MCITY BRAZIL PROJECT: ASSESSING URBAN CLIMATE FEATURES OF SÃO PAULO AND RIO DE JANEIRO

Amauri P. de Oliveira\textsuperscript{1*}, Edson P. Marques Filho\textsuperscript{2}, Mauricio J. Ferreira\textsuperscript{1}, Jacyra Soares\textsuperscript{1}, Georgia Codato\textsuperscript{1}, Eduardo Landulfo\textsuperscript{3}, Flávia N. D. Ribeiro\textsuperscript{1}, Eleonora S. Assis\textsuperscript{4}, Maxsuel M. R. Pereira\textsuperscript{5}, João F. Escobedo\textsuperscript{6}, Primoz Mlakar\textsuperscript{7}, Marija Z. Boznar\textsuperscript{7}

\textsuperscript{1}University of São Paulo, São Paulo, Brazil
\textsuperscript{2}Federal University of Rio de Janeiro, Rio de Janeiro, Brazil
\textsuperscript{3}Institute of Nuclear Energy Research, São Paulo, Brazil
\textsuperscript{4}Federal University of Minas Gerais, Minas Gerais, Brazil
\textsuperscript{5}Federal University of Espírito Santo, Espírito Santo, Brazil
\textsuperscript{6}State University of São Paulo, Botucatu, Brazil
\textsuperscript{7}MEIS d.o.o., Mali Vrh pri Smarju, Slovenia
FINANCIAL SUPPORT

State of São Paulo Research Fundation (FAPESP) (Grant N. 2011/50178-5).


National Council for Scientific and Technological Development (CNPq). (Grant N. 476812/2011-9).
BRAZILIAN RESEARCH INSTITUTIONS

University of São Paulo (USP)
State University of São Paulo (UNESP)
Institute of Nuclear Energy Research (IPEN)
Federal University of Rio de Janeiro (UFRJ)
Federal Rural University of Rio de Janeiro (URFRJ)
Federal University of Minas Gerais (UFMG)
INTERNATIONAL COLLABORATION

Bob Bornstein (SJSU, USA)
Júlia Hidalgo (Meteo-France, France)
Primoz Mlakar and Marija Boznar (MEIS, Slovenia)
Claudia Furlan (Padova University, Italy)
Monique Leclerc (GSU, USA) (INITIAL PHASE)
TOPICS

1. MAIN GOAL
2. MOTIVATION
3. URBAN EFFECTS ON CLIMATE
4. MCITY PROJECT
5. MICROMET NETWORK & FIELD CAMPAIGNS
6. PRELIMINAR RESULTS
7. CONCLUSION
1. MAIN GOAL

Urban heat island

Surface energy balance

Urban Boundary Layer

Landuse characterization
2. MOTIVATION

The investigation of urban heat island and other urban effects on the climate of cities located at tropical and subtropical areas have received less attention than in other latitudes, as result much less is known about urban climate in these regions.
85% BRAZILIAN POPULATION ARE “LIVING” IN URBANS AREAS
# SOCIAL AND ECONOMICS

<table>
<thead>
<tr>
<th>Descrição</th>
<th>RMSP</th>
<th>RMRJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>CITIES</td>
<td>38</td>
<td>20</td>
</tr>
<tr>
<td>AREA (km$^2$)</td>
<td>7,944 km$^2$</td>
<td>5.682 km$^2$</td>
</tr>
<tr>
<td>POPULATION</td>
<td>19,672,582</td>
<td>15,180,636</td>
</tr>
<tr>
<td>VEHICLES</td>
<td>6.900.000</td>
<td>3.630.678</td>
</tr>
<tr>
<td>BRAZILINA GPD</td>
<td>33.9%</td>
<td>11.2%</td>
</tr>
</tbody>
</table>

IBGE(2010)

GPD : GROSS DOMESTIC PRODUCT
# GREEN HOUSE GAS EMISSION

## TABLE 2
Selected urban greenhouse gas emissions

<table>
<thead>
<tr>
<th>City (date of study)</th>
<th>Total GHG emissions (million tonnes CO$_2$ equivalent)*</th>
<th>GHG emissions per capita (tonnes of CO$_2$ equivalent)</th>
<th>National GHG emissions per capita (tonnes of CO$_2$ equivalent)</th>
<th>City emissions as percentage of national emissions (per capita)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>European cities</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barcelona (1996)$^1$</td>
<td>5.1</td>
<td>3.4</td>
<td>10.03 (2004)</td>
<td>33.9%</td>
</tr>
<tr>
<td>London (2006)$^3$</td>
<td>44.3</td>
<td>6.2</td>
<td>11.19 (2004)</td>
<td>55.2%</td>
</tr>
<tr>
<td><strong>North American cities</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>District of Columbia (2005)$^4$</td>
<td>11.3</td>
<td>19.7</td>
<td>23.92 (2004)</td>
<td>82.4%</td>
</tr>
<tr>
<td>New York City (2005)$^5$</td>
<td>58.3</td>
<td>7.1</td>
<td>23.92 (2004)</td>
<td>29.7%</td>
</tr>
<tr>
<td><strong>South American cities</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rio de Janeiro (1998)$^7$</td>
<td>12.8</td>
<td>2.3</td>
<td>8.2 (1994)</td>
<td>28.0%</td>
</tr>
<tr>
<td>São Paulo (2003)$^8$</td>
<td>15.7</td>
<td>1.5</td>
<td>8.2 (1994)</td>
<td>18.3%</td>
</tr>
</tbody>
</table>

POLLUTION – WINTER (OZONE)
SEVERE WEATHER (SUMMER FLOOD)

3. URBAN EFFECTS ON CLIMATE

What we now about urban effects on the climate of São Paulo and Rio de Janeiro?
Sea Breeze in São Paulo

Relative Humidity increases

Wind Direction Shits from NE to SE

Temperature Decreases.
Sea Breeze - São Paulo

Hodograph
Elliptical shape
Counter clockwise (SH)

Local time
JANUARY 1978
Sea Breeze - São Paulo

PENETRATES AROUND 14:00 LT
Sea Breeze  Topographic  Roughness

(a) February  (b) May  (c) November

Lower wind

Higher wind

Wind speed (m s⁻¹)

Mean divergence (10⁻⁵ s⁻¹)

Local time (h)
SÃO PAULO: $\Delta T_{U-R}$ MAX SOLAR HEATING

$SW^* = SW\downarrow + SW\uparrow$

$SW = \text{SHORT WAVE RADIATION}$

Ferreira, et al. (2012)
Diurnal variation in stored energy flux in São Paulo city, Brazil. Urban Climate, 5, 36-51.
PBL HEIGHT AND STRUCTURE (00 and 12 GMT)

RESIDUAL MIXED LAYER

Valença, 2013
LIDAR PBL ESTIMATES

Landulfo et al., 2010
WHAT WE KNOW ABOUT SÃO PAULO

• Surface wind patterns are associated to sea-breeze, topographic (Mountain-Valley thermal circulation) and landuse (Roughness) effects;

• UHI maximum occurs between 14:00-16:00LT (daytime), varied from 2 to 6.5°C (monthly average) and is driven by the net solar radiation;

• Anthropogenic energy flux (diurnal evolution amplitude 20 Wm\(^{-2}\)) 50 % Vehicular, 41% Stationary and 9% Human metabolism;

• Stored energy flux correspond to 50% of net radiation during daytime and 100% during nighttime.

• PBL height (100-2500m) and Low Level Jet (10-15 ms\(^{-1}\), 300-600m, NE).
4. MCITY BRAZIL PROJECT

BRAZIL

23°32'36" S 46°37'59"W

22° 54' 10" S, 43° 12' 28" W
MCITY NETWORK – SÃO PAULO

23.2 KM
### Metropolitan Region of São Paulo

<table>
<thead>
<tr>
<th>Site</th>
<th>Landuse</th>
<th>Height (m)</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Altitude (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAG</td>
<td>Suburban</td>
<td>17</td>
<td>23° 33' 34&quot; S</td>
<td>46° 44' 01&quot; W</td>
<td>744</td>
</tr>
<tr>
<td>ITU</td>
<td>Rural</td>
<td>0</td>
<td>23° 49' 32&quot; S</td>
<td>46° 30' 32&quot; W</td>
<td>760</td>
</tr>
<tr>
<td>SFZ</td>
<td>Urban</td>
<td>77</td>
<td>23° 33' 01&quot; S</td>
<td>46° 37' 49&quot; W</td>
<td>741</td>
</tr>
<tr>
<td>AIRPORT Campo de Marte</td>
<td>Suburban</td>
<td>0</td>
<td>23° 30' 32&quot; S</td>
<td>46° 38' 04&quot; W</td>
<td>722</td>
</tr>
</tbody>
</table>

### Metropolitan Region of Rio de Janeiro

<table>
<thead>
<tr>
<th>Site</th>
<th>Landuse</th>
<th>Height (m)</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Altitude (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGEO</td>
<td>Suburban</td>
<td>12.5</td>
<td>22° 51' 26&quot; S</td>
<td>43° 14' 01&quot; W</td>
<td>10</td>
</tr>
<tr>
<td>AIRPORT Galeão</td>
<td>Suburban</td>
<td>0</td>
<td>22° 48' 32&quot; S</td>
<td>43° 14' 59&quot; W</td>
<td>10</td>
</tr>
</tbody>
</table>

(*) Above the mean sea level
MCITY NETWORK IN SÃO PAULO

- IAG (23°33′34″ S; 46°44′01″ W; 744 m)
- ITU (23°49′32″S ;46°30′32″W ;760 m)
- SFZ (23°33′0.23″S; 46°37′48.85″W; 758 m)
MCITY NETWORK IN RIO DE JANEIRO

- IGEO (23°33’34” S; 46°44’01” W; 744 m)
- ITU (23°49'32"S ;46°30'32“W ;760 m)
- SFZ (23°33'0.23"S; 46°37'48.85“W; 758 m)
IGEO MICROMETEOROLOGICAL PLATFORM
SUBURBAN SITE
IAG MICROMETEOROLOGICAL PLATFORM

IAG – INSTITUTE OF ASTRONOMY, GEOPHYSICS AND ATMOSPHERIC SCIENCES
IAG

SUBURBAN SITE MEASUREMENTS
DECEMBER, 2012
ITUTINGA
MICROMETEOROLOGICAL PLATFORM

04/02/2014
ITUTINGA PILÕES PARK

ATLANTIC FOREST

04/02/2014
ITU - MICROMETEOROLOGICAL TOWER (10 m)

Temperature and Relative Humidity

Soil heat plate and temperature

Tipping bucket rain gauge
Cup Anemometer and wind vane

Net radiometer

Temperature

3D Sonic Anemometer and Infrared Gas Analyzer
LABMICRO TEAM

Maurício Pós-Doc  
AMAURI  
Georgia Meteorologist
URBAN SITE (SP DOWNTOWN)
SECRETARIA DA FAZENDA BUILDING
MICROMETEOROLOGICAL PLATFORM

SFZ

(70 m)
SFZ - URBAN SITE - SENSORS

- Net radiometer
- 3D Sonic Anemometer and Infrared Gas Analyzer
- Cup Anemometer and wind vane
- IR temperature sensor
SFZ URBAN SITE - SENSORS

Tipping bucket rain gauge

Temperature and Relative Humidity
SFZ
URBAN SITE
MEASUREMENTS
JULY 3, 2013
DATA AND IMAGE ARE AVAILABLE AT THE INTERNET FOR ALL SITES OF SP AND RJ.
5. FIELD CAMPAIGNS

- RADIOSONDES (VAISALA)
- FEB 19-28: SUMMER CAMPAIGN
- AUG 06-15: WINTER CAMPAIGN
- 80 RELEASES (EACH 3 HOURS) PER CAMPAIGN
- LIDAR
- FEB: SUBURBAN SITE
- AUG: 3 SITES (URBAN, RURAL AND SUBURBAN)
FIELD CAMPAIGN IN SÃO PAULO AT THE CAMPO DE MARTE AIRPORT

04/02/2014
MOST OF THE TRAJECTORIES WERE LOCATED OVER THE URBAN AREA (Z<4000 M)
6. RESULTS
UHI IN SÃO PAULO (Monthly average)

\[\Delta T_{U-R} \, ^\circ C\]

Month + (Local time)/24

JULY

AUGUST
UHI IN São Paulo (hourly values)
SEAZONAL VARIATION H AND LE IN SÃO PAULO

(RABELO, 2013)
INTERANUAL VARIATION IN SÃO PAULO

(SABELO, 2013)
NET RADIATION AT SURFACE SÃO PAULO

(RABELO, 2013)
LIDAR MEASUREMENTS IN SÃO PAULO

Temporal Evolution of the Planetary Boundary Layer

Mobile Lidar System - IPEN

São Paulo - IPEN

residual layer

subsidising air

clouds

greavity

waves

PBL

surface layers

Date
20/02/2013

Time
05:31
SUMMER CAMPAIGN IN SÃO PAULO

1st Experiment (02/20/2013)

- Visual
- \(Ri\) (1.00)
- \(Ri\) (1.46)
- LIDAR

PBL height (m)

Year day
WINTER CAMPAIGN SÃO PAULO

2nd Experiment (08/08/2013)

- Visual
- \( \text{Ri (1.46)} \)

PBL height (m) vs. Year day
CONCLUSION

• MCITY BRAZIL ACCOMPLISHED ALL GOALS
• SÃO PAULO FLUX NETWORK: URBAN, SUBURBAN AND RURAL ARE OPERATING.
• 4 FIELD CAMPAIGN: FEBRUARY (SUMMER) AND AUGSTU (WINTER). 162 RADIOSSONDES DURING 20 DAYS, EACH 3 HOURS.
• LIDAR MEASUREMENTS IN SÃO PAULO AND RIO DE JANEIRO
CONCLUSION

Urban heat island: *Nighttime also*

Surface energy balance: $H_{\text{URBAN}} < H_{\text{RURAL}}$

Urban Boundary Layer: *PBL height (100-2500)*
*Low Level Jets (nocturnal)* more evident in winter.

Landuse characterization: *we still need to work on that.*