Analysis of the urban surface radiative budget and urban heat islands: How can HyspIRI data be used?

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What Happens to the Sun's Energy?
Sketch of an Urban Heat-Island Profile

Late Afternoon Temperature

°F

°C

-33

-32

-31

-30

85

92

Rural  Commercial  Urban Residential  Suburban Residential  Downtown  Park  Rural Farmland
Volatile Organic Compounds + Nitrogen Oxides + Sunlight → Ozone

- Air pollution remains a National issue.
- Temperature increases the ozone levels.
- Urban heat island has major effect on temperature and height of mixing layer.
- Measurement program is defining land use patterns and relationship to heat production.
- Remote sensing data are being used to improve air quality modeling.
How Cities Make Their Own Weather

WHEN HOUSTON IS HIT BY A SUDDEN storm, the city may be partly to blame. Increasingly, urban centers don’t merely endure bad weather; they help create it. Researchers believe the phenomenon may be more common now than ever before.

Scientists have known for 200 years that the temperature in a city can be higher than that in its environs—something they learned when an amateur weather watcher detected a 1.8°F temperature difference between London and its suburbs. Modern cities, with their cars and heat-trapping buildings, can create an even bigger temperature gap, sometimes as much as 10°F.

Islands of urban heat can do funny things with weather. Hot city air, like hot air anywhere else, rises—even more so because of the turbulence caused by tall buildings. When that air is damp enough and collides with colder layers above it, water can condense out as a sudden burst of rain, especially if there are few frontal systems to disrupt the layers, as in summer. In a spot storm above a city or just downwind of it, it’s likely that nature alone isn’t behind the downpour.

NASA and the University of Arkansas have been using satellite mapping and ground-based temperature readings to determine how widespread this phenomenon is. This spring researchers got a situation when they turned their attention to Houston. Because it’s near a coast and sea breezes tend to cool and disperse hot air, Houston was thought to be comparatively safe from homemade rain. Now it appears that the opposite may be true. “The sea breeze may exacerbate the rainfall,” says research meteorologist Marshall Shepherd of NASA’s Goddard Space Flight Center. The warm air and sea air collide, he explains, and “move straight up like the front ends of two cars that hit head on, providing a pump of moist air that helps thunderstorms develop.”

Hot, waterlogged cities can be cooled off in the usual ways—by limiting auto exhaust, for example. Using light-colored roofing and paving materials in place of black, heat-absorbing tar will also help. As a bonus, the cooler roof will reduce the need for air conditioning. —By Jeffrey Kluger

1. In big cities, heat-absorbing roofs, blacktop pavement and auto exhaust trap the sun’s rays and warm the air
2. Late in the day, the accumulated heat starts to be released. The light, warmed air begins to rise
3. In cities near large bodies of water, moist air flows in toward the rising urban air
4. The moist air and warm city air collide and drive each other higher, hitting the cooler layer of air above and creating clouds and rain
5. The prevailing wind blows the clouds. Areas downwind of cities get more rain than those upwind

HOT ZONE
High concentrations of buildings, roads and other artificial structures retain heat, leading to warmer temperatures. A NASA snapshot of Houston taken one evening in August 2000 demonstrates this urban heat island effect. The hot zone downtown stands in sharp contrast to the cooler suburbs to the south

Source: NASA/Goddard Space Flight Center
Map sharpened by Jetta Productions
Surface Radiation Budget

\[ Q^* = (K_{in} + K_{out}) + (L_{in} + L_{out}) \]

- \( Q^* \) = Net Radiation
- \( K_{in} \) = Incoming Solar
- \( K_{out} \) = Reflected Solar
- \( L_{in} \) = Incoming Longwave
- \( L_{out} \) = Emitted Longwave
Surface Energy Budget

\[ Q^* = H + LE + G \]

- \( H = \) Sensible Heat Flux
- \( LE = \) Latent Heat Flux
- \( G = \) Storage (maybe + or - )
<table>
<thead>
<tr>
<th>Surface</th>
<th>Albedo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soils</td>
<td>0.05-0.40</td>
</tr>
<tr>
<td>Desert</td>
<td>0.20-0.45</td>
</tr>
<tr>
<td>Grass</td>
<td>0.16-0.26</td>
</tr>
<tr>
<td>Crops</td>
<td>0.18-0.25</td>
</tr>
<tr>
<td>Forests-deciduous</td>
<td>0.15-0.20</td>
</tr>
<tr>
<td>Forests-coniferous</td>
<td>0.05-0.15</td>
</tr>
<tr>
<td>Water (small zenith angle)</td>
<td>0.03-0.10</td>
</tr>
<tr>
<td>Snow (fresh)</td>
<td>0.40-0.95</td>
</tr>
</tbody>
</table>
## Albedo of Typical Urban Materials & Surfaces

<table>
<thead>
<tr>
<th>Surface</th>
<th>Albedo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt Roads</td>
<td>0.05-0.20</td>
</tr>
<tr>
<td>Concrete</td>
<td>0.10-0.35</td>
</tr>
<tr>
<td>Brick</td>
<td>0.20-0.40</td>
</tr>
<tr>
<td>Tar &amp; Gravel Roofs</td>
<td>0.08-0.18</td>
</tr>
<tr>
<td>Tile Roofs</td>
<td>0.10-0.35</td>
</tr>
<tr>
<td>Corrugated Iron Roofs</td>
<td>0.10-0.16</td>
</tr>
<tr>
<td>White Membrane</td>
<td>0.64-0.84</td>
</tr>
<tr>
<td>Paint-White</td>
<td>0.50-0.90</td>
</tr>
<tr>
<td>Paint- Red, Brown, Green</td>
<td>0.20-0.35</td>
</tr>
<tr>
<td>Urban Areas</td>
<td>0.10-0.27 (0.15)</td>
</tr>
</tbody>
</table>
ATLAS

Typical Spectral Response Curves

Reflected Bands

D. Rickman, et al., Nov. 9, 1999
ATLAS

Typical Spectral Response Curves

Thermal Bands

D. Rickman, et al., Nov. 9, 1999
Emissivity Differences in Natural Surfaces

Increasing energy

W m\textsuperscript{-2} micron\textsuperscript{-1} sr\textsuperscript{-1}

W m\textsuperscript{-2} micron\textsuperscript{-1} sr\textsuperscript{-1}
San Juan
CH 10 vs CH 11

Energy
W m\(^{-2}\) sr\(^{-1}\) micron
Overall Process Flow

Airborne Sensor
- Examine Housekeeping & Video Data Streams "AtlasHouseKeeping"
  - Extract Geometry ELAS's "GR*" series
  - Convert to Absolute Units & Correct for Atmosphere "Watts"
    - Albedo, Temperature & Net Radiation "Energy"
      - Shadow Correction "DBAS"
      - Geometric Correction "GRRMAP"
      - Mosaic All Lines "MOSAIC"
      - Compute TRN

Initial Atmospheric Modeling
- Radiosonde
  - Model Aerosols "MODTRAN4"
    - 7 Model Atmospheres "MODTRAN4"

Ground Atmospheric Data
San Juan F5 Mosaic True Color
El Yunque F4 Mosaic Temperature

°C  20 24 27 30 32 36 39 43
El Verde "Urban" Albedo

Freq %

Albedo
El Yunque
Albedo vs Temperature

Temperature
°C

Albedo

0.10
0.70
10
70
Urban Heat Island Mitigation Pilot Project

EPA/NASA Marshall Space Flight Center
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Dale Quattrrochi
Maury Estes
Doug Rickman
Urban Heat Island Mitigation Strategies

- **Albedo Modification**
  - Lighter colored roofs and pavements
  - New materials/coatings

- **Plant trees and increase green space**
  - Shade buildings, rooftops, parking lots and roads
  - Cool the air through transpiration

- **Rooftop gardens**
  - Keep roofs cool by shading and/or transpiration
  - Storm water reduction
SMUD’s Urban Heat Island mitigation efforts

✓ Increased Vegetation—SMUD’s Shade Tree program (1990)
✓ Increased Roof’s Albedo—SMUD’s Cool Roof program (2001)

☑ Light colored pavements (i.e. Cool Parking Lots)—Sacramento Cool Community Project (1999)
SMUD Shade Tree Program

- started in 1990
- implemented in collaboration with the Sacramento Tree Foundation (STF)
- over 100,000 program participants
- approximately 300,000 trees planted
- annual budget over $1.5 million
- over $20 million invested since 1990
- received several national and state awards
- pay-for-performance contract with STF based on observed Present Value Benefits (PVB)
SMUD Shade Tree Program

Estimates of Savings for mature trees

- Average energy cooling load savings are 153 kWh/year/ per tree
- Average demand savings are 0.056 kW
- When 300,000 trees are mature = about 16 MW
SMUD Cool Roof Program

Program Objectives

• Load Reduction-- reduce electricity peak demand and air conditioning energy load associated with high solar energy absorbed on the surface of roofs and rooftop ducts during the summer months

• Urban heat island effect mitigation

• Market Transformation-- expand the commercial retrofit and new construction roofing marketplace for highly reflective and emissive roof coatings and materials.
SMUD Cool Roof Program

Estimates of Savings

- Average energy cooling load savings of 20%
- Average energy cooling load savings are 0.15 kWh/year/Sq.Ft.
- Average demand savings are 0.25 W/Sq.Ft.
Spatial Growth Models

• Empirical
  – statistically matching temporal trends and/or spatial patterns with a set of predictor variables

• Dynamic Process
  – Interactions between agents/organisms and environment (Cellular Automata, SLEUTH)
  – Cells can represent parcels of land with unique characteristics and each changing as a result of rules on both the cell’s state and state of neighbors

• Agent-based
  – Micro-scale behaviors of individuals (farmers, ranchers, etc.) or institutions (industries, gov’t, etc. with feedback loops (Research)
Surface Temperature by Land Use Class

Based on ATLAS aircraft data, May 1997

- Water
- Forest
- Low-density Residential
- Agriculture
- Recreation
- Quarries/Rock
- Institutional Urban
- High-density Residential
- Industrial/Commercial
Problem description

• Istanbul is the largest city in turkey
  – Population 11 million

• Traffic congestion:
  – 600 cars enter the system every day

• Infrastructure project under consideration includes construction of a third bridge across the Bosporus, north of the city
  – How would the proposed infrastructure project affect the ecologically sensitive area located in the north?
  – Answer needed in days!!
  – This project is the first step towards a DSS that would provide an answer to such questions
LULC statistics for Istanbul

Istanbul Area

<table>
<thead>
<tr>
<th>Land Use Type</th>
<th>1986</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>15%</td>
<td>10%</td>
</tr>
<tr>
<td>Crop</td>
<td>40%</td>
<td>50%</td>
</tr>
<tr>
<td>Forest</td>
<td>35%</td>
<td>45%</td>
</tr>
<tr>
<td>Urban</td>
<td>10%</td>
<td>15%</td>
</tr>
<tr>
<td>Bare</td>
<td>5%</td>
<td>10%</td>
</tr>
</tbody>
</table>
1986 Land Use – Bridge Area
2007 Land Use – Bridge Area
LULC statistics around the bridge

Fatih Sultan Mehmet Bridge Area

Percent Coverage

- Water
- Crop
- Forest
- Urban
- Bare

1986 2007

Land Processes Research and Applications Team, NASA Marshall Space Flight Center, Huntsville, AL
LST as a function of LULC and season

Mean land surface temperature by season and land use type, from all Aqua and Terra MODIS observations, 2003-2006.
LST differences due to urbanization, 1986-2007

Inferred relative differences in seasonal LST attributed to LULC changes in vicinity of the second bridge between 1986 and 2007.
2007 LST based on 2003-2006 mean MODIS LST for each LULC type and 2007 Landsat LULC. 1986 LST estimated from the different proportions of LULC from the 1986 Landsat LULC.

Land Processes Research and Applications Team, NASA Marshall Space Flight Center, Huntsville, AL
Modeled 2-m air temperature
Bridge Area

Mean WRF 2 m air temperatures - Bridge Area

- Winter: +0.51 °C
- Spring: +0.01 °C
- Summer: +0.28 °C
- Fall: +0.45 °C

Legend:
- 1986
- 2007
What can HysplRI data provide for urban heat island research and applications?

- Scale consistency with complex urban surfaces
- Well calibrated data allows quantifiable radiative & energy budgets:
  - Analysis of albedo
  - Analysis of surface temperature
  - Analysis of emissivity
- Scale consistent to plan alteration of the urban fabric to mitigate the urban heat island
- Swath width scale for urban climatology studies - urbanization of RAMS.
- Global cities.
- Only multispectral thermal at 60 m
- 5 day repeat for thermal for short & long term trend analysis
- Allow for functional classification of urban surfaces