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The Burning Man Experiment:
Micrometeorological impacts of an ephemeral desert city

Photo by Ryan Thorp

The festival and the city

Lat: 40° 47′ 5″ N
Long: 119° 12′24″ W
Elev.: 1,190 m a.s.l.

- The festival: Annual summer week-long art, culture and community gathering on a barren playa in Black Rock Desert, Nevada, USA
- The city: Black Rock City, NV (BRC) is a radially structured urban plan of 4.7 km^{-2} to house the festival goers

In 2013,
Peak population = 69,613   Peak population density =~ 14,800 people km^{-2}

Areial UAV photo of BRC 2013 by Greg Briggs

"El Pulpo" art car,

Focus of this presentation

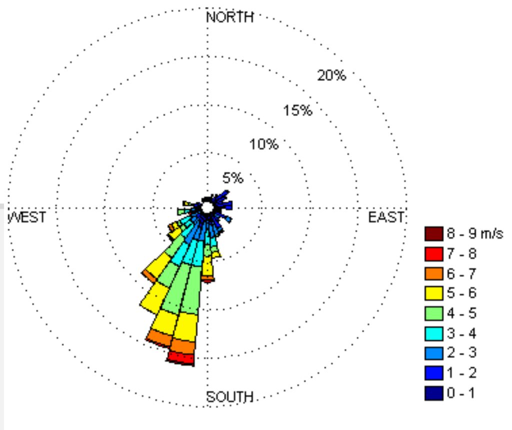
1. How does the city impact frictional properties of the surface?
2. How does it impact the surface energy balance and UHI?
3. How does the population and its activities impact surface-atmosphere exchanges of CO_2?

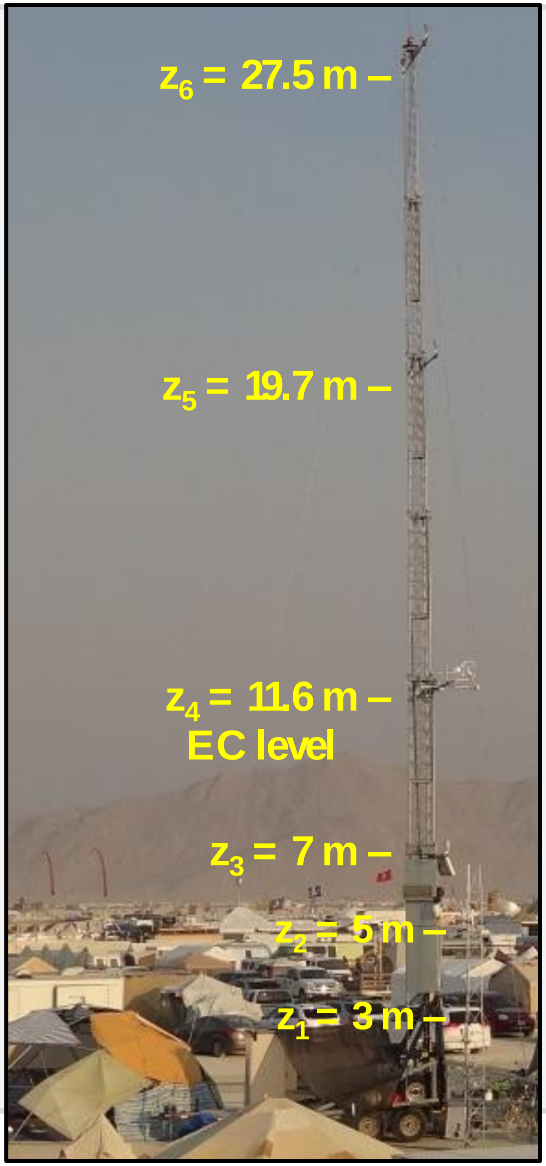
The changing nature of the surface

August 23rd

August 30th

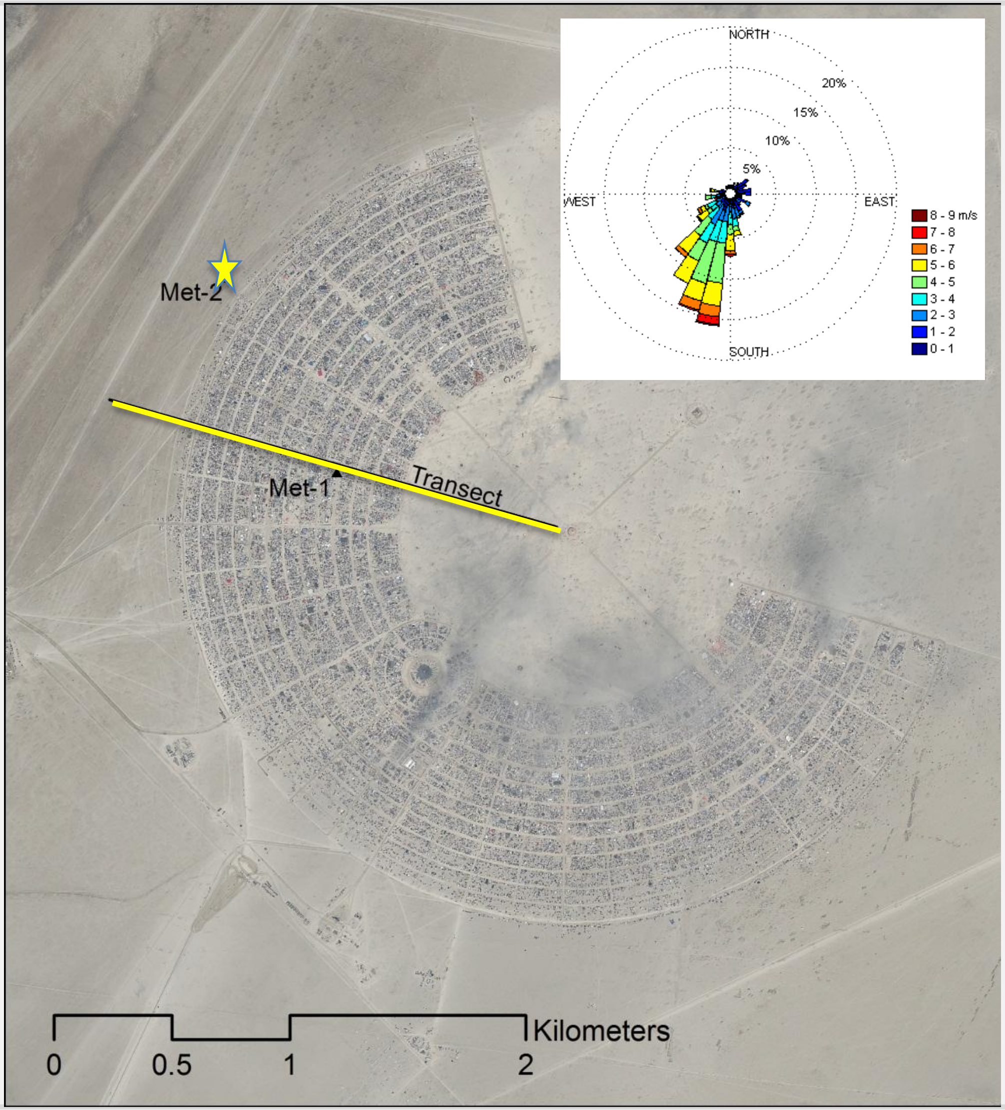
Main tower and source area for EC



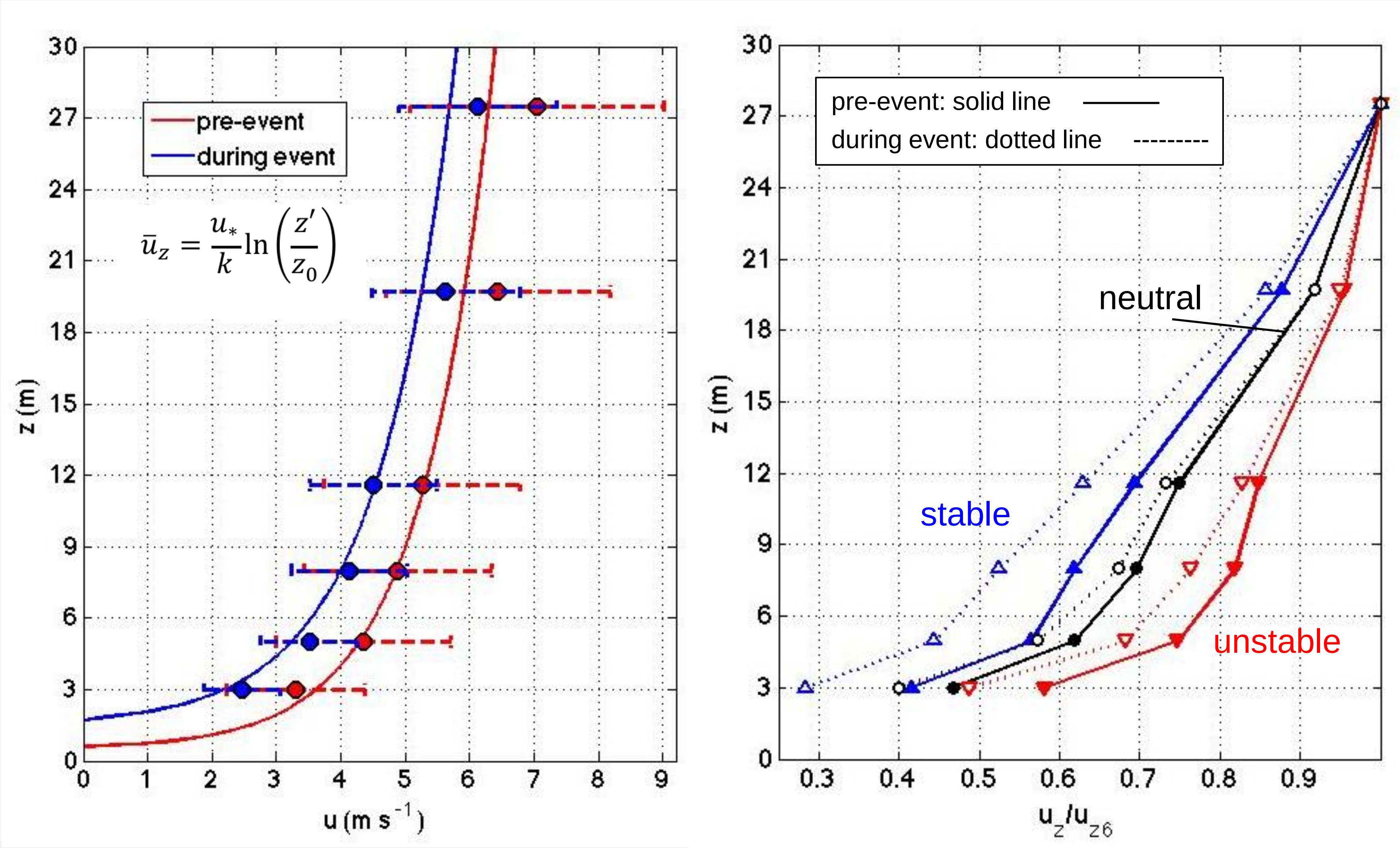


70% flux source area from Hsieh (2000) footprint model, under mean wind direction and speed and neutral stability (at 11.6 m)

Met2 is 3 m playa tripod
Mobile transect of 2.5 m profile



1. Changes in surface frictional properties



Changes in z_d and z_0 using anemometric approach

	Pre-event		Event	
	Mean	Std	Mean	Std
$z_{d\ Ro}$	0.25-0.71 m	+/- 2.62 m	0.3-1.04 m	+/- 1.44 m
$z_{0\ Es}$	0.07-0.33 m	+/- 0.16 m	0.1-0.34 m	+/- 0.12 m
$z_{0\ lp}$	0.48-0.58 m	+/- 0.32 m	0.7-0.72 m	=/- 0.21 m

z_d Displacement method ($z_{d\ Ro}$)

Rooney (2001)

$$z_{d\ Ro} = \frac{z_1 e^{-ku_1/u_*} - z_2 e^{-ku_2/u_*}}{e^{-ku_1/u_*} - e^{-ku_2/u_*}}$$

z_0 Eddy covariance stress method ($z_{0\ Es}$)

(e.g. Grimmond et al. 1998)

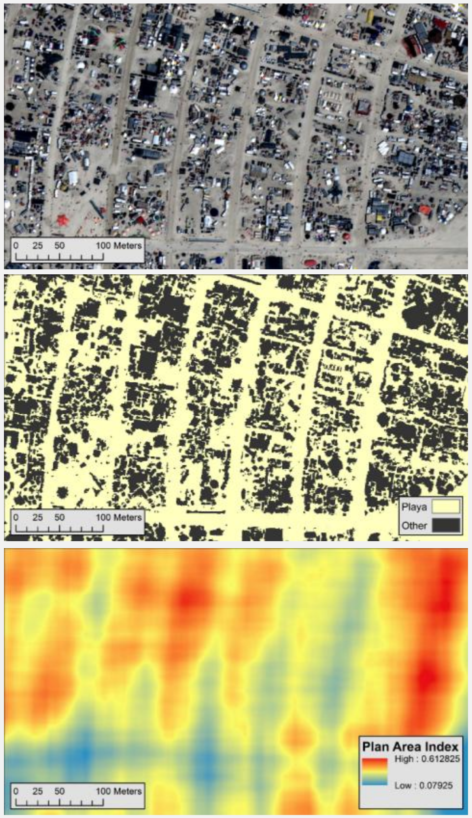
$$z_{0\ Es} = \frac{z - z_d}{exp\left(\frac{\bar{u}_z k}{u_*}\right)}$$

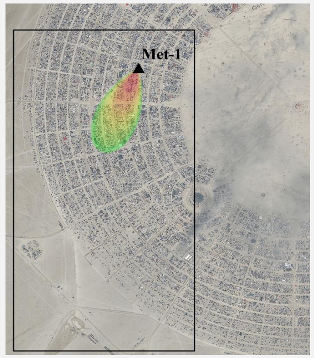
$z_0 + z_d$ Log profile method ($z_{0\ lp}$)

$$z_{0\ lp} = (z_2 - z_1)/[exp(kU_2/u_*) - exp(kU_1/u_*)]$$

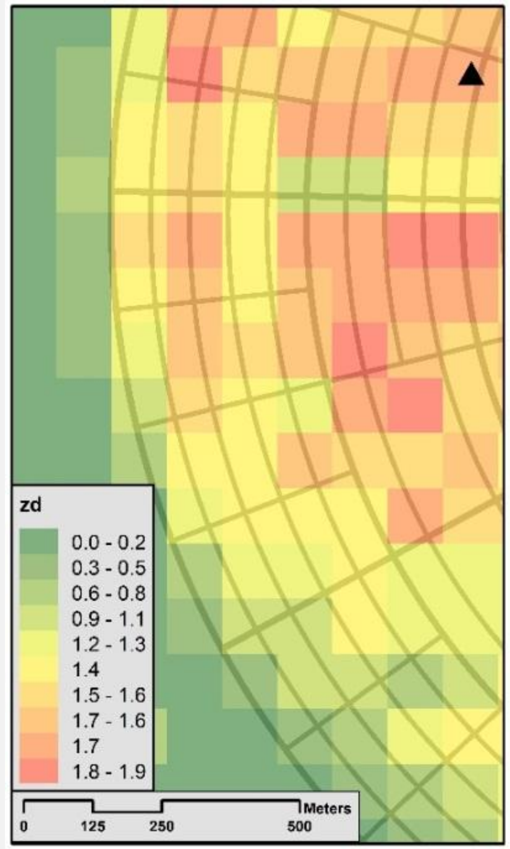
Restricted to near-neutral conditions ($-0.1 < z/L < 0.1$) and binned by directional sector

Changes in z_d and z_0 using morphometric approach

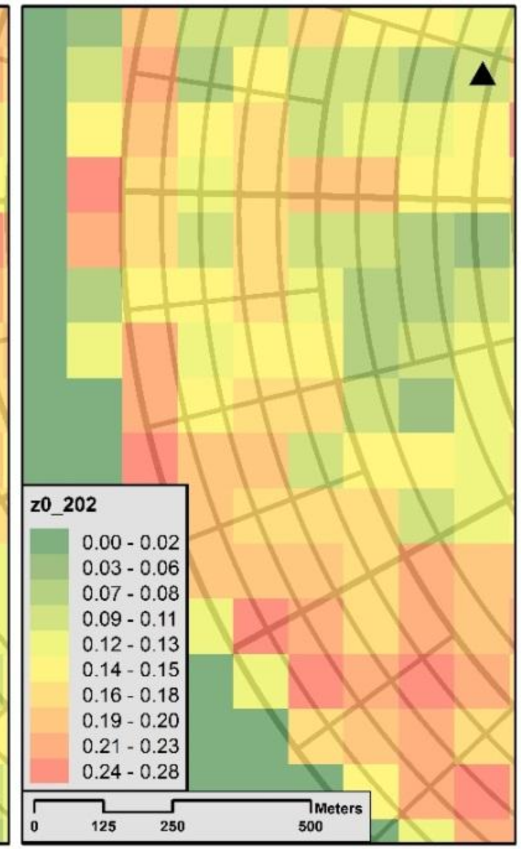




z_d

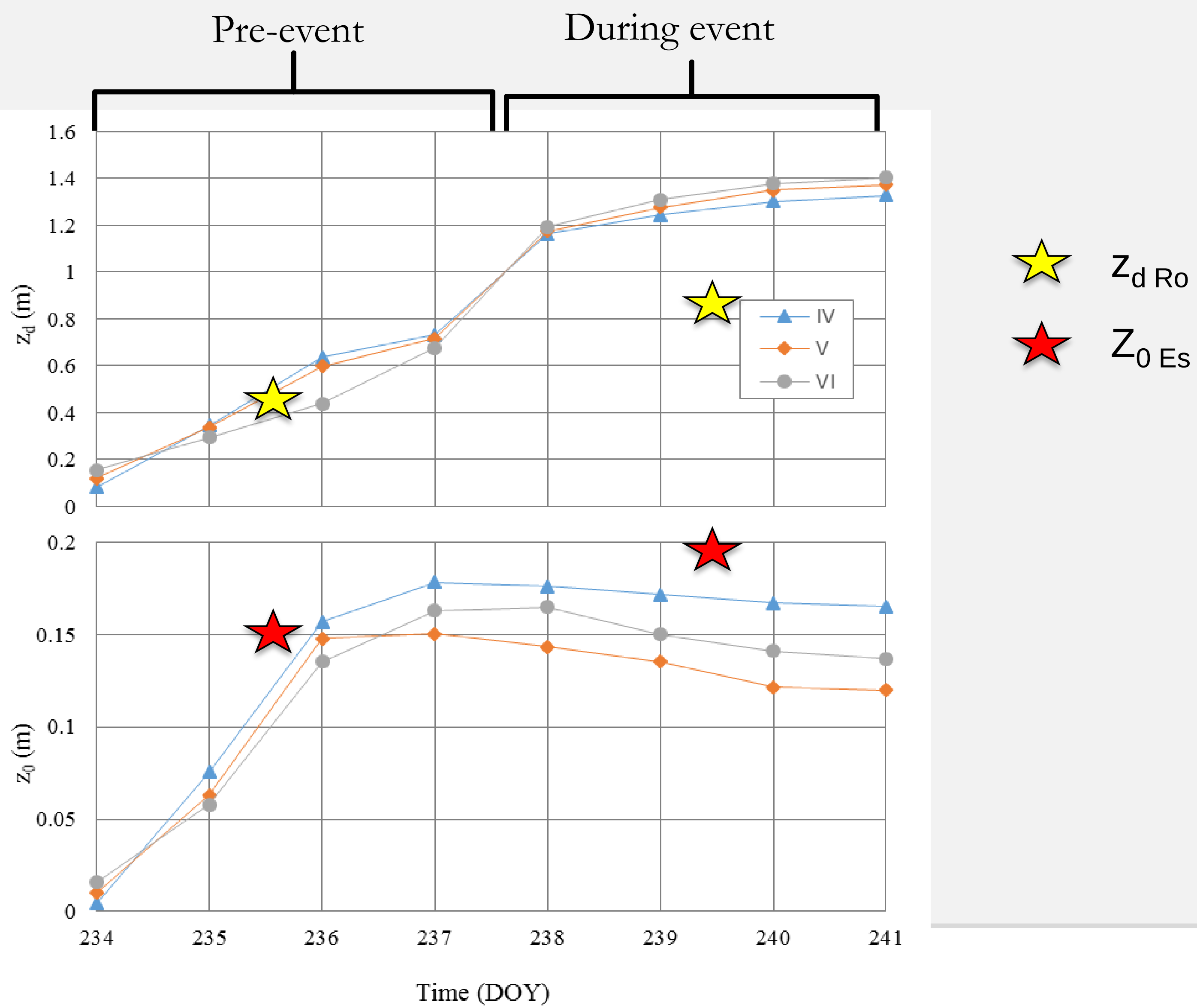


z_0



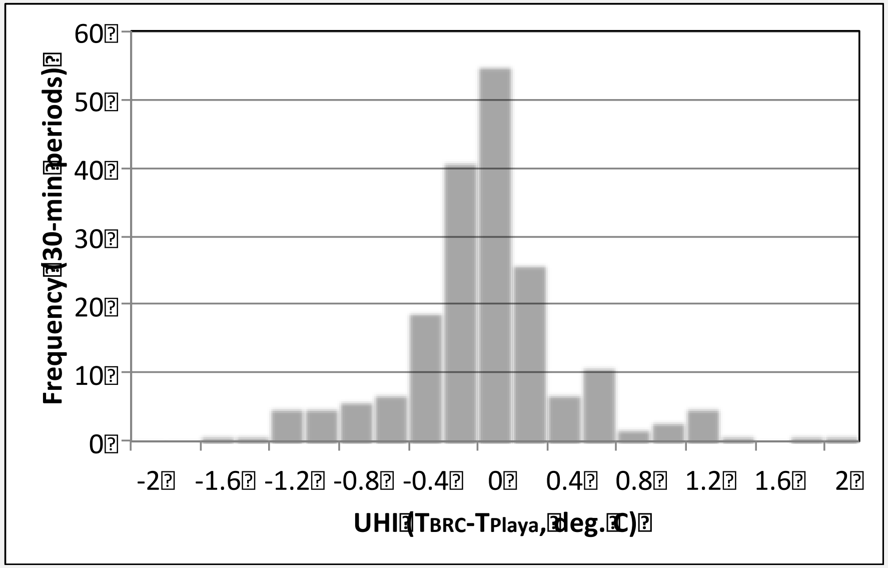
Based on MacDonald (1998); derived from planimetric area index and frontal area index of roughness obstacles, classified from QuickBird image taken 8/29/2013

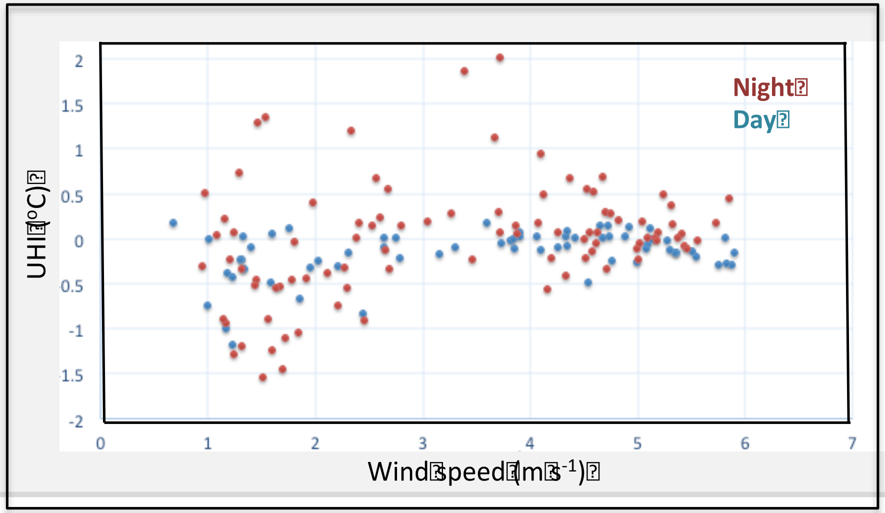
Changes in z_d and z_0 using morphometric approach

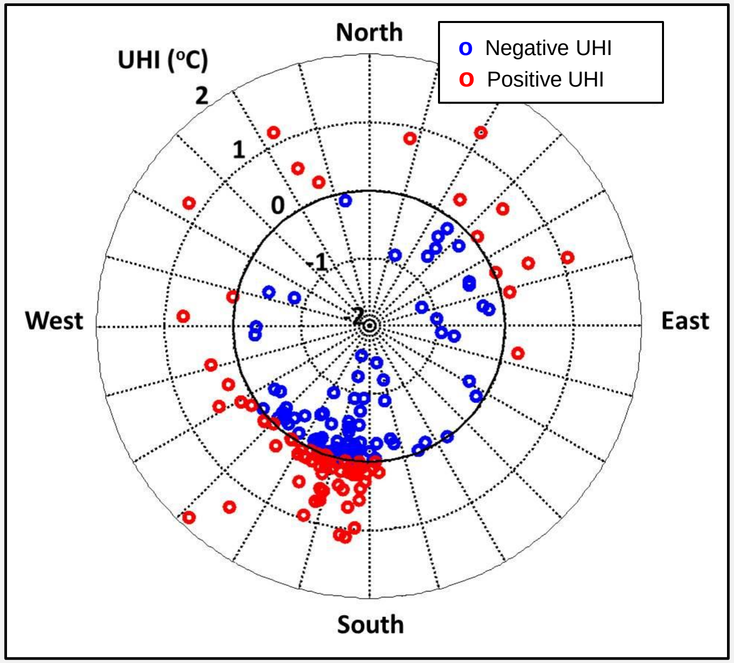


2. Urban Heat Island?

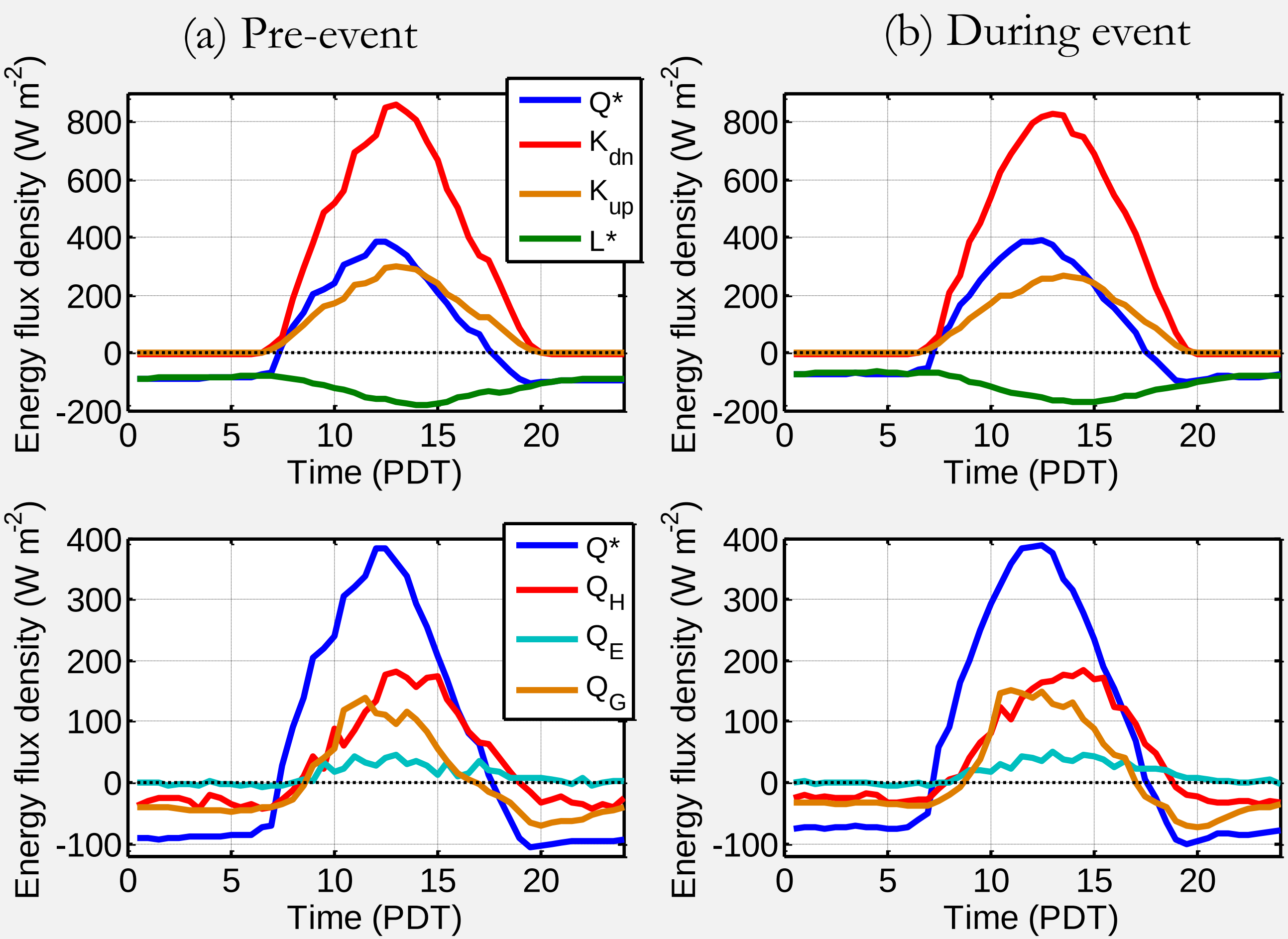
UHI from 30-min average air temps at 3 m for 5 days during the Burning Man festival.







2: Changes in surface heating and UHI



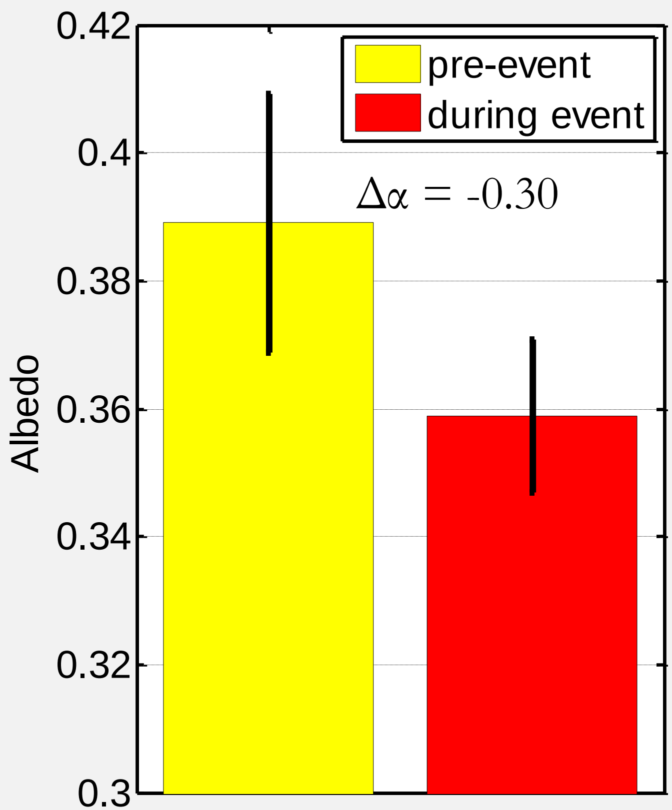
Q*: Net Radiation
K: Short-wave radiation
L: Long-wave radiation

Q_H: Sensible heat flux
Q_E: Latent heat flux
Q_G: Ground heat flux

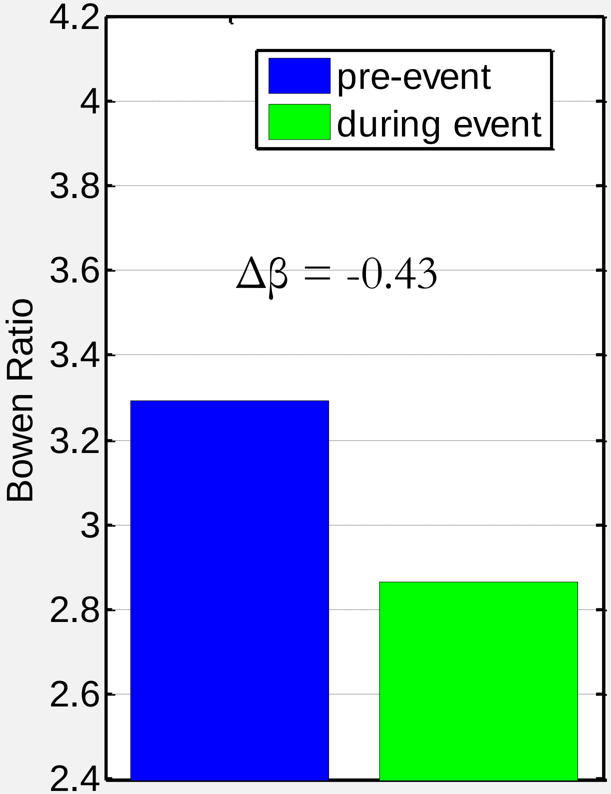
Diurnal ensemble averages of the surface radiation budget (upper) and surface energy balance (lower) prior to and during the Burning Man event

Surface Energy Balance: albedo change

Albedo



Bowen ratio $\beta = Q_H/Q_E$

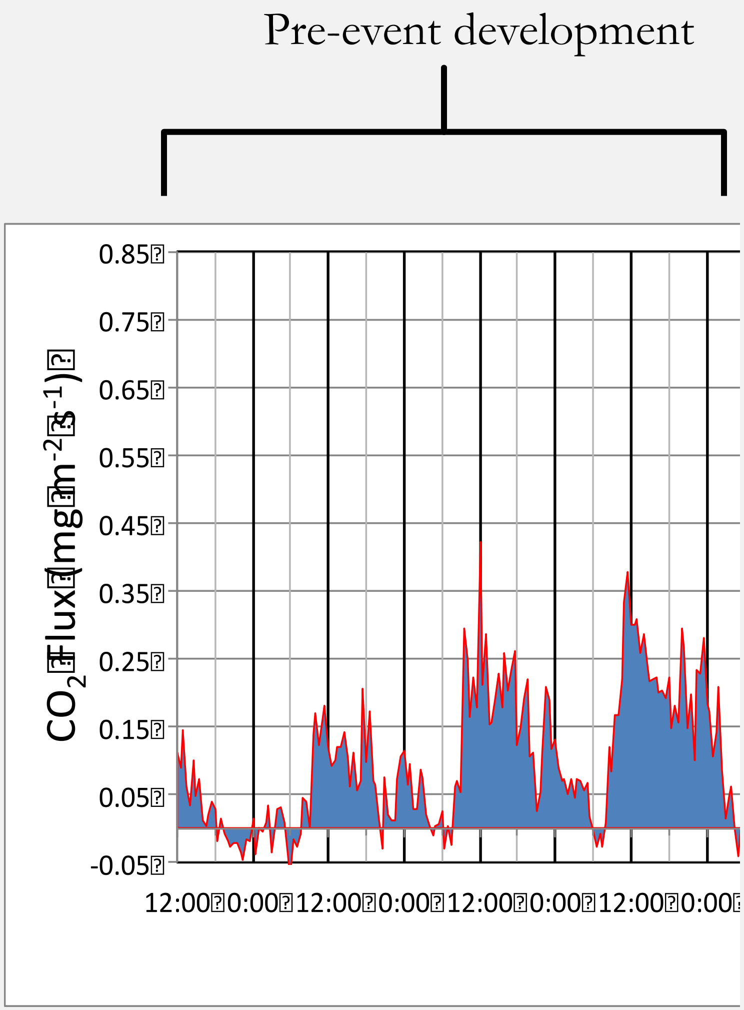


What UHI causes

	BRC	Other cities	Other arid cities
UHI observed	no	yes	yes
Anthropogenic heat flux	yes	yes	yes
Reduction in availability of surface water	no	Yes, most	Not really
Albedo	Small decrease	mixed	mixed
Large heat storage fluxes in urban fabric	no	yes	yes

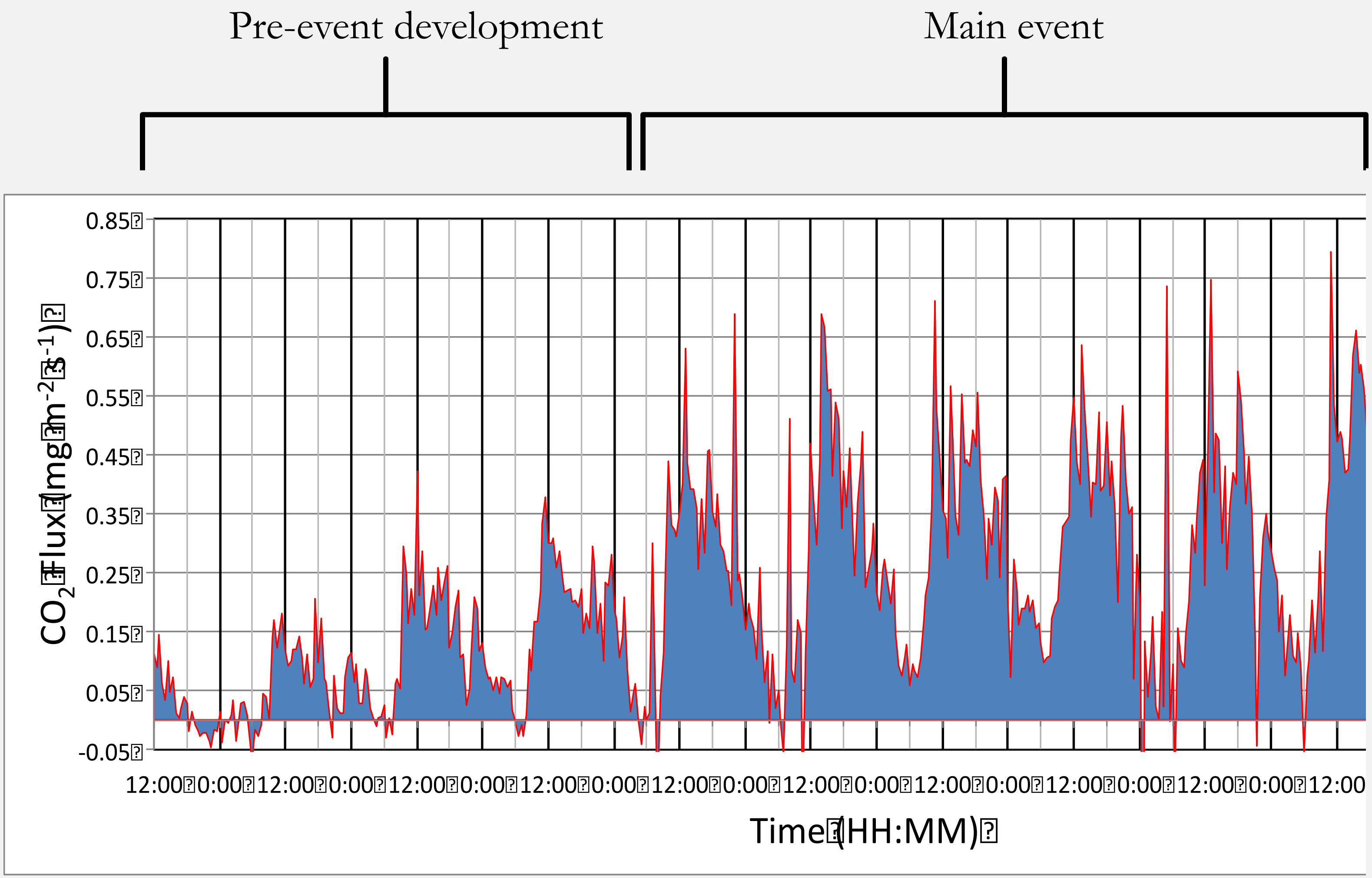
- UHI Tuscon Arizona ≈ 3 ^{o}C (Comrie 2000)
- UHI Phoenix Arizona ≈<10 ^{o}C (Hawkins et al. 2004).

3. CO_2 fluxes



Pre-event development
CO2 Flux (mg m-2 s-1)
0.85
0.75
0.65
0.55
0.45
0.35
0.25
0.15
0.05
-0.05
12:00 0:00 12:00 0:00 12:00 0:00 12:00 0:00

CO_2 fluxes


Pre-event development
Main event
0.85
0.75
0.65
0.55
0.45
0.35
0.25
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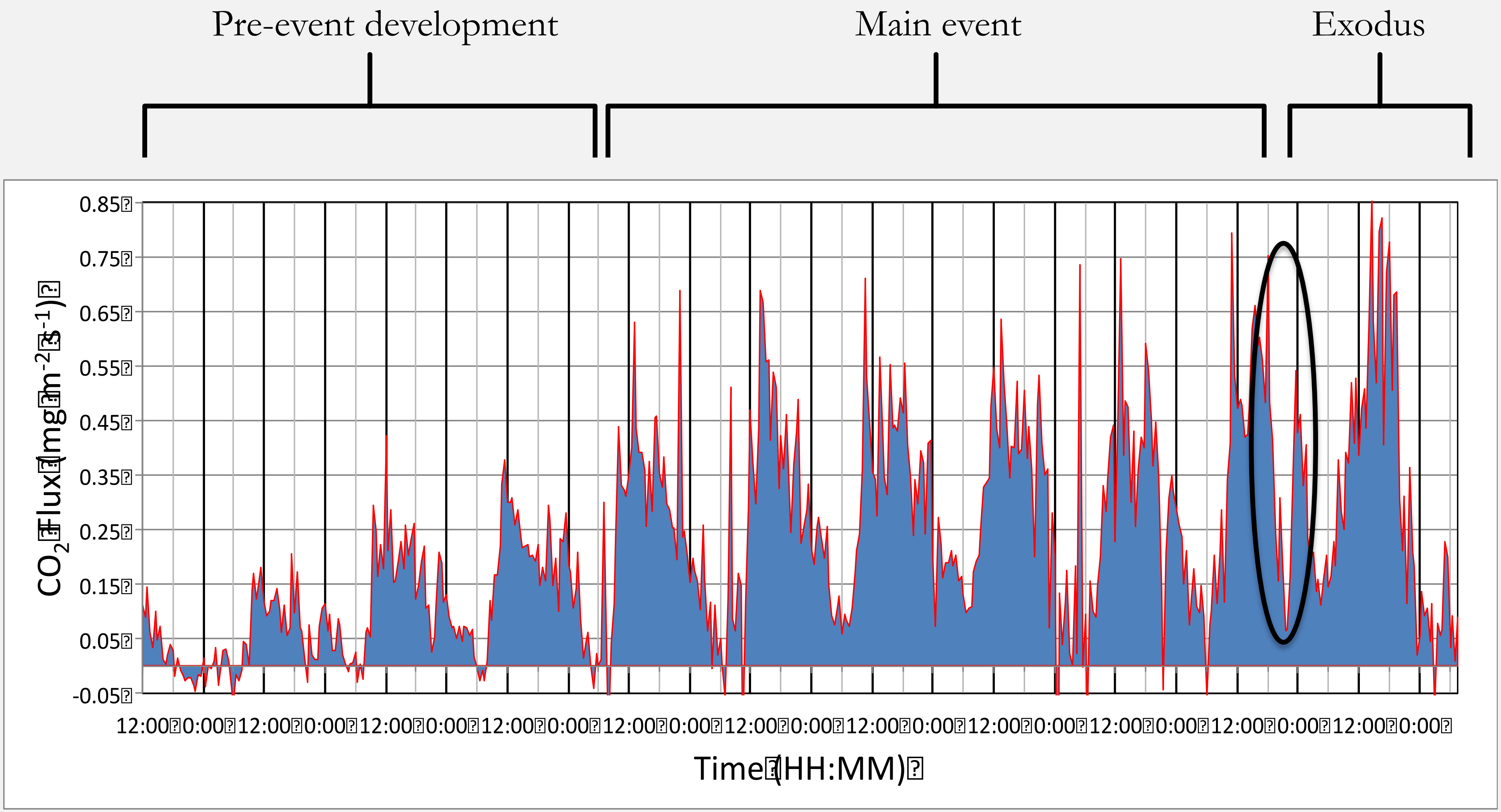
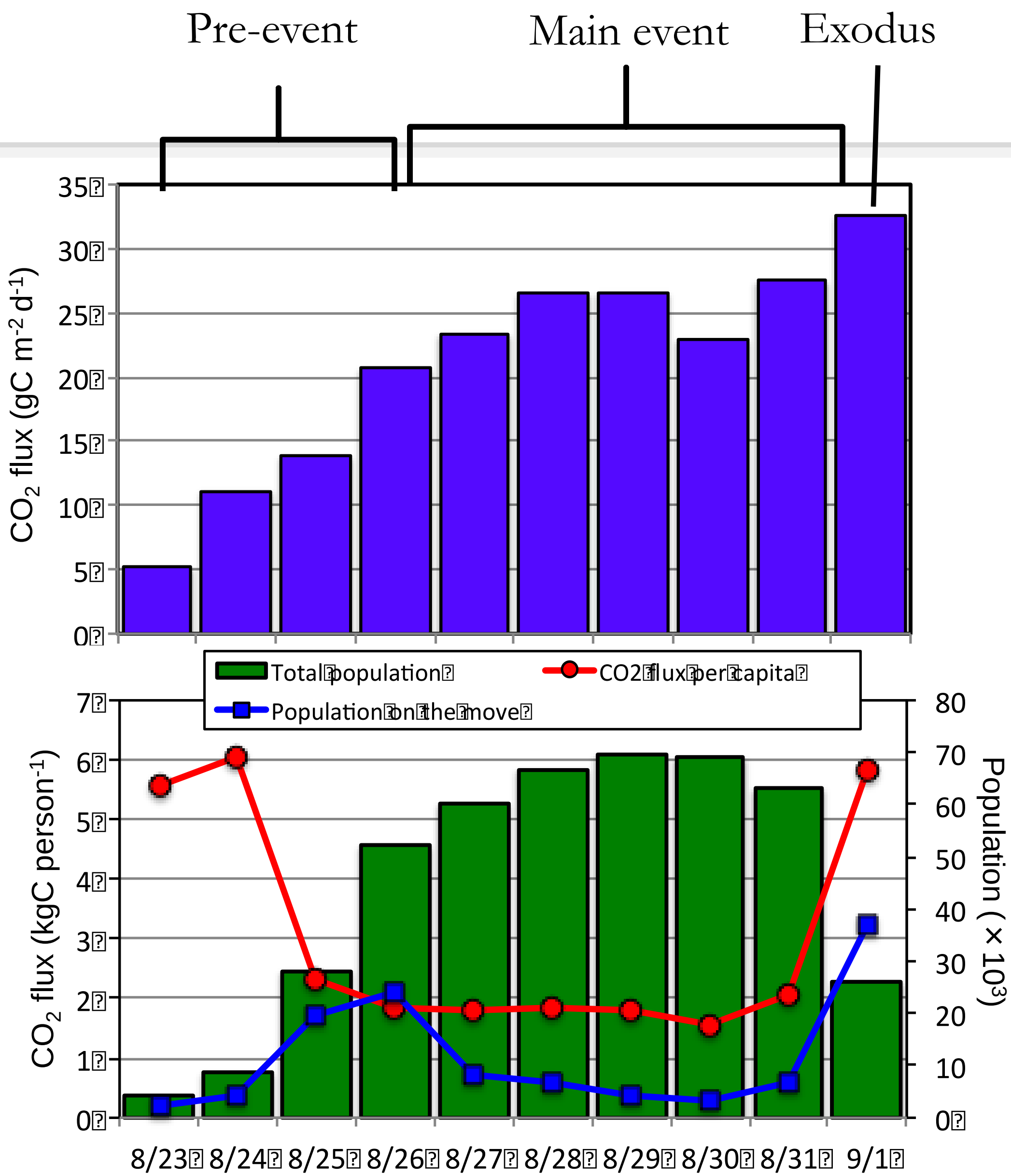
-0.05
CO2 Flux (mg m-2 s-1)
12:00 0:00 12:00 0:00 12:00 0:00 12:00 0:00 12:00 0:00 12:00 0:00 12:00 0:00 12:00 0:00 12:00 0:00 12:00
Time (HH:MM)

CO_2 fluxes



Pre-event development
Main event
Exodus
0.85
0.75
0.65
0.55
0.45
0.35
0.25
0.15
0.05
-0.05
CO2 Flux (mg m-2 s-1)
12:00 0:00 12:00 0:00 12:00 0:00 12:00 0:00 12:00 0:00 12:00 0:00 12:00 0:00 12:00 0:00 12:00 0:00 12:00 0:00 12:00 0:00
Time (HH:MM)

Daily CO_2 emissions



<u>During the main event</u>
<u>(Wed 8/28 – Saturday 8/31)</u>

Daily average CO_2 flux:
= 25.9 gC m^{-2} d^{-1}.

Daily total BRC CO_2 flux:
= 121.6 tC d^{-1}

Population density
= **14,280** people km^{-2}

CO_2 per person during event
= **1.82** kgC p^{-1} d^{-1}
CO_2 per person during transitions
= **5.82** kgC p^{-1} d^{-1}

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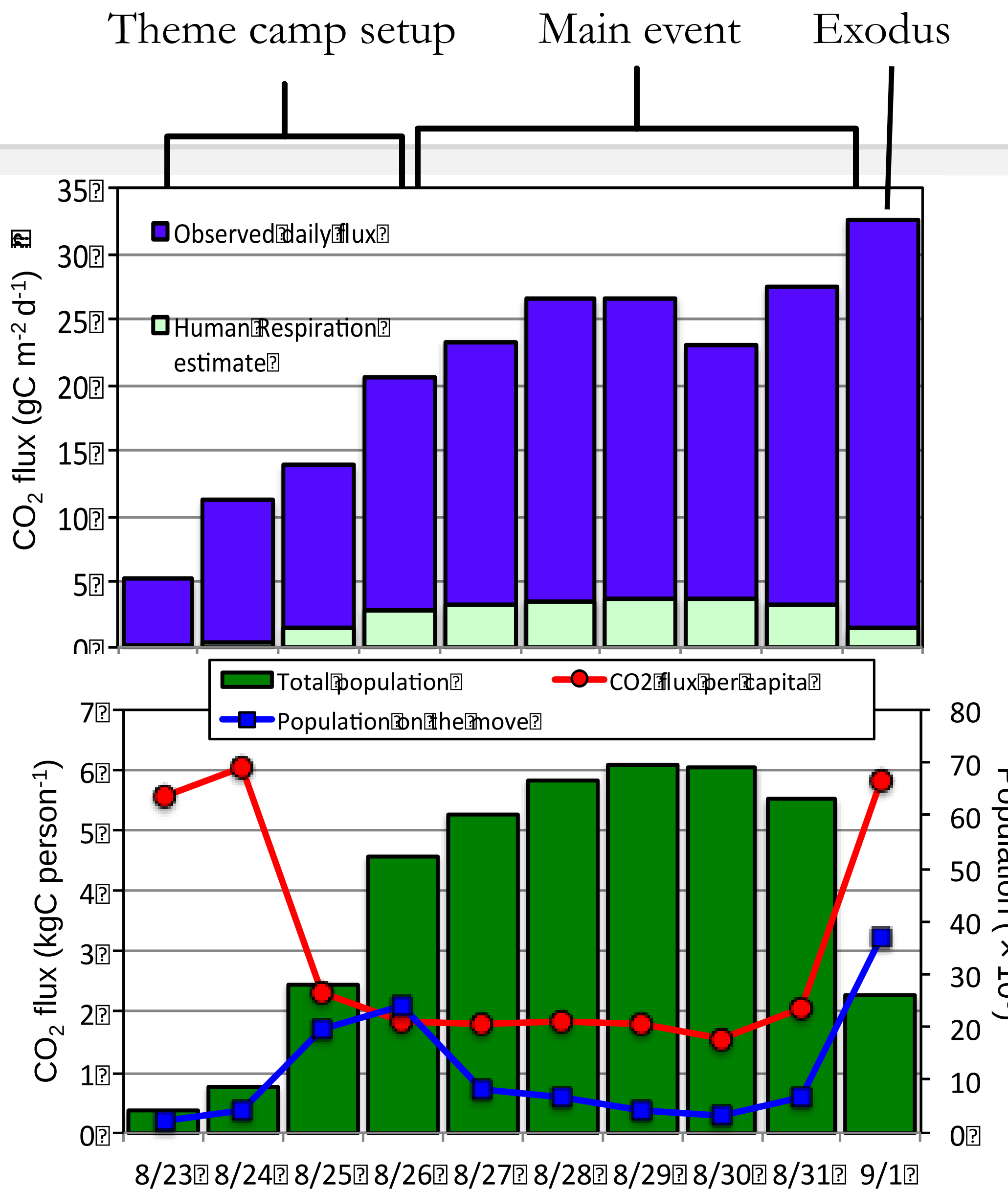


Conclusions

1. Its rough in the city!

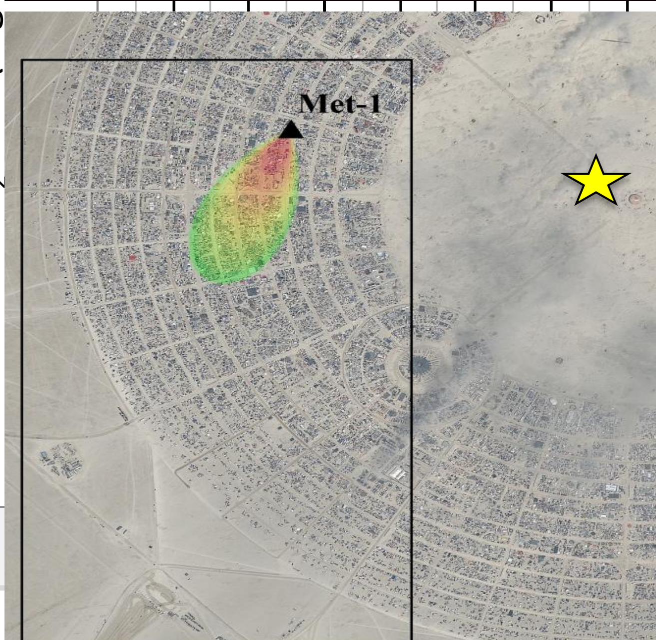
   z_d increased throughout the event as density increased while z_0 increased initially and then stabilized at ~0.2 m

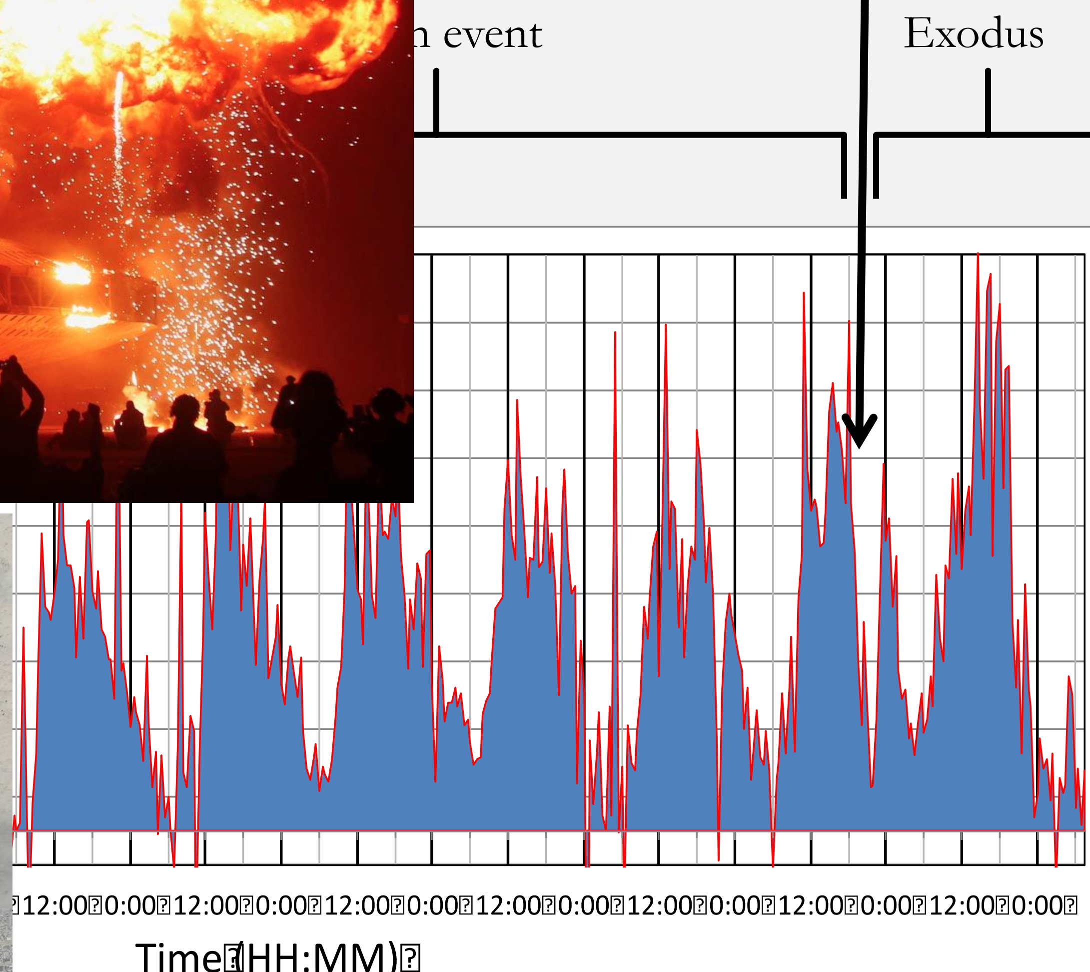
2. There's no heat island!

   Not found in this study at all, pointing to the importance of urban fabric in storing and releasing heat

3. Carbon emissions equivalent to central Mexico City (per unit area)!

   CO_2 rose from negligible levels to 26 gC m^{-2} d^{-1}. Resulted primarily from burning fossil fuels, particularly related to transport


Met-1


Burning The Man!
Exodus
CO2 Flux (mg m-2 s-1)
12:00 0:00 12:00 0:00 12:00 0:00 12:00 0:00 12:00 0:00 12:00 0:00 12:00 0:00
Time (HH:MM)

Background

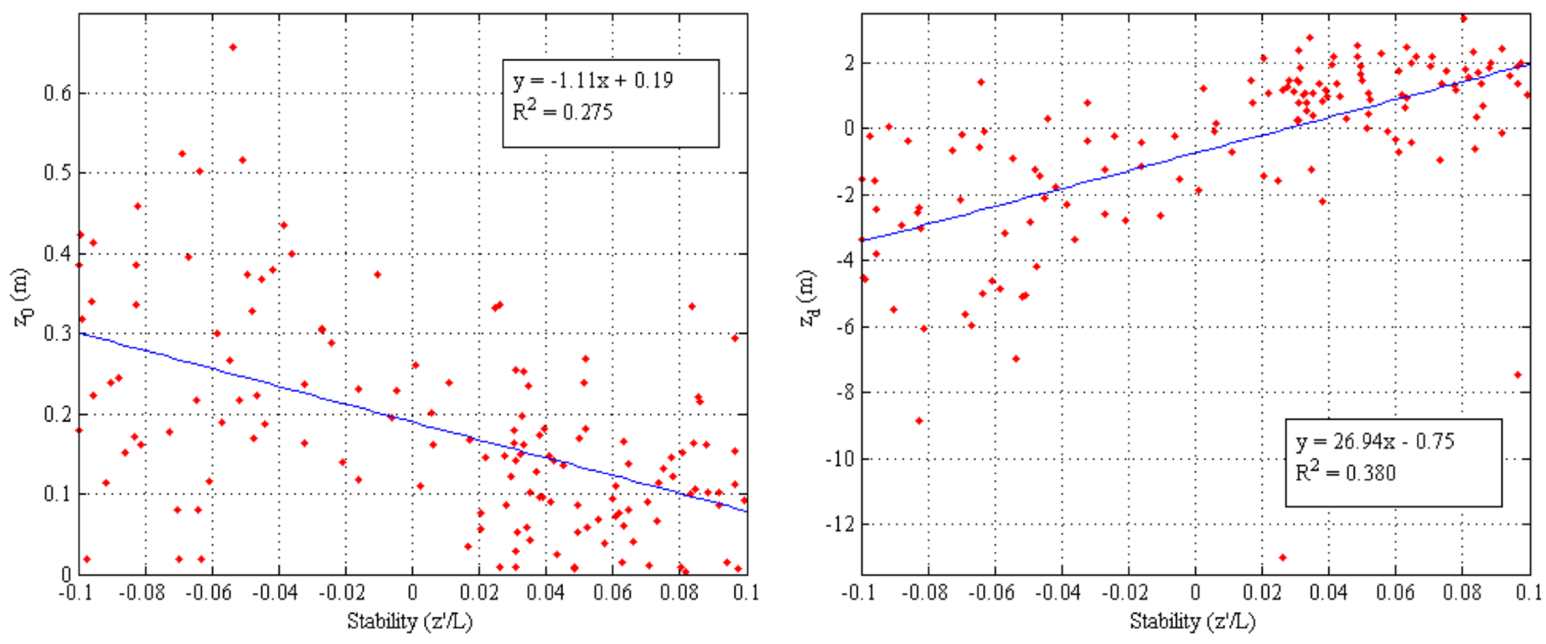
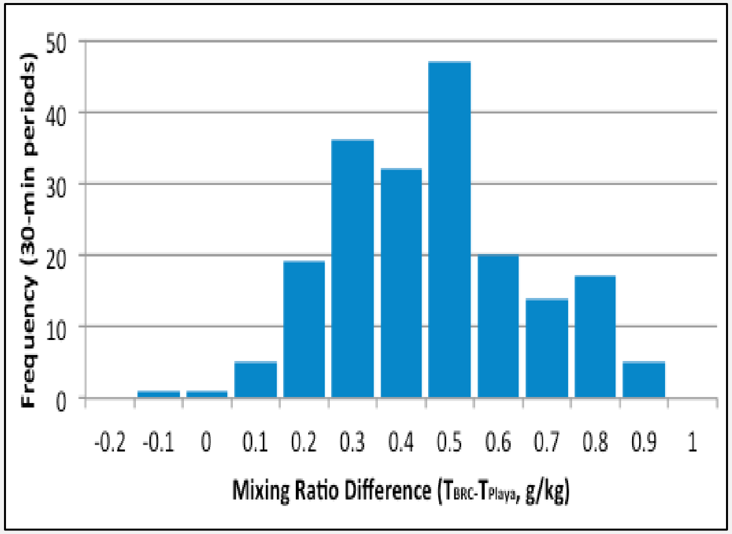
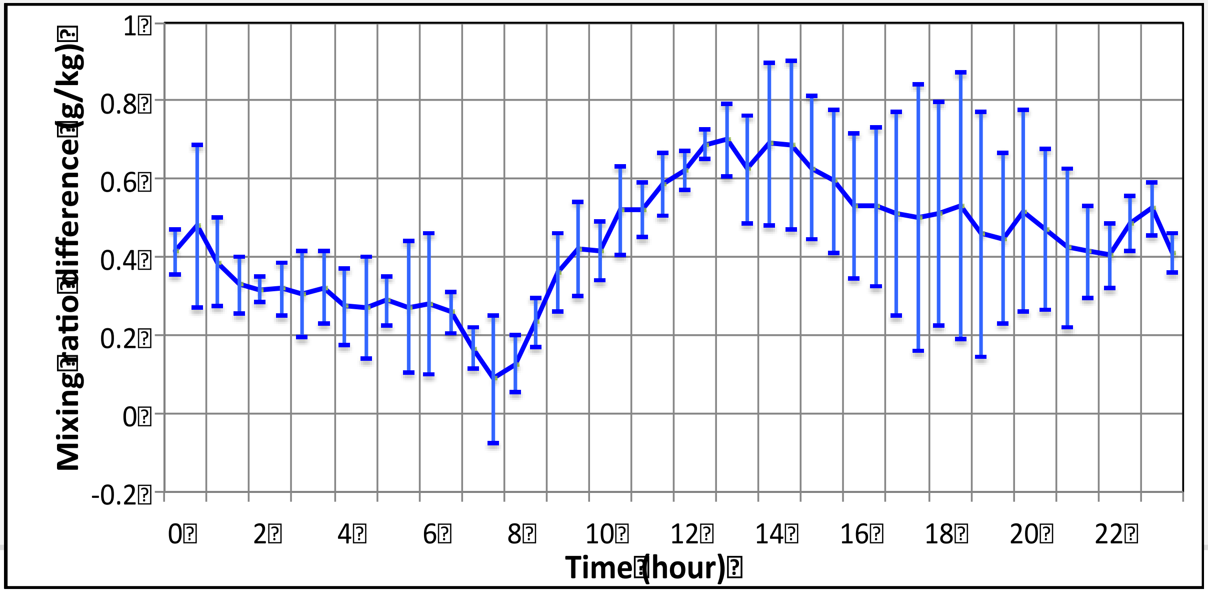


Figure 6: Estimated surface roughness length (z_0), left, and zero-plane displacement height (z_d), right, plotted as functions of the dimensionless stability parameter (z'/L) for all Sector V Event Week observation periods.

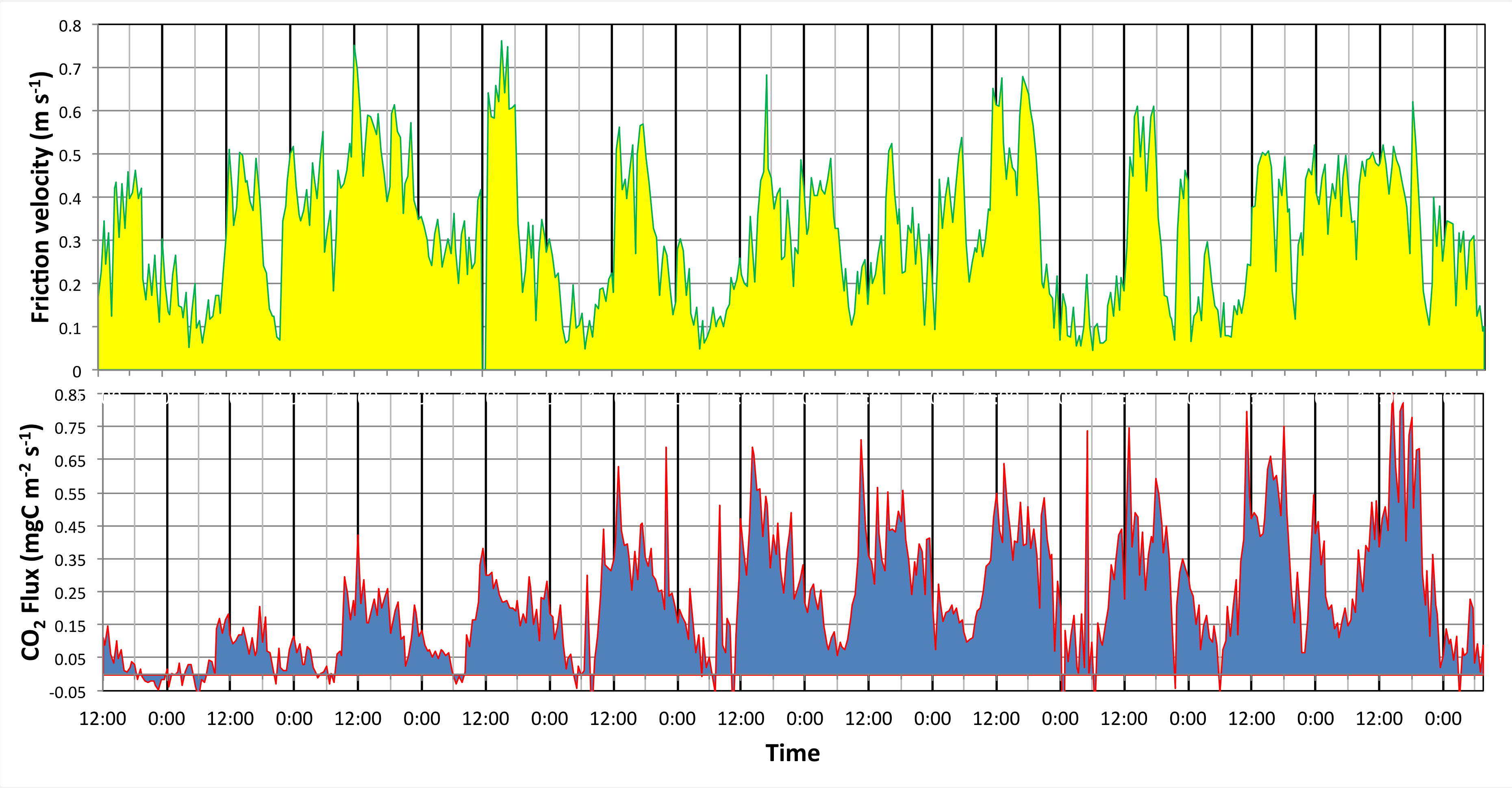
Urban moist island?



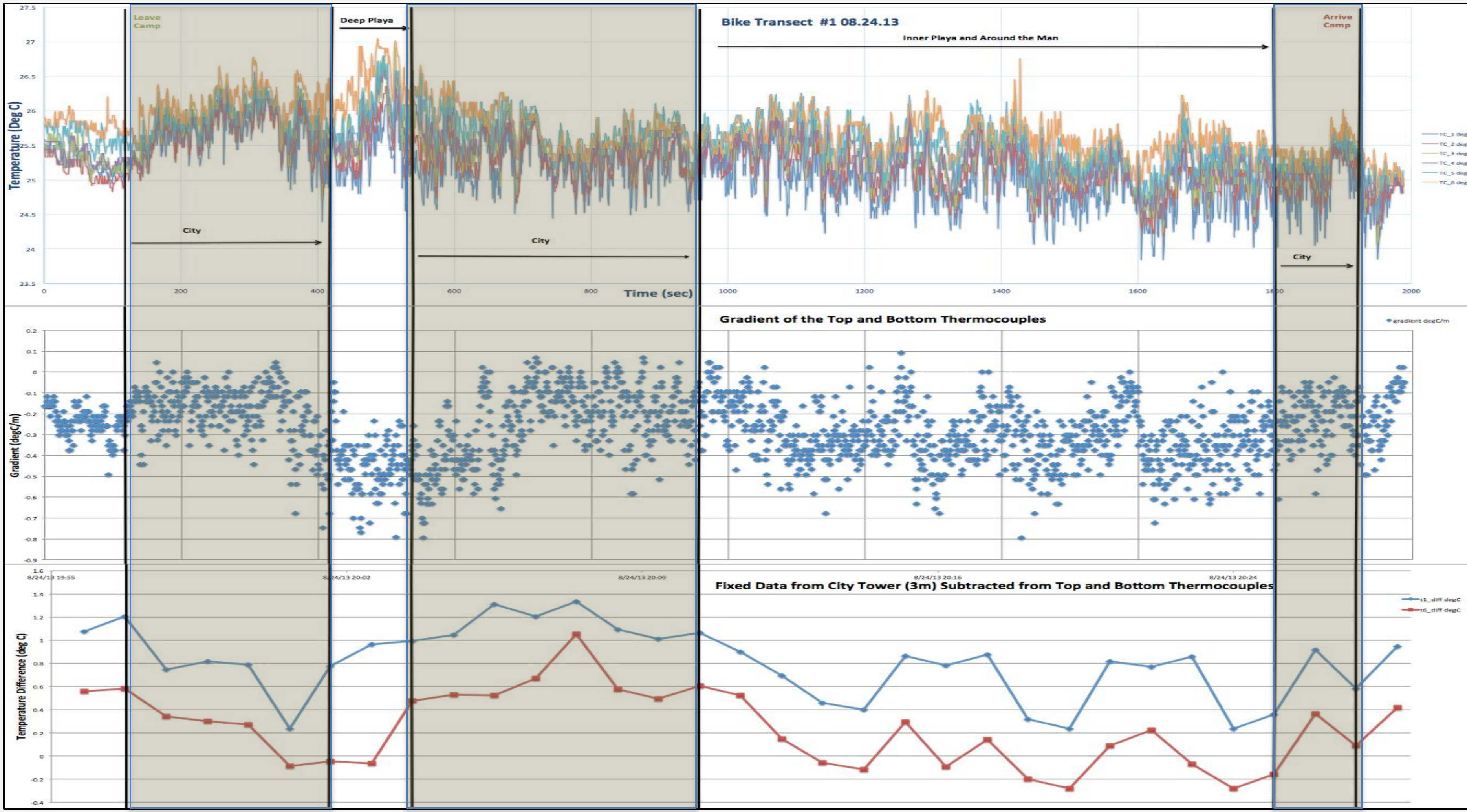
Mixing ratio differences from 30-min averages at 3 m for 5 days during the Burning Man festival.



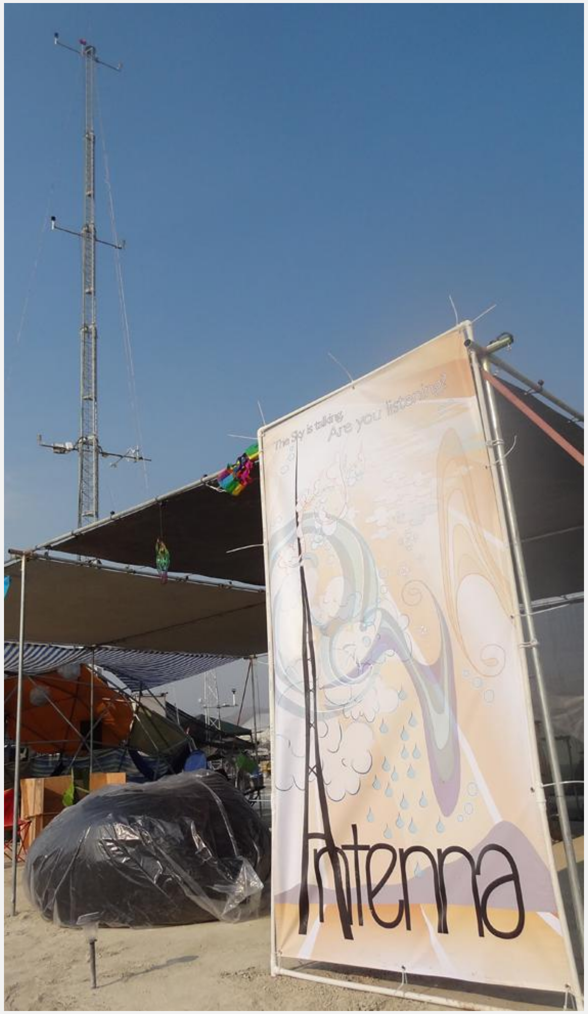
Turbulence and CO_2 transport

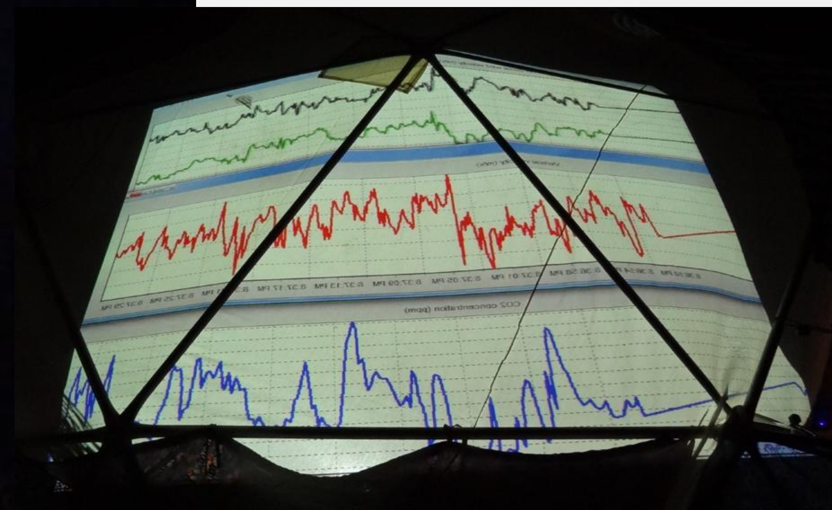


Bicycle transect data



Micrometeorology as theme camp





Morphometric Methods

Macdonald *et al.* (1998):

$$z_{d\,Ma} = (1 + \alpha^{-\lambda_P}(\lambda_P - 1)\bar{z}_H$$

$$z_{0\,Ma} = \left(1 - \frac{z_d}{z_H}\right) exp\left\{-\left[0.5\beta\,\frac{C_D}{k^2}(1 - \frac{z_d}{z_H})\lambda_F\right]^{-0.5}\right\}\bar{z}_H$$

- C_D: drag coefficient (1.2 for bluff bodies)
- α, β: model coefficients, calibrated