat flux and to the type of rural vegetation

Oleson et al. (2008) J. Appl. Meteor. Climatol., in press

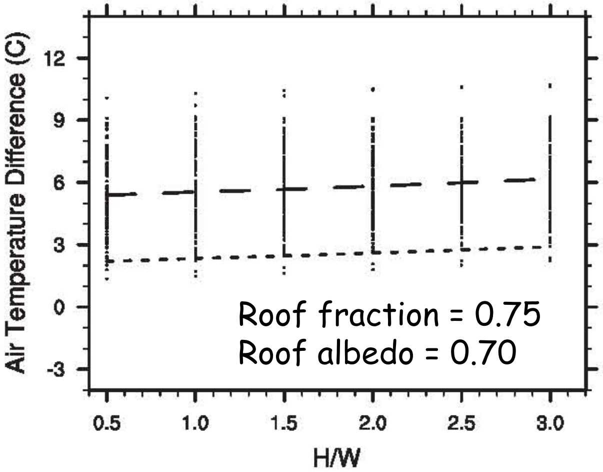
Urban heat island mitigation

Default



Roof fraction = 0.25
Roof albedo = 0.15
Wall albedo = 0.25

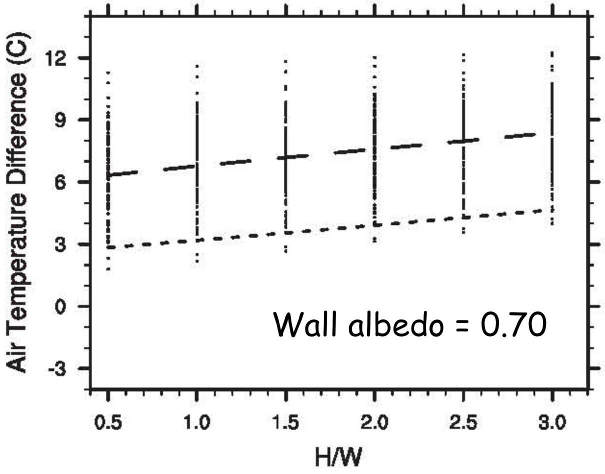
Roof albedo



Roof fraction = 0.75
Roof albedo = 0.70

White roofs reduce heat island

Wall albedo



Wall albedo = 0.70

Summer urban heat island (T_{urban} - T_{rural}) in U.S. cities

Instantaneous maximum heat island during summer

⋮ Range over U.S. cities

– – – – – City average

Daily average maximum heat island during summer

- - - - - - - City average

White walls have negligible effect

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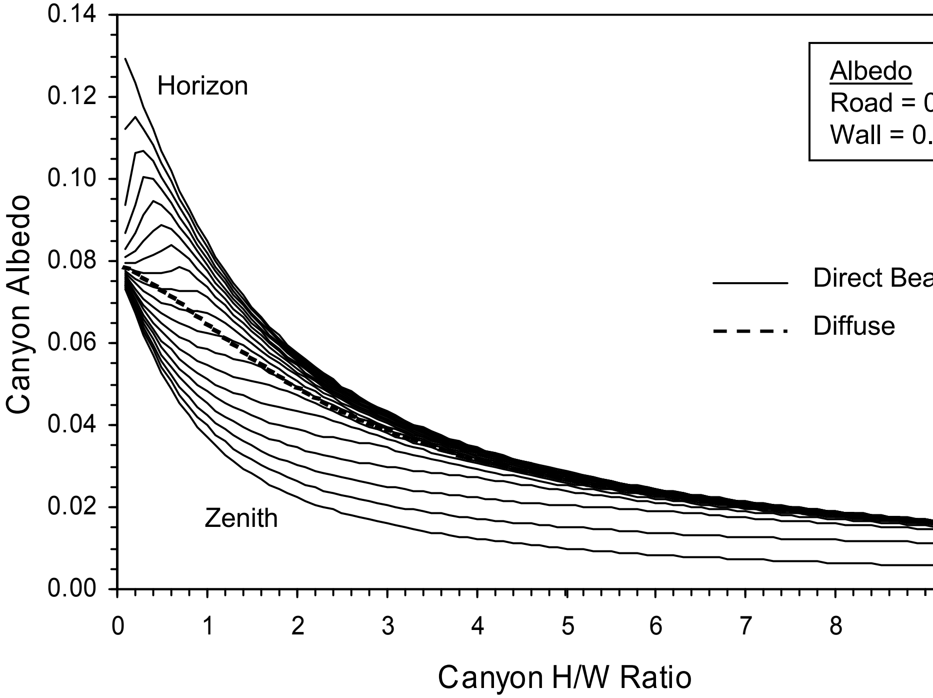
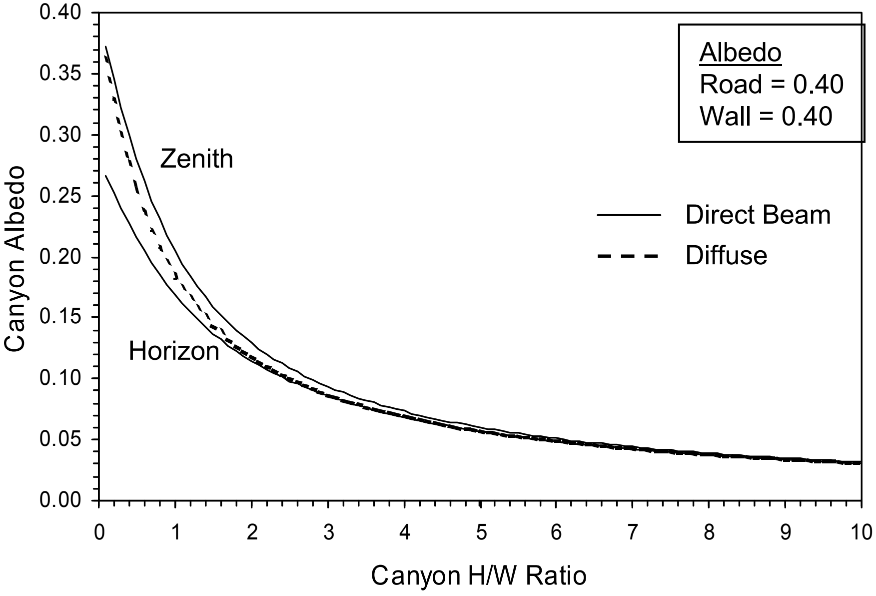
Simulated albedo



Albedo decreases with greater H/W, even for high surface albedo



Urban heat island mitigation

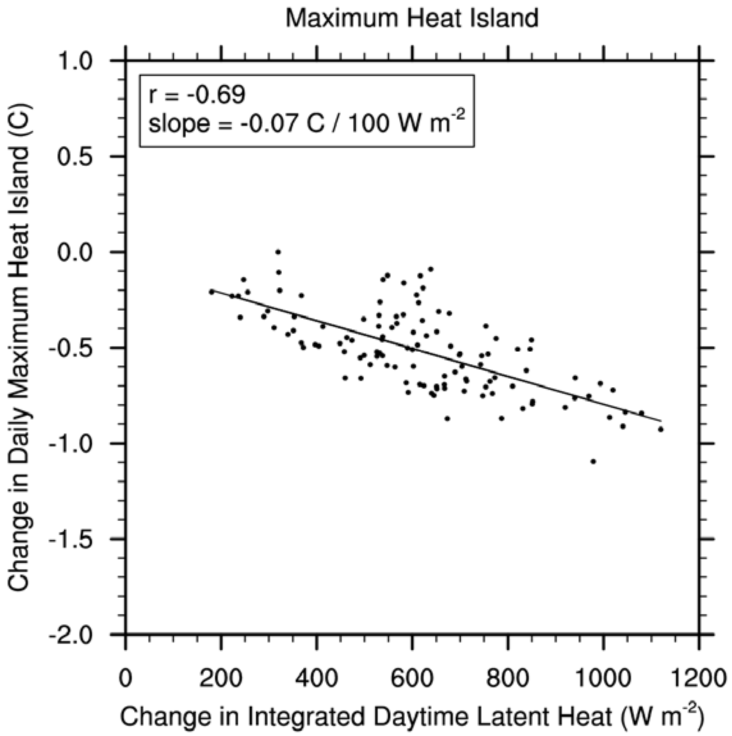
Urban parks decrease temperature

Change in daily maximum heat island in summer as a function of summed hourly daytime latent heat flux

$H/W = 3$
$f_{pervious} = 0.8$

vs.

$H/W = 3$
$f_{pervious} = 0$

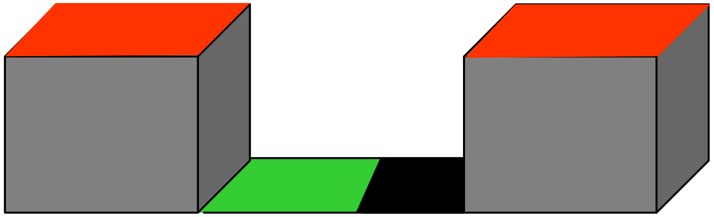


The urban heat island is reduced in proportion to the increase in latent heat flux

Oleson et al. (2008) J. Appl. Meteor. Climatol., in press

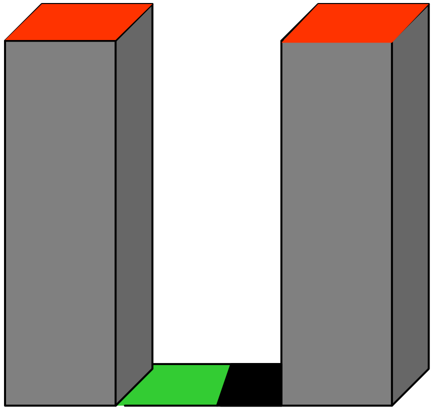
Urban heat island mitigation

Urban sprawl, Los Angeles



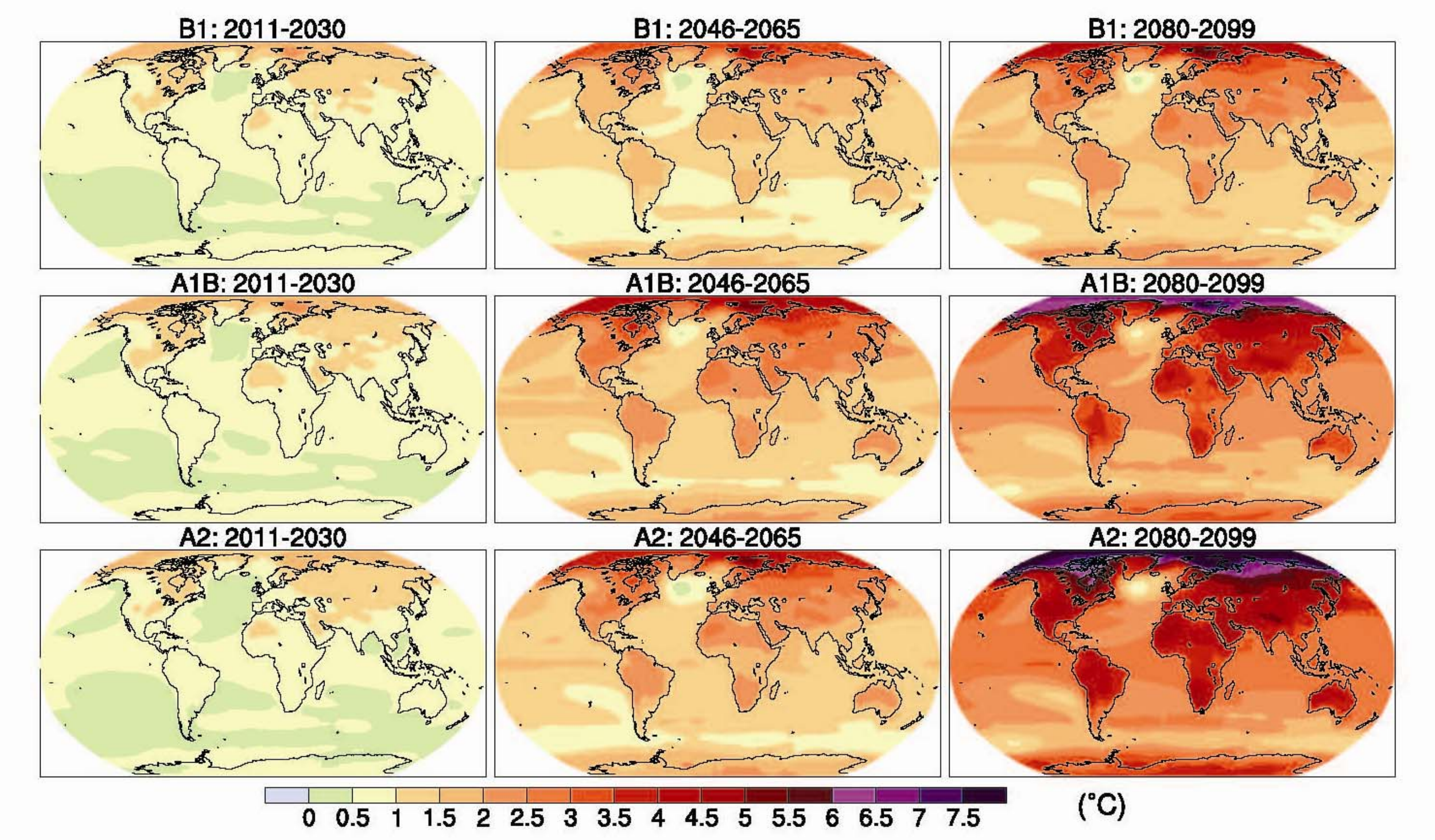
Geographically extensive
Low H/W
High vegetated fraction
Relies on automobile

Infill development, Arlington, VA



Geographically concentrated
High H/W
Low vegetated fraction
Relies on mass transportation

Climate change mitigation



We can now model the temperature in cities and its response to climate change and we can explore strategies to mitigate warming

Colonial Americans and forests

Thomas Cole – "View from Mount Holyoke, Northampton, Massachusetts, after a Thunderstorm (The Oxbow)", 1836

Conveys the views Americans at that time felt toward forests. The forest on the left is threatening. The farmland on the right is serene.

Atmospheric science – geophysical view expanded to a biogeophysical view

Ecology – ecosystem goods and services

Architecture and planning – ecological design