A Statistical View of the Phoenix Urban Heat Island during the Past 86 Years (1933–2018)

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Background and Summary

The *urban heat island* (UHI) effect is the characteristic warmth of a city when compared to its suburban and rural surroundings (Oke et al., 2017). The UHI effect can lead to several detrimental consequences such as the increase in energy consumption and outdoor water use during hot summers, the deterioration of nocturnal air quality, the reduction of thermal comfort level in summer, the rise in heat-related morbidity and mortality, etc.

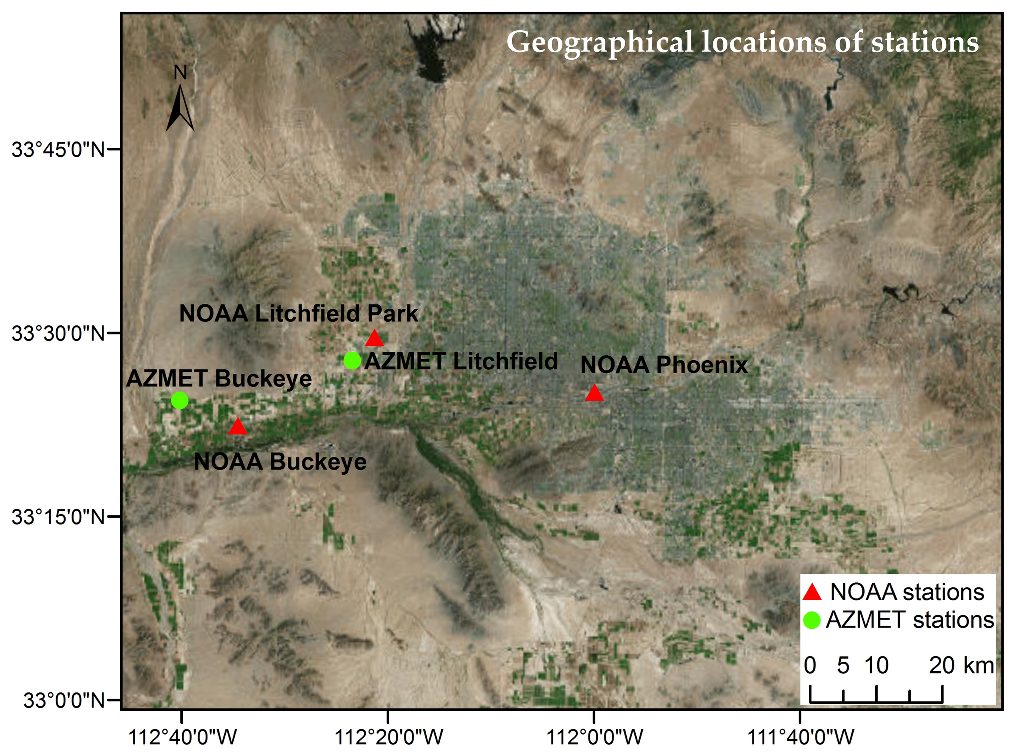
The **Phoenix Metropolitan Area** has experienced extensive land use and land cover changes from agricultural and natural landscapes to the built environment during the past decades. As a unique metropolitan located within an arid and semi-arid environment, it features strong nighttime UHI effect and distinct daytime urban cool island effect, and therefore has been studied by numerous studies (e.g. Chow et al., 2012).

The present study aimed to investigate the canopy UHI effect with an 86-year (1933–2018) air temperature dataset in the Phoenix Metropolitan Area. We intended to provide new insights into the Phoenix UHI effect from a statistical point of view.

Data and Methodology

Data sources (daily maximum and minimum air temperature, Tmax and Tmin)

- Study period: 86 years (1933–2018)
- Three NOAA stations: Phoenix Airport (urban), Buckeye (rural), Litchfield Park (rural → urban)
- Two AZMET stations: Buckeye (rural) and Litchfield (rural → urban)



NOAA stations:
Phoenix Airport (1933/06/01–present)
Buckeye (1893/03/01–2003/11/30)
Litchfield Park (1917/08/01–present)

AZMET stations
Buckeye (1998/01/24–present, ~10 km from NOAA Buckeye)
Litchfield (1987/05/12–2003/02/03, ~5 km from NOAA Litchfield Park)

UHI intensity – temperature difference between urban and rural sites

- Phoenix–Buckeye: a relatively consistent reference rural site
- Phoenix–Litchfield: a reference site transforming from rural to urban

A 4-step gap filling approach for missing data

- Daily temperature gap filling at 2 NOAA stations using records at 2 nearby AZMET stations (simple linear regression). Daily records are then aggregated to monthly records.
- Monthly temperature gap filling using records at 2 nearby NOAA stations (multiple linear regression within each 5-year moving window).
- Monthly temperature gap filling using records at 1 nearby NOAA station (simple linear regression within each 5-year moving window).
- Remaining missing data (if any) are replaced with the climatological monthly average based on each 5-year moving window.

Change-point detection

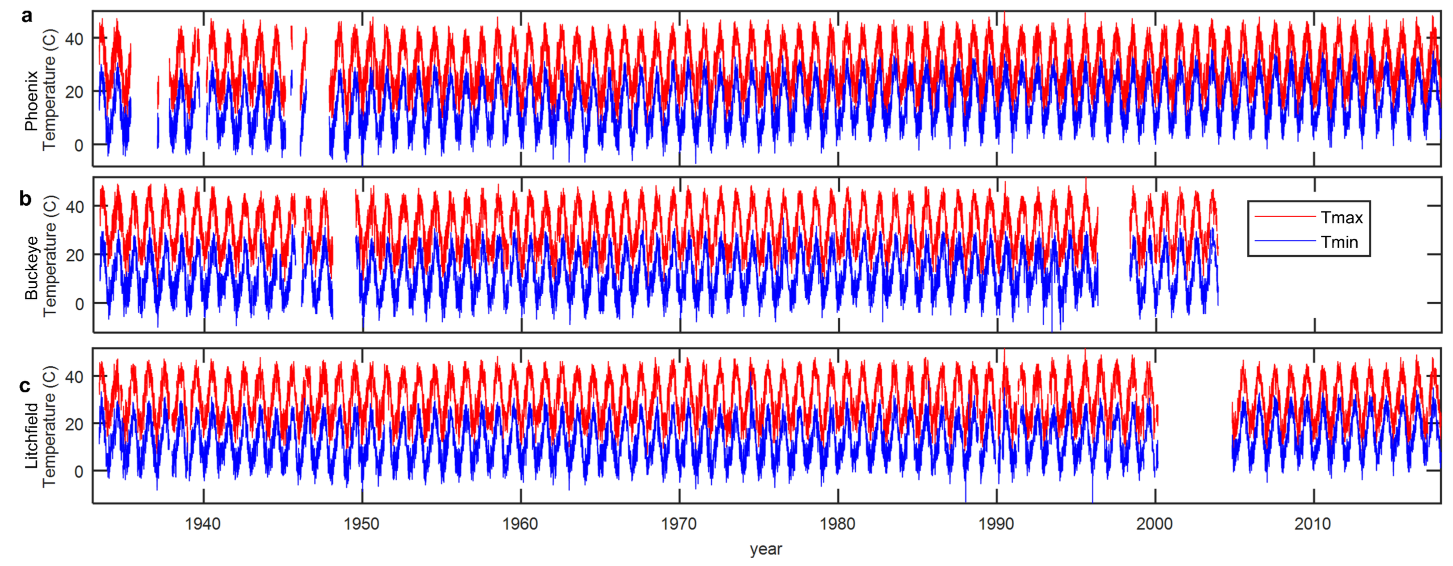
Pettitt's test: the change-point is considered to be significant when $p \leq 0.05$.

Spectral analysis

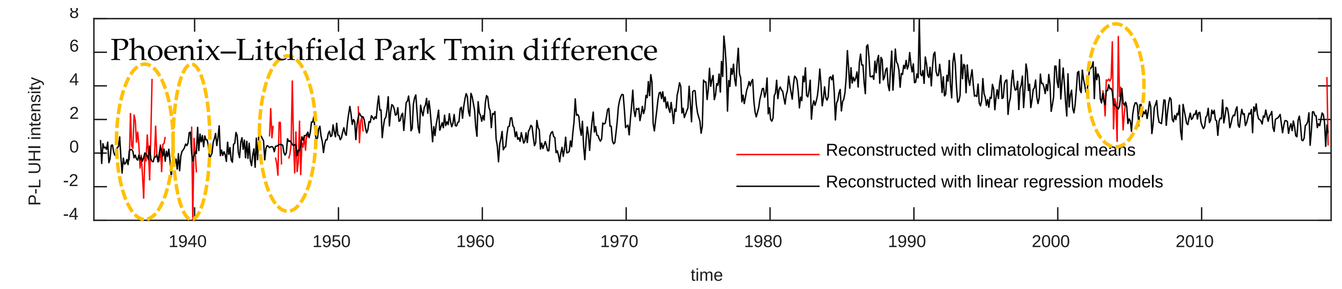
Fourier transformation is used to decompose the time series into a combination of sinusoids in its frequency domain (possibly physical processes that vary at different speeds). The autocorrelation coefficients are also used to explain the spectra.

Results and Discussion

Time series reconstruction with the 4-step gap filling approach

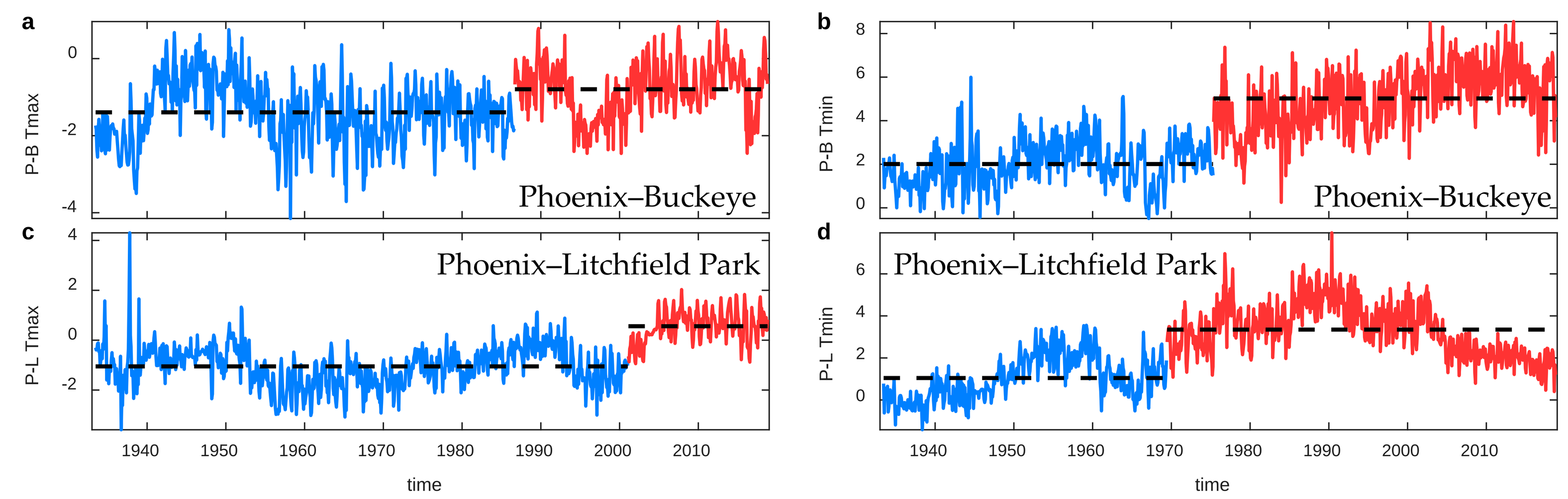


- The simple linear regression models for daily temperature gap filling: $R^2 > 0.917$, slope ranging from 0.986 to 1.021.
- No remaining missing data after preforming the first 3 steps.
- This approach can reconstruct more realistic time series than climatological mean approach (especially for the second-order effect such as UHI intensity).

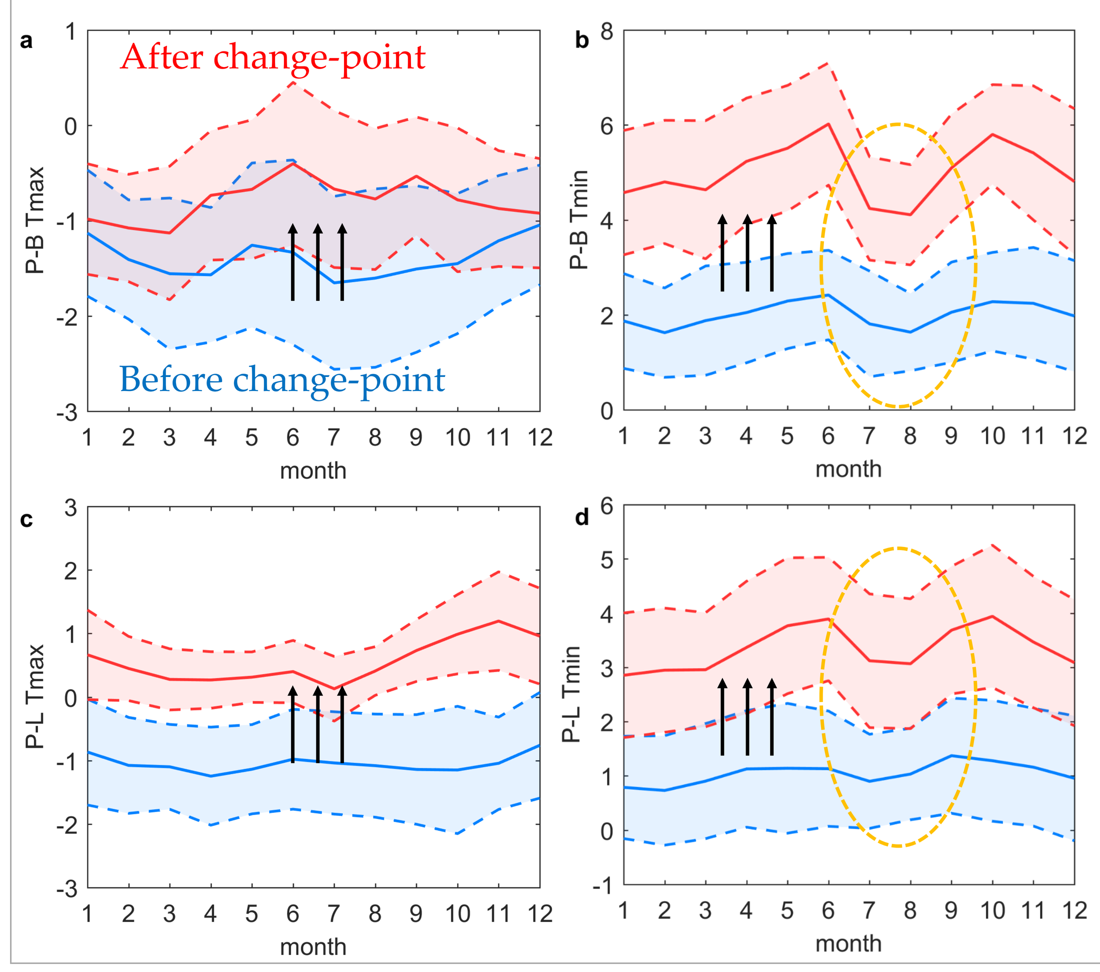


Change-point detection in the monthly series

- The change-points in 3 Tmax series are not significant.
- The change-points in 3 Tmin series are statistically significant, and are consistent with the major urbanization processes in this area.
- The change-points in UHI intensity series are statistically significant ($p < 0.001$).



- Mean daytime UHI over 86 years was negative, as Phoenix Metropolitan Area acts as heat sink when compared to surrounding environment (urban cool island or oasis effect, urban irrigation).
- Nighttime UHI effect was more significant.
- The impact of dynamic urbanization on the calculated UHI intensity (e.g. reduced daytime and nighttime UHI at Litchfield Park station after ~1990).

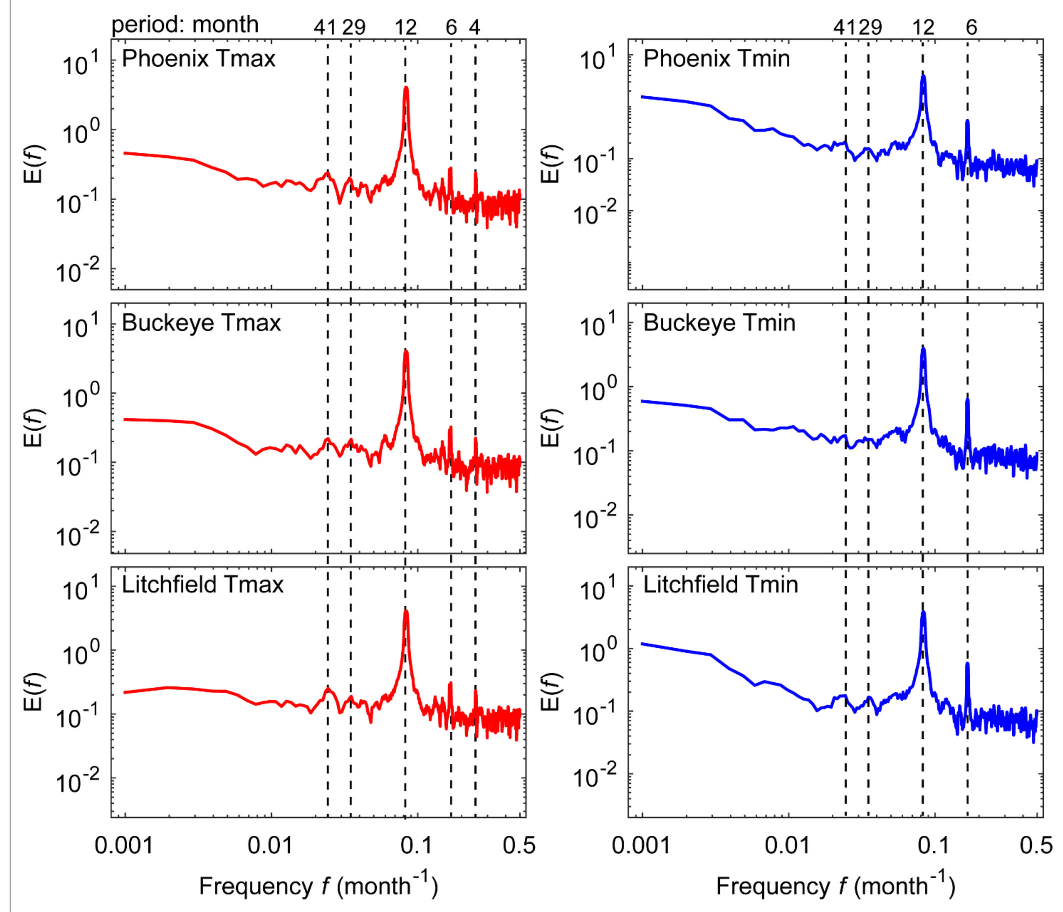


Monthly variability:

- Significant differences in both magnitude and seasonal patterns of UHI intensities before and after the change-points
- Nighttime UHI intensity during July–September owing to stronger convection in monsoon seasons

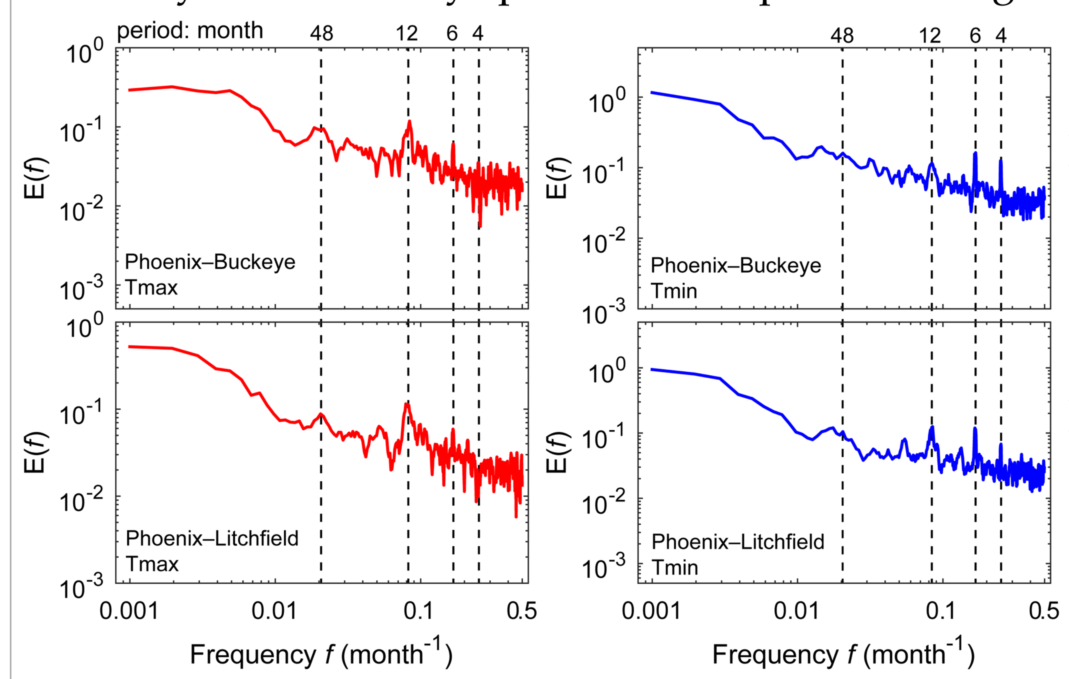
Spectral analysis of temperature and UHI intensity series

Monthly temperature spectra with 5-point moving average applied

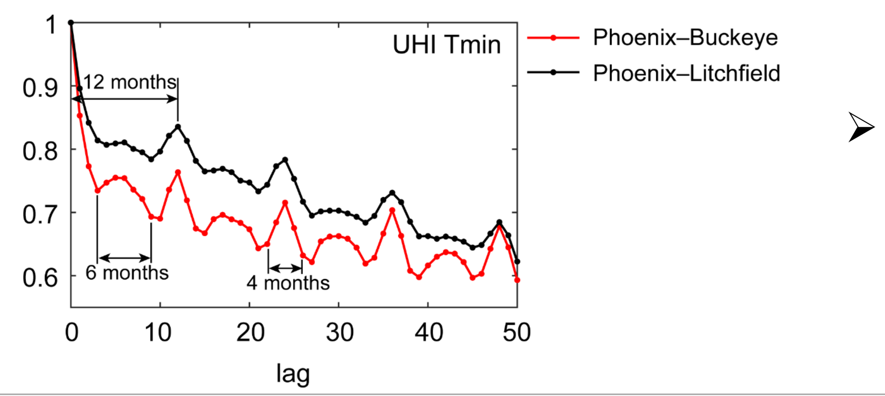


- 12-month period: annual cycle
- 6-month period: similar temperature in spring and fall
- 4-month period in Tmax series: similar daytime temperature patterns at the beginning and near the end of the monsoon season
- Longer periods (e.g. ENSO) are not significant

Monthly UHI intensity spectra with 5-point moving average applied



- Consistent periodicity for both daytime and nighttime UHI intensity series (4, 6, and 12 months)
- The reasons are similar



- The 4-month period is also supported by autocorrelation coefficients

Conclusion and Perspective

- The continuous 86-year monthly temperature series in Phoenix Metropolitan Area were reconstructed with a concise 4-step gap filling method.
- Statistically significant change-points were detected with Pettitt's test mainly due to the dynamic urbanization process.
- Spectral analysis suggests that the characteristic periodicities for the UHI intensity series were around 12, 6, and 4 months.
- The significant impact of seasonal cycle and dynamic urbanization process on the UHI intensity suggests that the conclusions can be strongly dependent on the selection of both representative stations and time series in this area.
- Multiple change-points detection methods; hourly temperature records to detect periodicity at frequencies higher than 1 month^{-1}.

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