Quantifying water and energy fluxes over different urban land covers in Phoenix, Arizona

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Central Arizona-Phoenix Long-Term Ecological Research CAP LTER

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Motivation

- As cities continue to grow worldwide, the transformation of natural environments into urban land covers will accelerate.
- Urban land use exemplifies a shift to impervious surfaces and landscaping with different irrigation requirements, however urban flux observations are limited, particularly over different urban land cover types.
- Meteorological flux measurements using the eddy covariance (EC) technique quantifies surface energy balance (SEB) processes and their interactions with atmospheric and land surface conditions.
- Understanding the links between urban land cover and the SEB processes, which mediate microclimatic conditions, is important for planning and design purposes.

Objectives

1) Quantify and compare the surface energy balance (SEB) processes over different urban land cover types in relation to a reference location.
2) Relate the differences in the observed SEB metrics to characteristics of the urban source areas of the flux measurements.
3) Evaluate the influence of precipitation events on the partitioning of the turbulent fluxes over different urban land cover types.

Study Sites

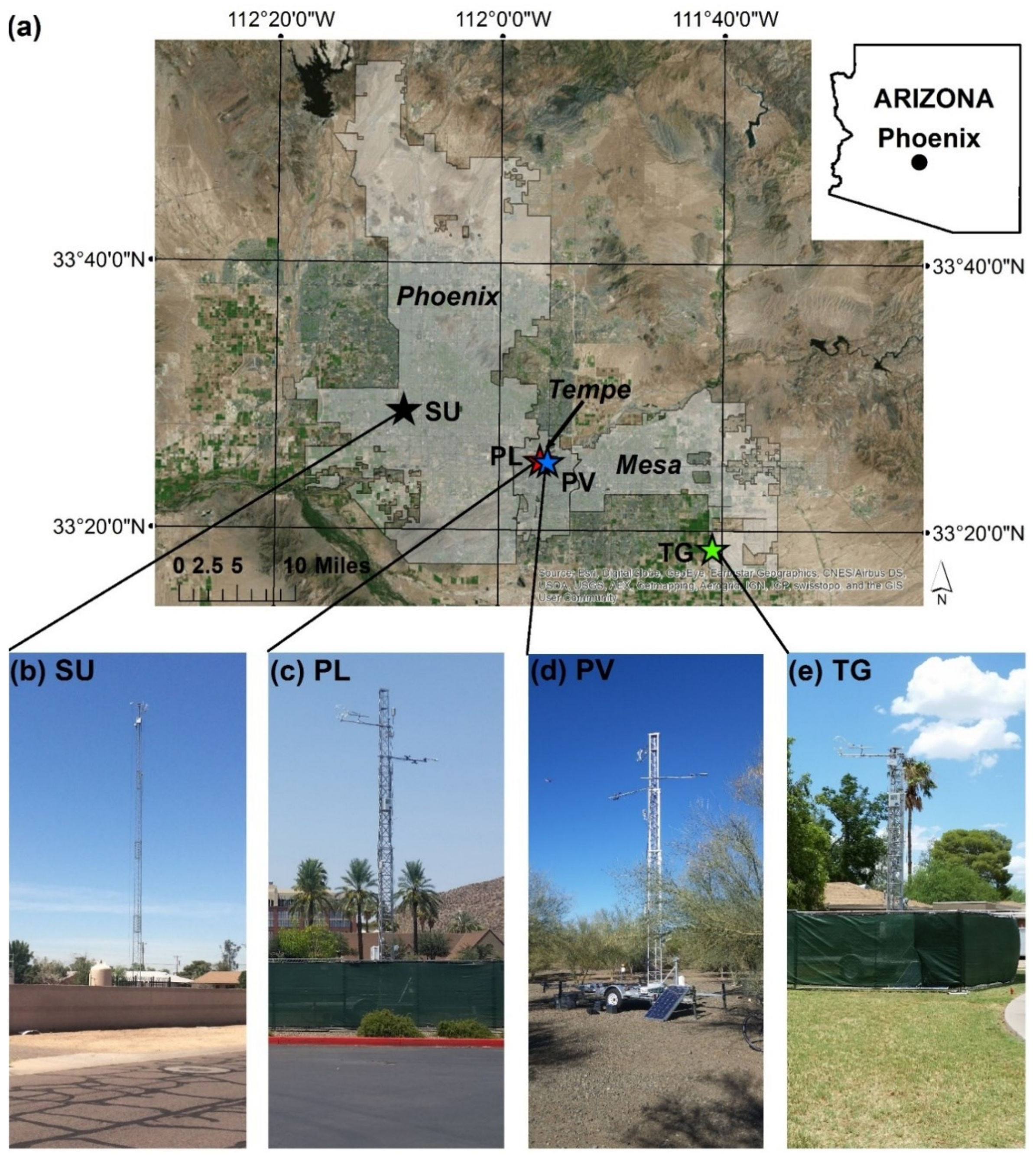

Fig. 1 Four study sites located in the Phoenix, Arizona, metropolitan area (a), including photographs of the EC deployments at: (b) suburban (SU) site, (c) parking lot (PL) site, (d) palo verde (PV) site, and (e) turf grass (TG) site.

Eddy Covariance (EC) Tower Measurements:

Turbulent Fluxes
- Sensible Heat (Q_H)
- Latent Heat (Q_E)

Meteorological
- Incoming and Outgoing longwave ($L_{in/out}$) and shortwave radiation ($K_{in/out}$)
- Net radiation (Q^*)
- Air temperature
- Relative humidity
- Precipitation
- Surface temperature

Ground
- Soil moisture
- Soil temperature
- Ground heat flux (Q_G)

Reference site:
SU: Suburban site in low-rise, single-family residential area in Phoenix, AZ (managed by CAP-LTER and described in Chow *et al.*, 2014).
Evaluated from **1/1/2015 0:00 to 9/30/2015 23:30** — 273 days.

Mobile Sites:
PV: Palo verde landscape (xeric) consisting of drip-irrigated trees with gravel surface at ASU Tempe campus in Tempe, AZ.
Deployment from **1/20/2015 12:00 to 3/13/2015 8:30** — 53 days.

PL: Parking lot site at ASU Tempe campus in Tempe, AZ, on an impervious surface near a high traffic intersection.
Deployment from **5/19/2015 15:00 to 6/30/2015 6:00** — 43 days.

TG: Turf grass landscape (mesic), regularly irrigated with sprinklers, near residential housing at ASU Polytechnic campus in Mesa, AZ,
Deployment from **7/9/2015 13:00 to 9/18/2015 8:30** — 74 days.

Footprint - Land Cover Characterization

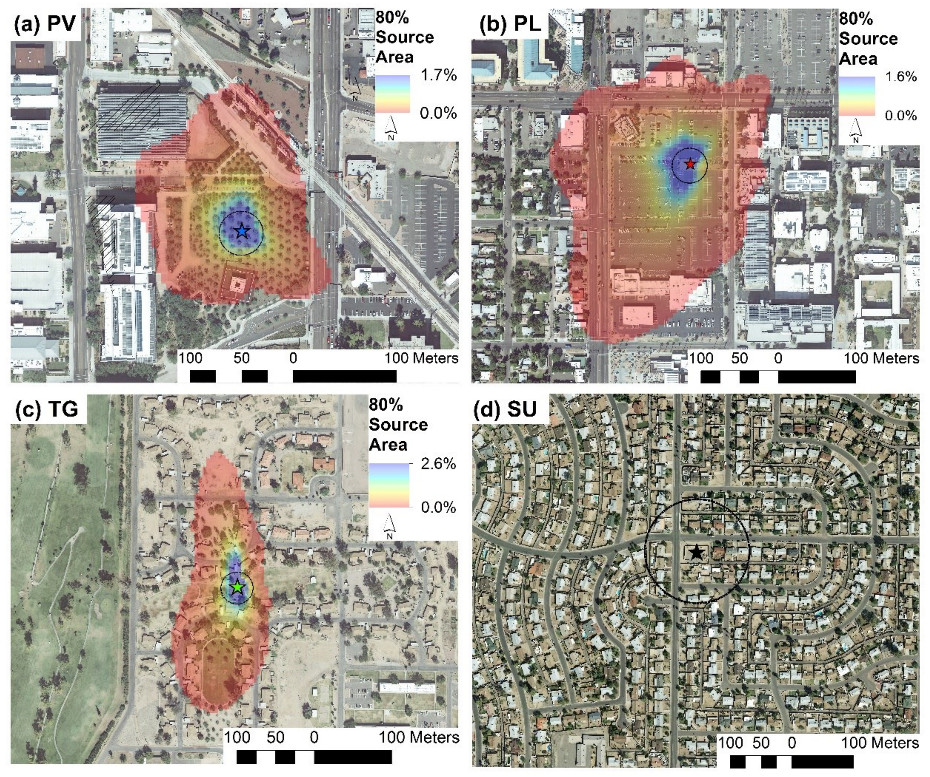

Fig. 2 Study site orthoimagery with the 80% source areas (colored 5 m pixels with percent contribution) and radiometer footprints (black circles) at: (a) PV, (b) PL, (c) TG and (d) SU sites.

- Determined 80% EC footprint following the analytical model of Korman and Meixner (2001), to derive the EC footprint for each deployment period.
- Computed radiometer footprint based on height (Schmid *et al.*, 1991).
- Obtained high-resolution color orthoimagery (0.30 m cell size) from USGS.
- Classified orthoimagery using a maximum likelihood method in ArcGIS 10.4 to classify land cover into five general types:
  a) Trees
  b) Grass
  c) Undeveloped (gravel or bare soil)
  d) Pavement
  e) Buildings or cement
- SU site classification obtained from Chow *et al.*, 2014.

Urban Land Cover	80% Source Area			Radiation Footprint			
	PV	PL	TG	PV	PL	TG	SU
Trees	38.2%	5.9%	16.2%	34.4%	2.2%	6.8%	4.6%
Grass	0.4%	0.7%	28.1%	0.0%	0.7%	43.6%	10.0%
Undeveloped	29.7%	13.9%	34.6%	65.6%	29.6%	34.5%	36.8%
Pavement	8.3%	57.4%	12.8%	0.0%	67.5%	4.1%	22.0%
Buildings or Cement	23.4%	22.1%	8.3%	0.0%	0.0%	11.0%	26.4%

Meteorological and Flux Differences

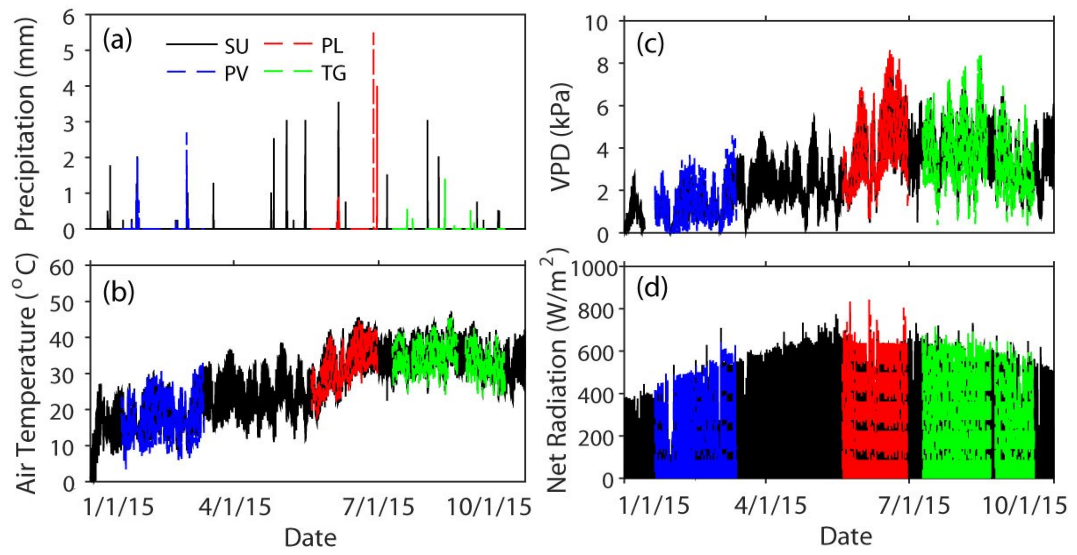

Fig. 3 Meteorological measurements during entire study period (1 January to 30 September, 2015) including: (a) precipitation, (b) air temperature, (c) vapor pressure deficit (*VPD*) and (d) net radiation (Q^*), shown as 30 min averages.

- Variability in precipitation likely due to spatial variation.
- Low monsoonal rainfall (5.4 mm at TG and 13.7 mm at SU) compared to long-term average (150.4 mm).
- SU site is generally warmer compared to PV and TG, likely due to non-vegetated urban cover.
- Largest difference in Q^* is between the SU and TG sites, which has the largest difference of vegetation cover.

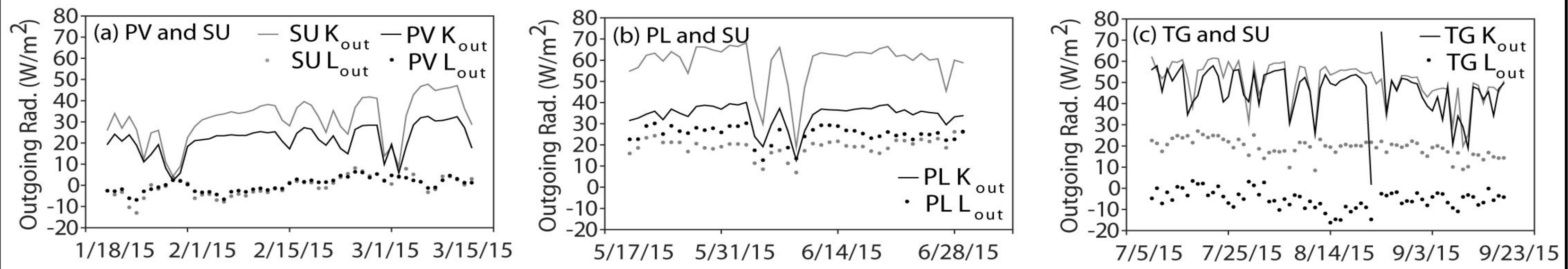

Fig. 4 Daily-averaged outgoing shortwave radiation (K_{out}, lines) and outgoing longwave radiation (L_{out}, dots) at: (a) PV and SU sites, (b) PL and SU sites and (c) TG and SU sites. Gray colors correspond to SU site.

Average albedo:
PV = 0.11, PL = 0.09, TG = 0.17, SU = 0.17

- K_{out} is generally higher at SU site, consistent with a lower Q^*, due to a higher albedo.
- Q^* differences between TG and SU are not due to shortwave radiation or albedo differences.
- Largest difference in L_{out} is observed between the TG and SU sites. Average soil temperature at the two sites has the largest difference (TG = 29.7 °C, SU = 41.2 °C).
- PL and SU sites differ in K_{out} and L_{out}, however SU has a higher Q^*, indicating the control of albedo is stronger (lower albedo and K_{out}).
- Q_H is dominant at all sites, except for TG site, where Q_E dominates.

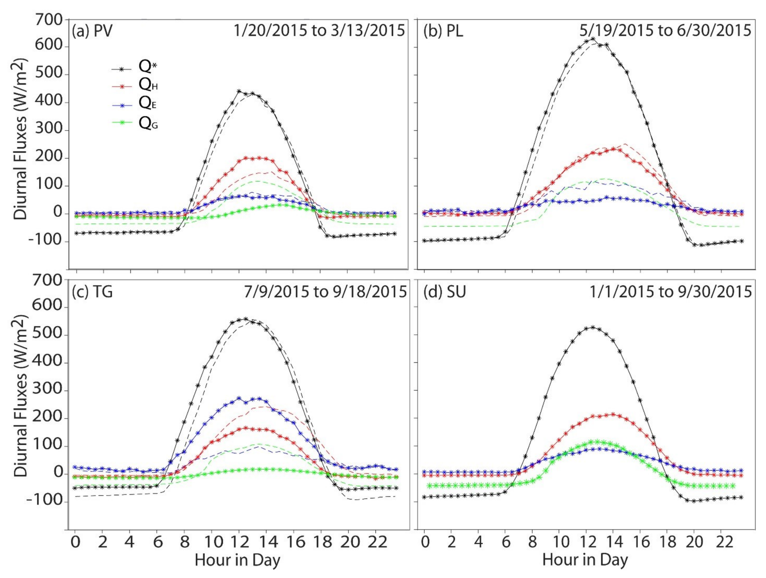

Fig. 5 Averaged diurnal cycle of surface energy fluxes at 30 min intervals for the: (a) PV, (b) PL, (c) TG and (d) SU sites. For reference, dashed lines in (a-c) represent the corresponding measurements at the SU site.

Flux Response to Precipitation

Computed and compared flux ratios for dry and wet days during each deployment period.

Evaporative Fraction (*EF*): $EF = \frac{Q_E}{Q_H + Q_E}$

Q_H and Q_E are normalized by total incoming radiation.

- At PV, PL, and SU sites, precipitation increases $Q_E/Q_\downarrow$, leading to higher *EF*, and no significant change in $Q_H/Q_\downarrow$, indicating water-limited conditions.
- No change in $Q_E/Q_\downarrow$ or *EF* occurs at TG site (change of <0.01 and 0.01 between dry and wet days), while the SU site shows an increase of $Q_E/Q_\downarrow$ and *EF* of 0.04 and 0.06.
- More frequent irrigation at TG site during the monsoon season shows the partitioning of turbulent fluxes is insensitive to storm events, therefore water is not limiting.

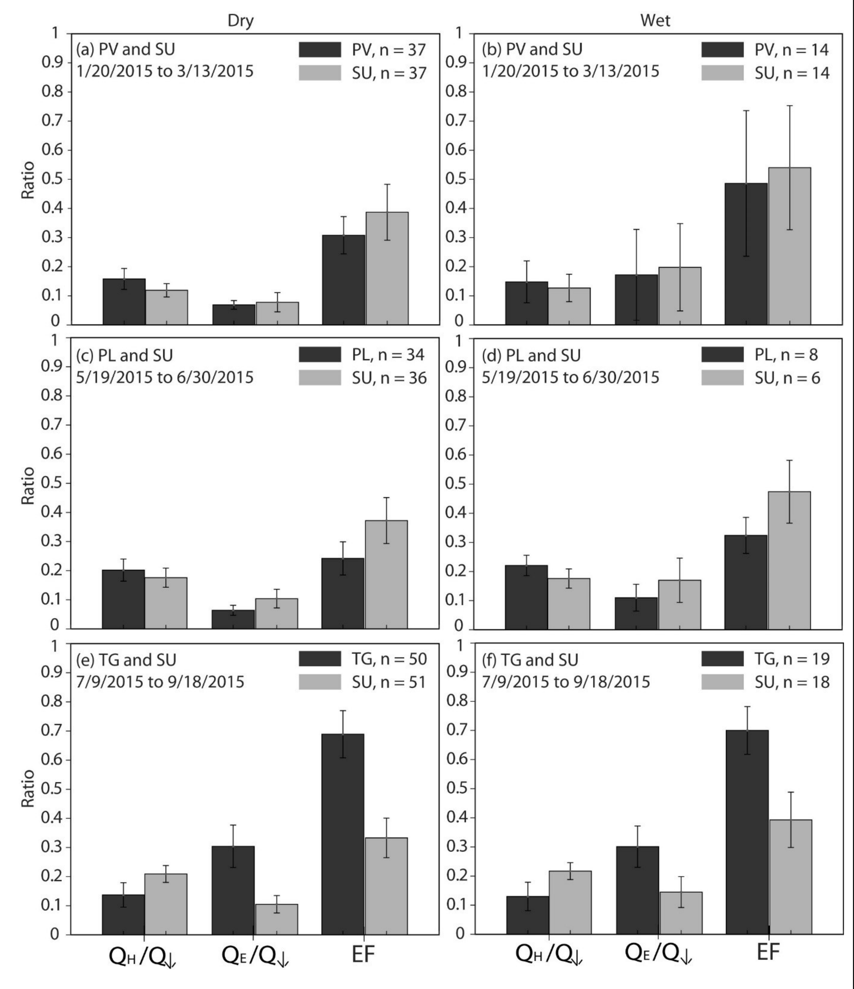

Fig. 6 Averaged daily $Q_H/Q_\downarrow$, $Q_E/Q_\downarrow$ and *EF* for dry (left) and wet (right) days during overlapping periods for the: (a, b) PV and SU site, (c, d) PL and SU site and (e, f) TG and SU site. *n* is the number of days and the error bars represent ±1 standard deviation.

Conclusions

- Meteorological conditions were similar between the mobile and reference sites. Small differences in air temperature and vapor pressure deficit are attributed to vegetated land cover differences. Larger biases are noted in net radiation, which may be due to the larger radiometer footprint at the SU site.
- Evaluating individual radiation components provides insight into the effects of albedo on outgoing shortwave radiation and shallow soil temperature on outgoing longwave radiation. The SU site has lower net radiation due to higher albedo (relative to xeric PV site), higher soil temperature (relative to mesic TG site), or a combination of both factors (relative to the parking lot at PL).
- The surface energy balance reveals higher sensible heat flux at PV, PL, and SU sites, while latent heat flux dominates at the TG site.
- Sensitivity of the surface energy balance processes to precipitation events varied among the sites depending on soil moisture conditions established through outdoor water use. The different urban land covers show similar sensible heat flux under different weather conditions, however latent heat flux varies significantly at PV, PL and SU sites, where water is limited. At TG site, latent heat flux and evaporative fraction are insensitive to additional water input, due to frequent sprinkler irrigation.

References

1. Chow WTL, Volo TJ, Vivoni ER, Jenerette GD, Ruddell BL. 2014a. Seasonal dynamics of a suburban energy balance in Phoenix, Arizona. *Int. J. Climatol.* 34: 3863 – 3880.
2. Kormann R, Meixner FX. 2001. An analytical footprint model for non-neutral stratification. *Bound. Layer Meteorol.* 99: 207 – 224.
3. Schmid HP, Cleugh HA, Grimmond CSB, Oke TR. 1991. Spatial variability of energy fluxes in suburban terrain. *Bound. Layer Meteorol.* **54**: 249 – 276.
4. U.S. Geological Survey, http://lta.cr.usgs.gov/high_res_ortho.

Acknowledgements

Funding for this work was provided by the U.S. Army Research Office (Grant 65962-EVII) and the National Science Foundation through Grant EF1049251 'Assessing Decadal Climate Change Impacts on Urban Populations in the Southwestern United States' and Grant DEB-1026865 'CAPIV: Central Arizona – Phoenix Long-term Ecological Research Program'. Special thanks to Ivan López-Castrillo and Thomas J. Volo for field assistance and the Facilities Department at ASU (Raymond Humbert, John Herrera and Jimmy Mastalsz) for help with securing site permits.