Climate Change Impacts on the Built Environment in the United States and Implications for Sustainability

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Climate Change Impacts on the Built Environment in the U.S. and Implications for Sustainability

Outline of the Talk

• What is the built environment and why is it important to assess how it will respond to climate change impacts?

• What are some key impacts of climate change on the built environment?

• Why we need to develop indicators of climate change for sustainable development and adaptation planning in response to impacts on the built environment?

• What are some examples of adaptation strategies for resiliency and sustainability of the built environment under climate change?
As an integral part of the National Climate Assessment (NCA), technical assessment reports for 13 regions in the U.S. that describe the scientific rationale to support climate change impacts within the purview of these regions, and provide adaptation or mitigation measures in response to these impacts.

These technical assessments focus on climate change impacts on sectors that are important environmental, biophysical, and social and economic aspects of sustainability within the U.S.:

- Climate change science
- Water resources
- Energy supply and use
- Transportation
- Agriculture
- Forestry
- Rural communities development
- Ecosystems and biodiversity
- Human health
- Water/energy/land use
- Urban/infrastructure/vulnerability
- Impacts of climate change on tribal/indigenous and native lands and resources
- Land use/land cover change
- Impacts on biogeochemical cycles, with implications for ecosystems and biodiversity
What is the Built Environment?

The ‘Built Environment’ is a key component of the National Climate Assessment's (NCA) Urban infrastructure/vulnerability sector.

- The Built Environment consists of components that have been made by humans at a range of scales from small (e.g., offices, houses, schools) to large (e.g., transportation networks and communities) to highly modified landscapes such as cities.

- Climate change will have significant impacts on the physical and biophysical interactions that occur between the land-atmosphere interface that presides over the Built Environment.

- It will also have consequences for social/human scale aspects of the Built Environment, such as energy, poverty, economic development, and urban migration. such as the exchanges between the land and atmosphere.
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Key Impacts of Climate Change on the Built Environment

Although certainly not all-inclusive, perhaps the most important impacts of climate change will be related to:

• Air Quality
• Urban Heat Island Effect
• Effects on Precipitation
• Urban Flooding
• Coastal Environment
• Human Health
Air Quality

• Coupled global climate model (GCM) and chemical transport model (CTM) studies show that climate change alone will increase summertime surface ozone in polluted regions by 1-10 ppb over the coming decade, with the largest effects in urban areas and during pollution episodes (Jacob and Winner, 2009).

• Climate change has the potential to push ground level $O_3$ concentrations beyond (EPA, 2009).

• In addition, it has the potential to lengthen the ground level $O_3$ season (EPA, 2009).

• Preliminary simulation results suggest that PM (particularly PM$_{2.5}$) response to climate change, depending upon the region, will potentially increase (EPA, 2009).
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Air Quality and the Built Environment

Sources of atmospheric emissions
- Fossil fuel combustion, agriculture, landfills

Natural and anthropogenic sources

Air pollution
- Sulphur dioxide (SO₂)
- Volatile organic compounds
- Nitrogen oxides (NOₓ)
- Particulate matter (PM)
- Carbon monoxide (CO)

Greenhouse gases
- Carbon dioxide (CO₂)
- Nitrous oxide (N₂O)
- Methane (CH₄)
- Hydrofluorocarbons
- Perfluorocarbons
- Sulphur hexafluoride

Meteorology
- Temperature, humidity, cloud cover, transport processes

Climate change

Warming and cooling effects
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Urban Heat Island Effect

Credit: Cynthia Rosenzweig
• Development of the UHI is forced by a number of causes related to the land and atmosphere interactions that occur over cities.
• These include: surface geometry, surface thermal properties, surface conditions, anthropogenic heat, and the urban greenhouse effect (Voogt, 2003).

120°F
49°C
• Urban warming carries the potential to not only enhance the magnitude of future warming trends, but to amplify the intensity of heat waves.

• Recent studies have found the UHI effect to be contributing to a rising number of extreme heat events in southeastern cities (Stone, Hess & Frumkin, 2010), as well as to an amplification of heat wave events in large cities such as Atlanta, Georgia (Zhou & Shepherd, 2010).
Effects on Precipitation

• While urban heat islands and urban air pollution are fairly common in the public and scientific vernacular, the “urban rainfall effect” is not as common (Shepherd et al. 2010).
• Potential of increased frequency and intensity of lightning due to thunderstorms.

Composite radar analysis for Atlanta, Georgia

a. The total number of day ≥ 40 dBZ

b. The Total number of 5-minute occurrences ≥ 40 dBZ for each 2-km grid cell versus distance from city center in the Atlanta domain for the 10-year, June-August period of record. NLCD urban delineated cells are colored red, whereas non-urban cells are blue. (Figure and caption following Ashley et al. 2011).
• Amplification of thunderstorms – both in frequency and intensity.

Difference (2025 – Current Land Cover) in simulated rainfall amount for a typical case day in Houston, Texas. Black outline represents 2025 urban land cover. (Courtesy of Marshall Shepherd – Univ. of Georgia)
Effects on Urban Flooding

- Hydrological extremes such as flooding and drought occurrence have increased markedly in the last three decades with more intense and longer episodes (Trenberth et al. 2007).

- Analysis by the NOAA NCDC suggests that in the southeastern United States, an increasing trend is detectable in the extreme precipitation record.

- The southeastern United States has experienced some of the most extreme urban flooding in recent years (e.g. Atlanta, Nashville).

- While many urban-related floods are explained by large scale meteorological and hydrological forcing, it is also clear that the urban environment may modify or increase the likelihood of flooding (Shepherd, 2011).
It is speculated that the urban landscape, through urban-enhanced precipitation, could have explained various regions of enhanced flooding around Atlanta during the historic North Georgia floods of 2009, even as large scale hydro-meteorological processes governed the main flooding event (Shepherd, 2009).
Shepherd et al., (2011) projected the growth of Houston, Texas urban land cover to the year 2025. They used the new land cover as a boundary condition for a set of regional modeling studies using current meteorological conditions.

Results illustrated that the regional precipitation climatology of southeastern Texas could be significantly altered, irrespective of greenhouse-gas driven climate changes, by changing the urban land cover and the interactions between the urban areas and sea-breeze circulations.
Coastal Environment

• Perhaps the most vulnerable Built Environments to climate change impacts are cities located in coastal areas.

• Impacts are far-ranging and include:
  1. Sea level rise
  2. Storm surge
  3. Heavy precipitation events

• Potentially severe Impacts on urban infrastructure, social structure, and human health.
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**Hurricane Sandy Storm Surge Impacts**

Population Density 2010
Persons per km²

- **0**
- **26–250**
- **251–1,000**
- **6–25**
- **> 1,000**

**Storm Surge Extent**

**Estimated Population and Land Area in Storm Surge Zones by State**

<table>
<thead>
<tr>
<th>State</th>
<th>Population 2010</th>
<th>Land Area (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New York</td>
<td>821,000</td>
<td>410</td>
</tr>
<tr>
<td>New Jersey</td>
<td>437,000</td>
<td>1,280</td>
</tr>
<tr>
<td>Massachusetts</td>
<td>59,000</td>
<td>170</td>
</tr>
<tr>
<td>Connecticut</td>
<td>57,000</td>
<td>120</td>
</tr>
<tr>
<td>Maryland</td>
<td>31,000</td>
<td>880</td>
</tr>
<tr>
<td>Delaware</td>
<td>25,000</td>
<td>500</td>
</tr>
<tr>
<td>Maine</td>
<td>13,000</td>
<td>130</td>
</tr>
<tr>
<td>Rhode Island</td>
<td>6,000</td>
<td>20</td>
</tr>
<tr>
<td>North Carolina</td>
<td>5,000</td>
<td>270</td>
</tr>
<tr>
<td>Virginia</td>
<td>5,000</td>
<td>70</td>
</tr>
<tr>
<td>New Hampshire</td>
<td>1,000</td>
<td>10</td>
</tr>
</tbody>
</table>

Gridded population counts for 2010 were constructed using official estimates from the US Census Bureau and TIGER geographic files.

Storm surge inundation data were developed by FEMA using the SLOSH P-Surge data for 10% probability of exceedance (i.e., the same surge data used for the official National Hurricane Center forecasts).
Projected Sea Level Rise Scenarios
Miami, FL

Projected 5 foot sea level rise

Projected 12 foot sea level rise

Projected 25 foot sea level rise

(based on USGS, NOAA, and Science data)
Projected Sea Level Rise Scenarios
San Francisco, CA

Projected 5 foot sea level rise

Projected 12 foot sea level rise

Projected 25 foot sea level rise

(based on USGS, NOAA, and Science data)
Inter-linkage of urban infrastructure sectors as impacted by climate drivers.

(NCA Infrastructure Technical Report, 2012)
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Social Structure Impacts

The “Climate Change Diaspora”

- Extensive or mass migration away from affected areas due to environmental impacts and circumstances (e.g., Hurricane Katrina)

- Severe impacts on non-mobile populations:
  - Economically disadvantaged
  - Elderly
  - Infirmed/assisted living/nursing homes
  - Persons unable to migrate because of family/cultural situations

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Potential Impacts of Global Climate Change on Human Health

Global climate change effects:
- Temperature
- Sea level
- Precipitation

Storms & flooding
- Morbidity / mortality / displacement

Heat
- Morbidity / mortality

Vector biology
- Infectious diseases

Air pollutants
- Respiratory diseases

Food supply
- Malnutrition

Civil conflict
- Morbidity / mortality / displacement
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The Need for Indicators of Climate Change for Sustainable Development and Adaptation Planning in Response to Impacts on the Built Environment

1) Provide meaningful, authoritative climate-relevant measures about the status, rates, and trends of key physical, ecological, and societal variables and values to inform decisions on management, research, and education at regional to national scales.

2) Identify climate-related conditions and impacts to help develop effective mitigation and adaptation measures and reduce costs of management.

3) Document and communicate the climate-driven dynamic potential and nature of climate impacts on the overall Built Environment.
Indicators of climate change need to provide solid bases for decision making at all levels and to contribute to the self-regulating sustainability of integrated and development systems

• Sustainability indicators must be more than environmental indicators; they must be about time and/or thresholds

• Development indicators should be more than growth indicators; they should be about efficiency, sufficiency, equity, and quality of life (D. Meadows, 1998. Indicators and Information Systems for Sustainable Development)
Who are the users sustainable development indicators of climate change impacts on the built environment?

Indicators need to provide information on:
• what impacts will occur
• under what climate change scenarios they will occur
• what the ramifications of these impacts will be

<table>
<thead>
<tr>
<th>Users of Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Federal/State/Local Government (examples of suggestions):</td>
</tr>
<tr>
<td>o Metropolitan, county, and municipal governments, zoning boards, etc.</td>
</tr>
<tr>
<td>o Chamber of Commerce</td>
</tr>
<tr>
<td>o Interested public</td>
</tr>
<tr>
<td>o General public</td>
</tr>
<tr>
<td>o Science/technical community</td>
</tr>
<tr>
<td>o Managers</td>
</tr>
<tr>
<td>o Regulators</td>
</tr>
<tr>
<td>o Have needs for indicators that are a little different than other decision makers</td>
</tr>
<tr>
<td>o American Medical Association, American Insurance Association, Air Transport Association, Cargo Association, etc.</td>
</tr>
<tr>
<td>o Business, industry, energy, transportation, insurance, agriculture, etc.</td>
</tr>
<tr>
<td>o Non-profit and Non-governmental organizations</td>
</tr>
<tr>
<td>o Defense/Intelligence community</td>
</tr>
<tr>
<td>o People who do mitigation and policy work</td>
</tr>
<tr>
<td>o Others not typically included, such as emergency planners and social scientists</td>
</tr>
</tbody>
</table>
Adaptation Strategies

• Although cities and their supporting human, biophysical, atmospheric, hydrologic, and socioeconomic individual components are subject to climate change impacts, assessing what adaptation measures can be taken to sustain these separate components, will ultimately make the entire ecosystem more resilient and adaptable.

• Because of the complexity of the city and its supporting ecosystems, we must really operate at a component-by-component level to assess what kinds of adaptability measures are needed to make the individual systems sustainable and resilient.

• Here it is both good stewardship of the resources that comprise the subcomponents of these individual ecosystems, and an understanding of what adaptation measures work best from a cost-benefit purview that matter most.
Flexible Adaptation Pathways approach that can evolve over time as understanding of climate change improves and that concurrently reflect local, national, and global economic and social conditions.

Flexible Adaptation Pathways is a concept that encourages building climate change adaptation strategies that can be adjusted and modified over time to reflect the dynamic and ongoing climate change understanding.
Some Insight into Selected Adaptation Strategies

Transportation:
• Adaptation strategies to address heat, sea level rise and inundation, and storm and precipitation extremes encompass the full spectrum of transportation functions including design, construction, operation and maintenance.

Telecommunications:
• Adaptation strategies appropriate for urban energy systems will vary.
• Some may have a temporal focus (e.g. short vs. long term) and be proactive or reactive.

- Overhead lines can be moved to underground cables where possible and economically feasible
- Trees can trimmed, where applicable (more often in suburban than urban areas), to avoid or reduce downed lines during wind, snow and ice storms
- Increasing fuel supplies for back-up power generators at cell phone towers, central offices, and radio/TV antennas, can sustain communication options during extended electric grid outages.
Some Insight into Selected Adaptation Strategies

Energy:

- In general, adaptation responses can be categorized as technological, behavioral, or structural.

  - **Technological** responses focus on the hardening of existing system assets to reduce their vulnerability to climate change risks.

  - **Behavioral** strategies may involve the relocation of critical energy system assets away from risk-prone areas.

  - **Structural** changes promoting adaptive capacity may include changes to fundamental energy market rules to create demand response programs that incentivize power load reductions during heat waves.
Some Insight into Selected Adaptation Strategies

Public Health:

• Shorter time scales:

- Adaptation efforts include infrastructure planning to reduce impacts, such as unimpaired emergency transportation systems and routes, improved sanitation systems, as well effective communication to the most highly vulnerable populations so they will take necessary actions, (i.e., move to cooling centers, evacuate appropriately, boil water, avoid contaminated water bodies).
Some Insight into Selected Adaptation Strategies
Public Health:

**Longer time scales:**

- Involve urban planning, increasing urban green space, access to low carbon footprint food, improved sanitation systems and sewage infrastructure.

- Access to clean water and reliable food supplies, effective and understood evacuation plans, and accessible transportation for evacuation and access to emergency facilities.

- Improvements in surge capacity for hospitals and emergency departments, training of hospital and medical personnel to deal with multiple emergencies and to detect new or emerging diseases and other health risks before an outbreak.
Some Insight into Selected Adaptation Strategies

Mitigation of the Urban Heat Island over the Built Environment:
• Urban forestry and trees
• Cool roofs
• Green roofs
• Urban Heat Island mitigation
  - 1) modifying urban geometry
  - 2) altering surface thermal and energy balance properties, 3) increasing energy efficiency,
  - 4) reducing anthropogenic heat.
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Adaptation Strategies: Summary

1. Identify current and future climate changes relevant to the system

2. Assess the vulnerabilities and risk to the system

3. Develop an adaptation strategy using risk-based prioritization schemes

4. Identify opportunities for co-benefits and synergies across sectors

5. Implement adaptation options

6. Monitor and reevaluate implemented adaptation options
There is a critical and timely need for the development of mitigation and adaptation strategies in response to climate change by the policy and decision making communities, to insure resiliency and sustainability of the built environment in the future.