A Spatiotemporal investigation of heat wave characteristics and trends in Los Angeles

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Outline

• Background and Motivation

• Heat waves
  – Definition
  – Detection
  – Trends

• Thermal remote sensing
  – Spatiotemporal LST patterns
  – Extreme heat day trends
  – Heat wave vulnerability maps
ENVIRONMENT + CLIMATE

Mercury rising: Greater L.A. to heat up an average 4 to 5 degrees by mid-century

LA: First Major City to Mandate Cool Roofs on All New Residences

POSTED BY CLIMATE RESOLVE IN #BLOG ON DECEMBER 17, 2013

The Los Angeles City Council unanimously passed an update to the Municipal Building Code on December 17th, 2013 making Los Angeles the first major city to require all new and refurbished homes to have a “cool roof.” Climate Resolve held the “Hot City, Cool Roofs”

UCLA LARC Study (Hall et al. 2012) – ensemble climate model projection
Average Decadal Trend in Max Temperature = 0.4 °F
~2.5 °F warming by 2060

Average Decadal Trend in Min Temperature = 0.74 °F
~4 °F warming by 2060

Data Source: NCDC COOP
On a global scale

Currently, about 30% of the world's population experiences at least 20 days per year of potentially deadly heat.

By 2100, this percentage jumps to 74% of the population if emissions continue unchecked.
Heat Waves

Most common cause of weather-related deaths in the United States!

They cause more deaths each year (~1,500) than hurricanes, lightning, tornadoes, floods, and earthquakes combined (~200).

The number of heat-related deaths is rising.

2003: 15,000 deaths in Paris
2010: 10,000 deaths in Russia
2013: 760 deaths in UK
Energy absorbed by man-made materials during day is released slowly at night resulting in heating of air.
2m HyTES Land Surface Temperature, La Brea, Los Angeles

‘White’ high albedo Roof: 110 °F

‘Black’ Roof: 140 °F
Heat wave definition

• **Excess Heat Index (EHI)**
  - Unusually high heat arising from daytime temperatures that is not discharged overnight due to combined overnight high temperature

\[
EHI = T_i - T_{97.5}
\]

Where,
\[
T_i = (T_{\text{max}} + T_{\text{min}})/2
\]

\[
T_{97.5} = 98^{th}\ percentile\ of\ daily\ T_i\ climatology
\]

\[
T_i = \text{apparent temperature} = -2.7 + 1.04*T + 2.0*RH - 0.65*Vs
\]

*Temperature equivalent as ‘felt’ by humans*

**Heat wave** = 3 or more consecutive days where EHI values exceed a threshold
Heat wave trend statistics using NOAA COOP air temperature data (1920 – 2017)
Heat Wave Detection
NCDC 2m Air Temperature – Downtown LA

**heatwave:** 3 or more consecutive days where EHI values exceed a certain threshold (0, or 20 for extreme)

LA July 2006 Heat wave:

- Valley temperatures peaked at 119 °F (all time record)
- Combination of high heat/humidity
- 30 deaths across CA state
Heat Wave Trends
(Each point represents 5-year average)

Increases Fire risk!

Human health/comfort impacts

Frequency (number/year)

Intensity (degrees)

Duration (days)

Doubled in past 10 years

- Frequency (number/year): $r^2 = 0.75$
  - $p = 0$
  - $0.43$/decade

- Intensity (degrees): $r^2 = 0.5$
  - $p = 0.0005$
  - $0.14$ °F/decade

- Duration (days): $r^2 = 0.63$
  - $p = 0$
  - $0.29$ days/decade

Doubled in past 10 years

- Frequency:
  - 2010: Doubled from 2000
  - 2020: Doubled from 2010

Increases Fire risk!

Human health/comfort impacts
Pasadena heat wave seasonality
Heat waves are starting earlier in the year and ending later = increased fire risk

Start day of heat wave season
- $r^2 = 0.62$
- $p = 0$
- -4.58 days/decade

End day of heat wave season
- $r^2 = 0.44$
- $p = 0.0015$
- 4.32 days/decade

Aug: June
Nov: Sep
## New MODIS LST Product (JPL) – Collection 6

<table>
<thead>
<tr>
<th>New Products</th>
<th>PI</th>
<th>Status</th>
<th>Spatial</th>
<th>Formats</th>
<th>Algorithm</th>
<th>SDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOD21</td>
<td>Hulley (JPL)</td>
<td>Released with Tier-2 Collection 6 (Fall 2017)</td>
<td>1-km</td>
<td>L2 Swath, L2 8 day 2X Daily</td>
<td>Temperature Emissivity Separation (TES)</td>
<td>- LST</td>
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<td></td>
<td></td>
<td></td>
<td>- Emissivity bands 29, 31, 32</td>
</tr>
</tbody>
</table>

LST and Emissivity physically retrieved (ECOSTRESS, HyspIRI, MASTER)
MOD21 Daily average heatwave LST (2003-2016)

Urban Hotspots

ECOSTRESS 60m

MODIS 1 km

Land Surface Temperature (LST) [°F]

South County
Beach cities

Hotspots lie in industrial complexes and lower income communities

Van Nuys
San Fernando
Norwalk
Chatsworth
Anaheim
Whittier

Central LA
Westside
South Bay
South LA
Eastside
Northeast LA
Verdugos
San Fernando Valley
Santa Monica Mnts
San Gabriel Valley
Pomona Valley
Southeast
The Harbor
North County
South County
Beach cities

Ocean moderating effect on temperature during heat waves
Heat Vulnerability map based on demographic information (income, education, age), identifies communities most vulnerable to rising temperatures.

**Good correlation with LST data from MODIS. But some areas missed!**

*Source: Climate Smart Cities program, Fernando Cazares.*
LST Data (MODIS, ECOSTRESS, HySpIRI)

Human-Comfort Model (COMFA)  
*Brown et al. 1995*

Urban Heat Stress Index (UHSI)

- Near real-time
- Communicated to local officials
- Heat warnings
- Used in mitigation efforts
- Extend to other major cities

Demographic Data  
(LA County Sustainability Office)
MOD21 day/night LST PDF

East LA, September

More extreme temperatures

Shift in mean and variance
Days with MODIS LST > 105 °F

Los Angeles Downtown

dD = 1.7 days/year, $R^2 = 0.62$, $p = 0.01$

@2015: 82
@2050: 140
Areas with significant trends (2003-2017)

60-70% increase by 2050
More extreme temperatures expected inland

\[ p < 0.05 \]
\[ R^2 > 0.3 \]
WE’RE TAKING ACTION
TO ENSURE A CLIMATE-RESILIENT LOS ANGELES

Join us.
Urban Thermal Sharpening

• Imaging spectroscopy in VSWIR (0.4-2.5 um) can be acquired at higher spatial resolution than TIR (8-12 um)

• TIR wavelengths are longer – larger optics, cooling challenges

<table>
<thead>
<tr>
<th>Resolution</th>
<th>SWIR</th>
<th>TIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODIS</td>
<td>250-500m</td>
<td>1 km</td>
</tr>
<tr>
<td>Landsat</td>
<td>30 m</td>
<td>100 m</td>
</tr>
<tr>
<td>HyspIRI</td>
<td>30 m</td>
<td>60 m</td>
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</tbody>
</table>
HUTS (High Resolution Urban Thermal Sharpener)  *Dominguez et al. 2011*

\[ \text{LST} = f(\text{Albedo, NDVI}) + d\text{LST} \]
Landsat 100 m LST

Landsat 30 m LST

Roads and runways delineated

Roofs distinguished

Crop fields delineated
MODIS LST (1km), 10/2/2010

Landsat LST (30m), 10/2/2010

Severe Heat Wave

Downtown LA

East LA

MODIS LST (1km), 10/10/2010

Landsat LST (30m), 10/2/2010

Silverlake reservoir

Downtown LA

East LA

MODIS LST (1km), 10/10/2010

Landsat predicted LST (30m), 10/10/2010

Silverlake reservoir

Downtown LA

East LA

Severe Heat Wave

Building shadows

Building shadows