The stone forest as a small-scale field model for the urban climate studies

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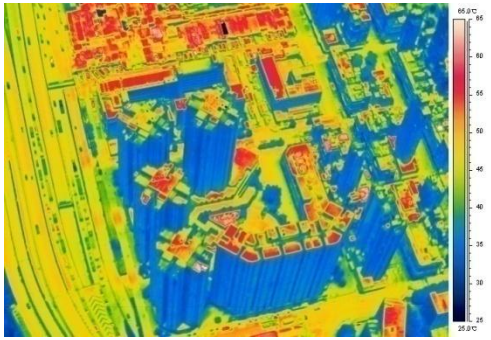
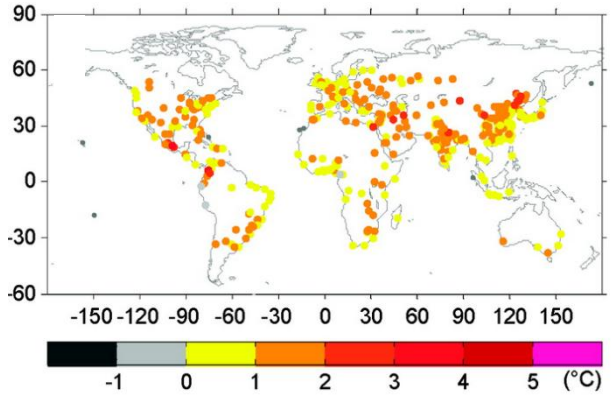
What have changed in cities?

- More man-made structures
- Less wind
- More airborne pollutant/aerosols
- More anthropogenic heat/moisture

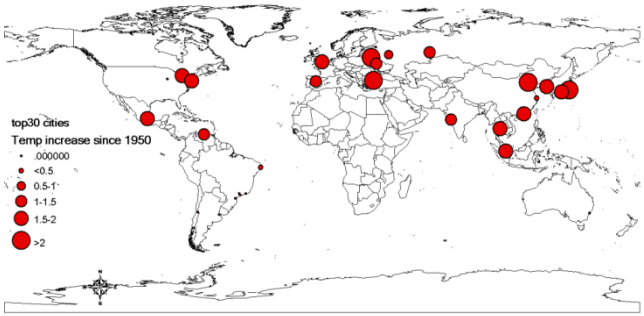


The phenomena of urban warming

- Urban heat island
- Larger warming trend
- Asymmetry daytime/nighttime warming

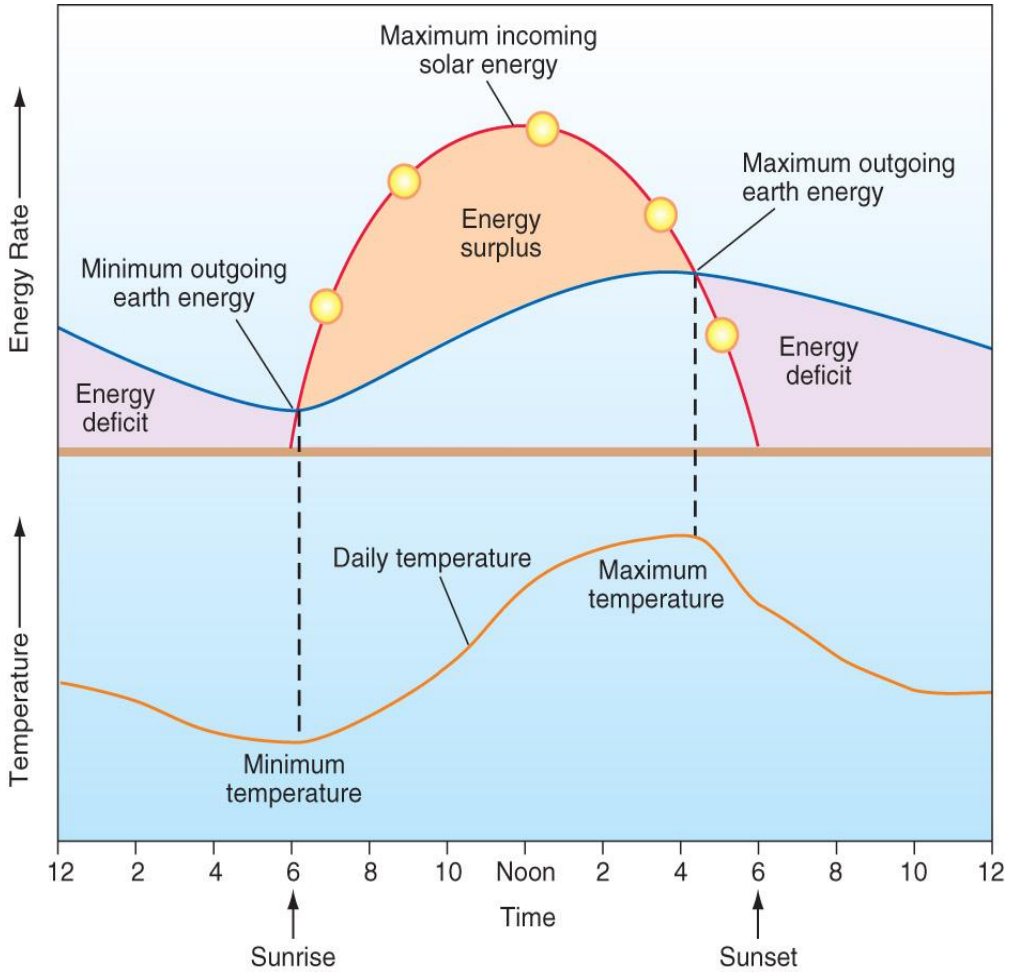


Surface urban heat island intensity across 419 cities (Peng et al 2012)



Temperature increase for the top 30 cities over the world since 1950

Fundamental: Daily temperature cycle



Sun's rays are most intense at 12pm

The daily maximum temperatures occur around 2-3 pm which lags behind insolation, and this is referred here as phase lag.

$$T_i = \tilde{T}_i + \Delta\tilde{T}_i \cos(\omega t - \beta_i)$$

$$\omega = 2\pi / 24$$

$\tilde{T}_i$ Mean temperature

$\Delta\tilde{T}_i$ Amplitude

β_i Phase

We suggest that understanding the daily temperature cycle is the key in urban climate studies

- The daily cycle of solar radiation governs the daily temperature cycle.
- The daily cycle of human daily activities leads to daily variation of anthropogenic heat, as well as other pollutants.
- The thickness of most man-made structures, such as buildings and roads, are less than 0.5 meter, which is more sensitive to the daily temperature cycle change.

The Forth-Restore Method derives the effective depth*(ds*)* that 'feels' the surface temperature cycles (Stull RB 1988)

$$ds = [(\kappa\tau)/(4\pi)]^{1/2}$$

τ period, eg. a day, or a year

κ thermal diffusivity, in soils is around 10^{-6} m^2/s

	1 day	1 year	1 decade
ds	≈0.1m	≈1.5m	≈5m

Study Area: The Stone Forest, Yunnan Province, China

- The heights of the karst stones range from 10 to 30m.
- The thermo-physical properties of the stones (limestone) are similar with the concrete of buildings.
- Minimum or zero air pollution and anthropogenic heat, which can isolate the effects of man–made structures.
- Different stone structures mimic different urban structures.

High-rise compact

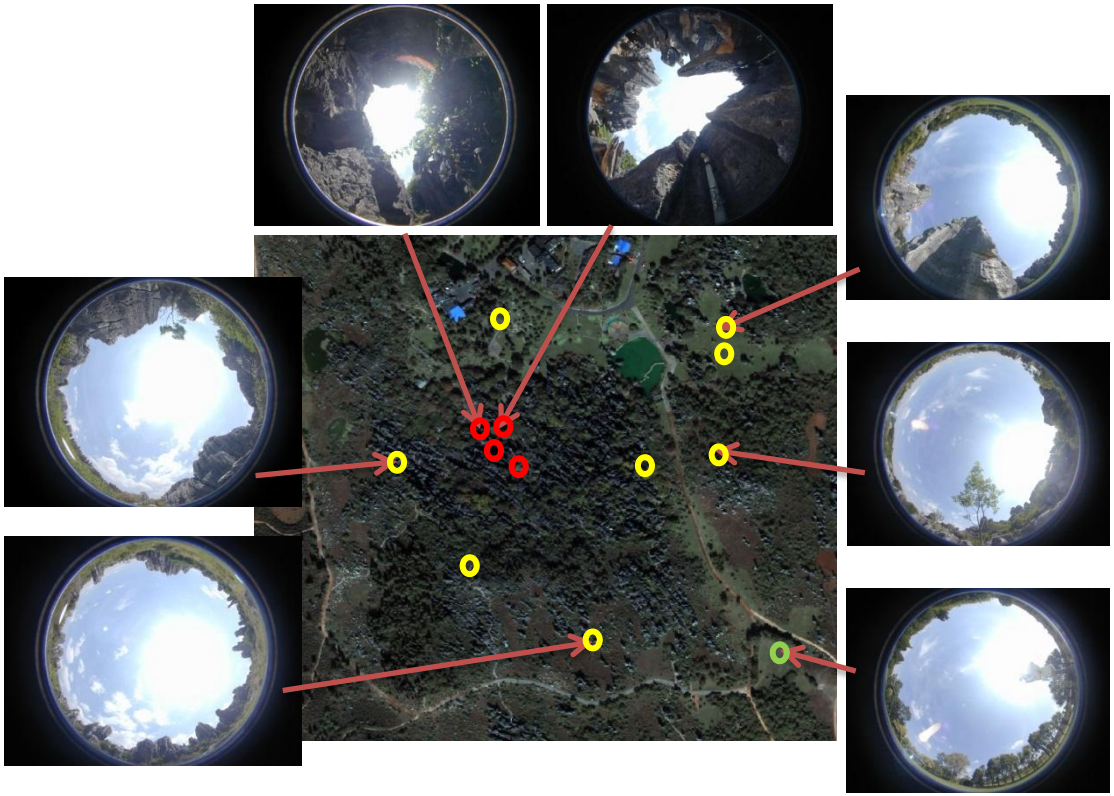
Low-rise sparse

Single Stone (Single Building)

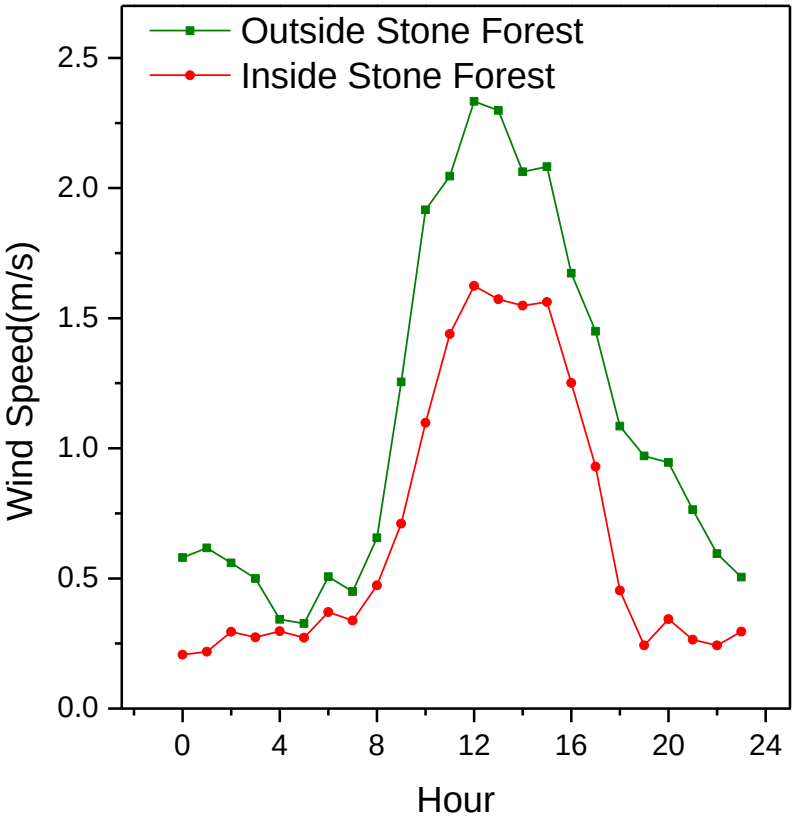
Garden City?

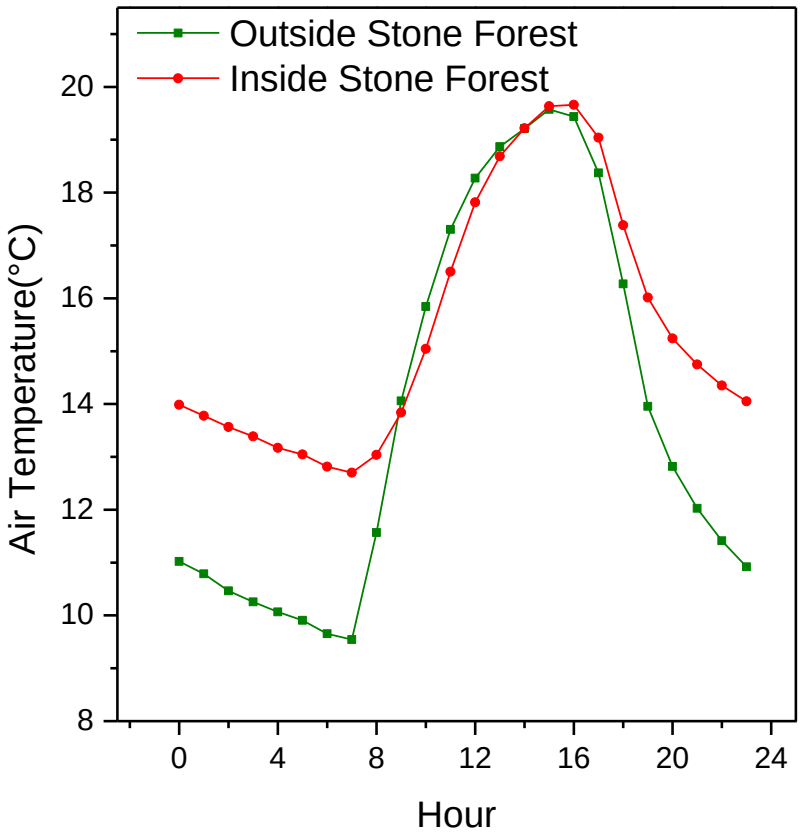
Measurements

- Air temperature at 2 m above ground (30 min interval, ibutton DS 1923 F5) at 13 locations (July 2013-date)
- Hourly surface temperature of the stones and vegetation using infrared camera(Flir SC600). (July 10-12th 2013; September 23-26th 2013; January 9-12th 2014)
- Two weather stations(Rainwise) outside/inside the Stone Forest (July 2013-date)



Comparison of daily air temperature and wind speed

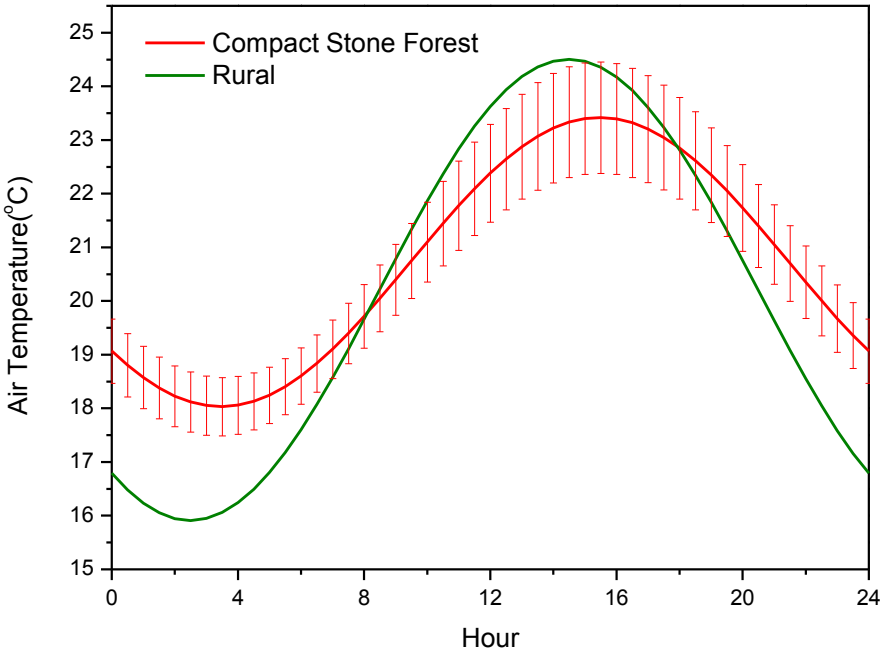


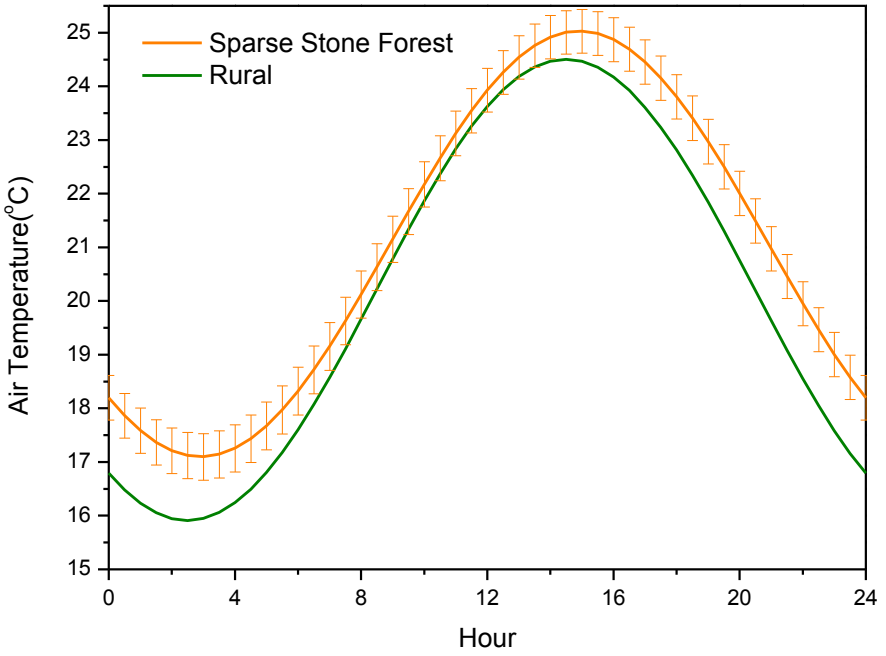


- There is always less wind inside the stone forest.

- The temperature difference inside/outside Stone Forest is much significant in the nighttime, not only due to the thermal storage of the stones but also the less wind in the nighttime.

Comparison of daily air temperature cycle in different Stone Forests and the rural area



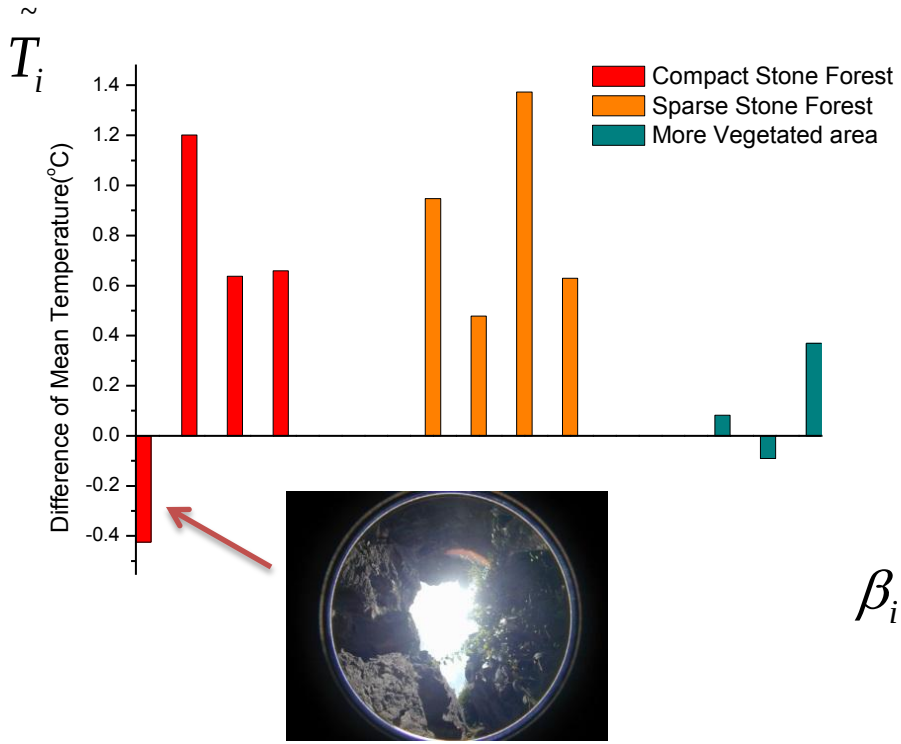


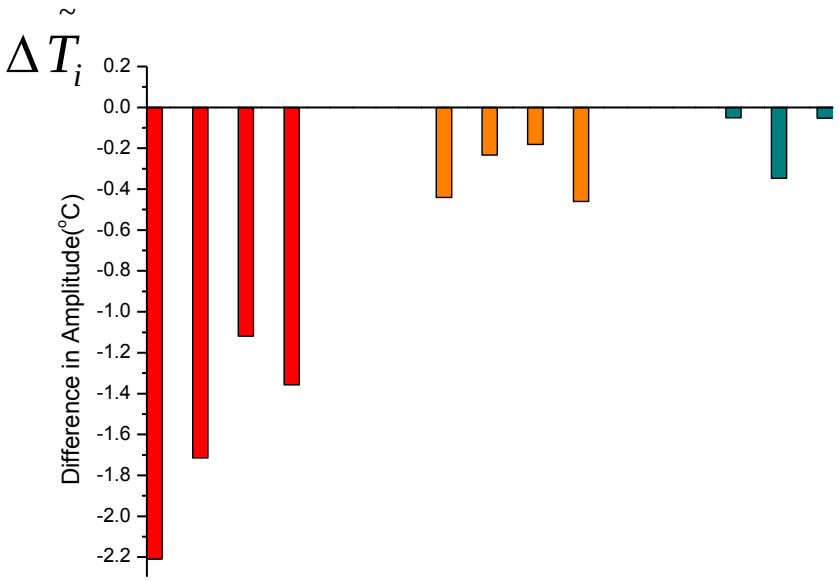
In comparison with the rural area,

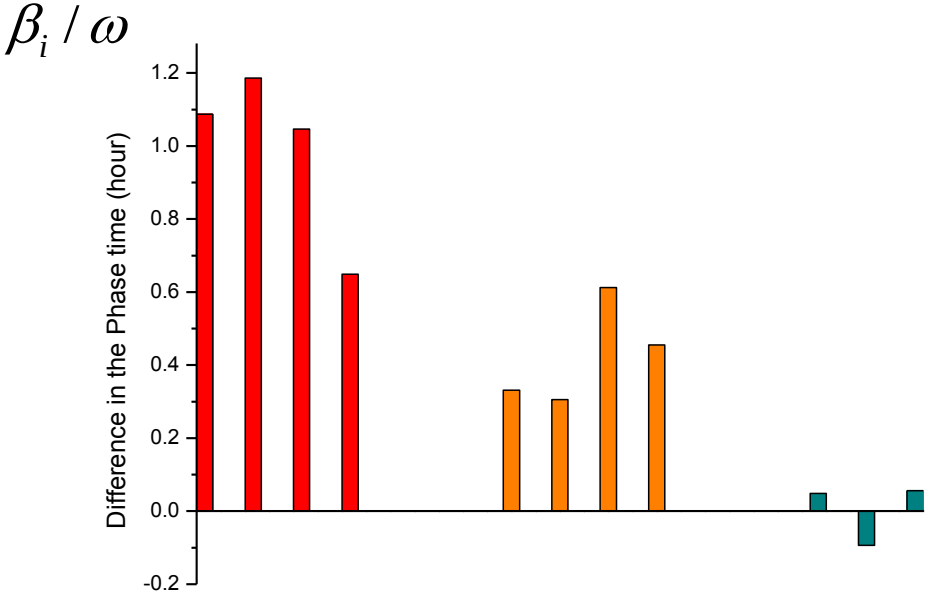
- The daily time cooler and night time warmer in the compact stone forest
- Both daytime and nighttime warmer in the sparse stone forest
- The time when daily maximum temperature occures later in the stone forest.

Differences in daily air temperature cycle between the measurements in Stone Forests and the rural area

$$T_i = \tilde{T}_i + \Delta\tilde{T}_i \cos(\omega t - \beta_i)$$







Higher Mean temperature

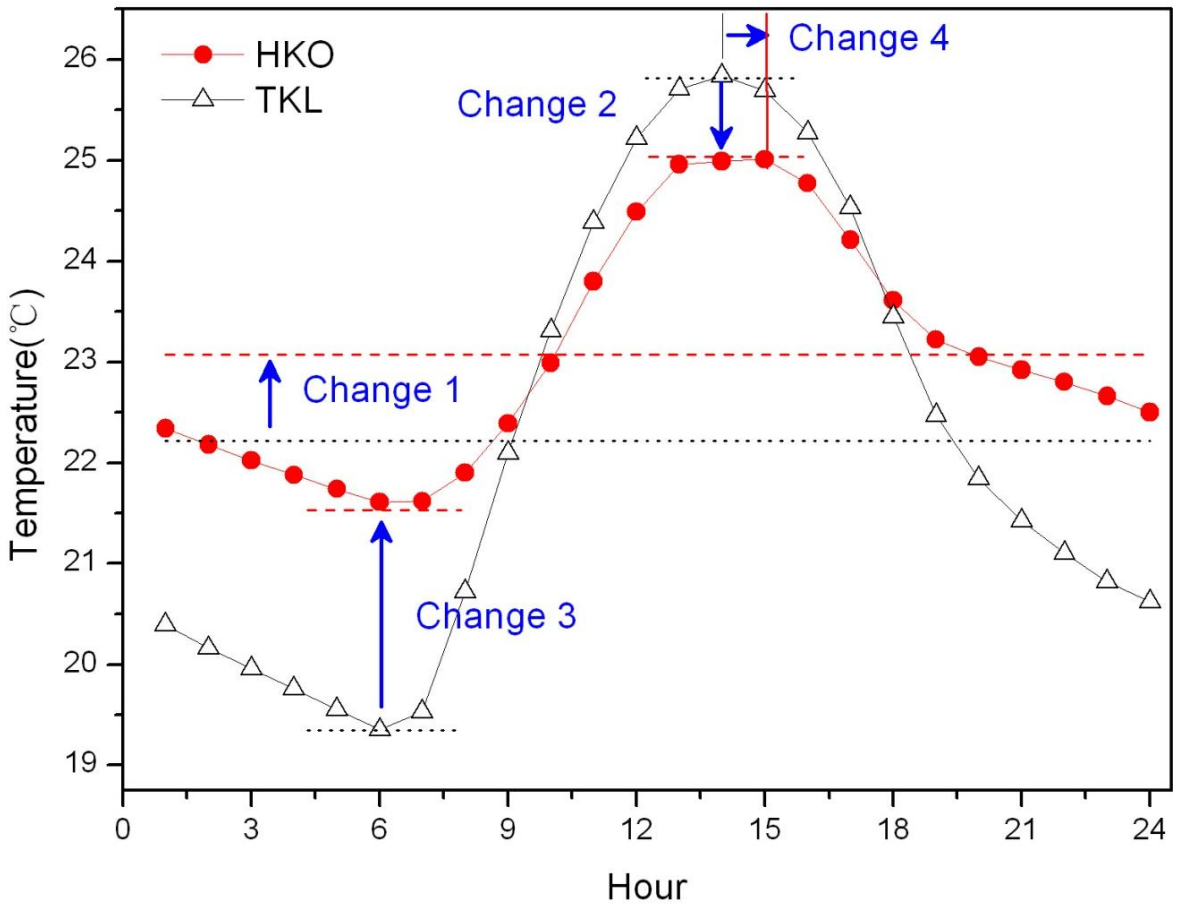
Smaller Amplitude

Delayed Phase time

Possible Implications for urban climate

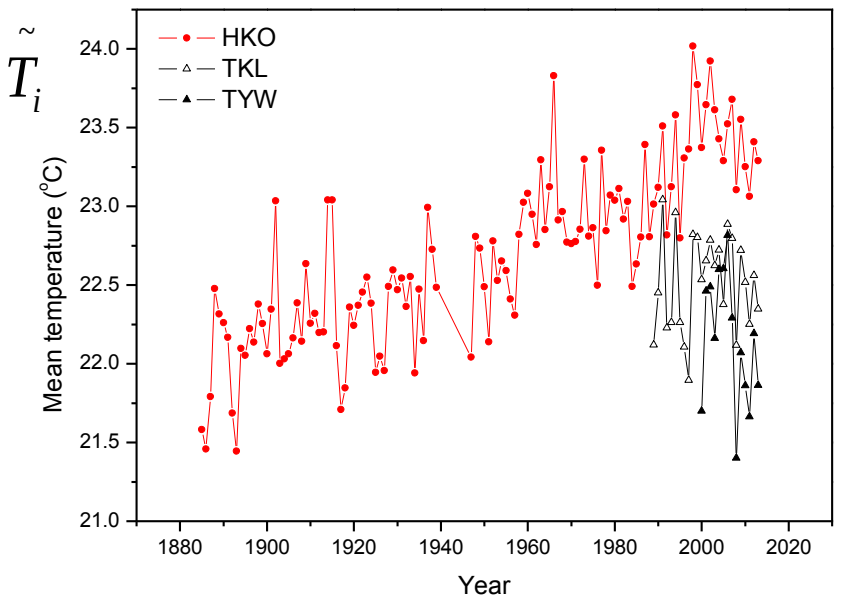
- The day time is cooler , night time is warmer, timing for the peak temperature delays in a ***compact stone forest*** than the rural area.
- In the ***sparse stone forest***, both daytime and nightime are warmer, timing for the peak temperature delays.
- Will such phenomena be observed in the urban area?

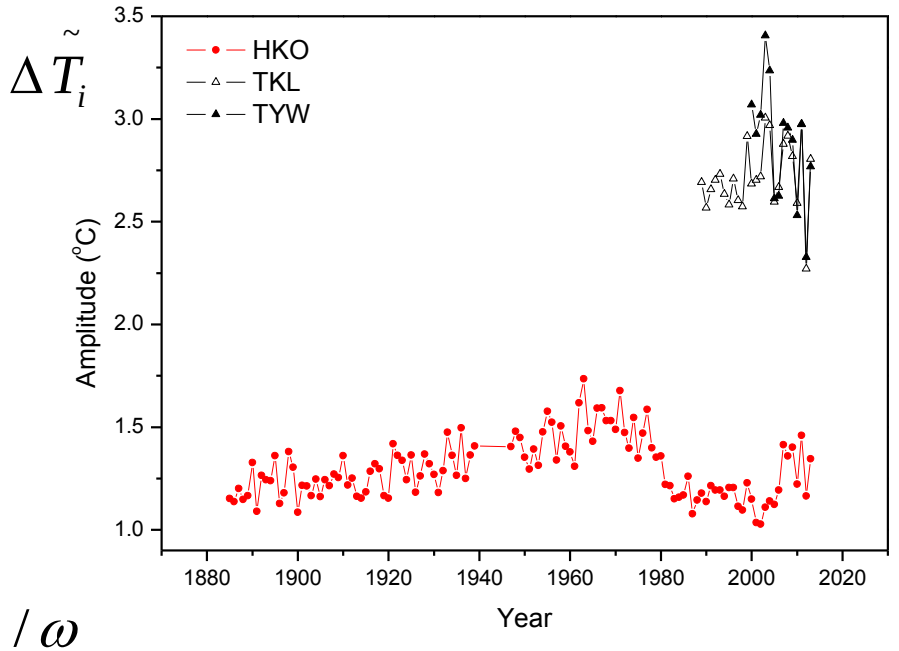
Comparison of daily air temperature cycle from the typical urban(HKO) and rural (TKL) stations in Hong Kong

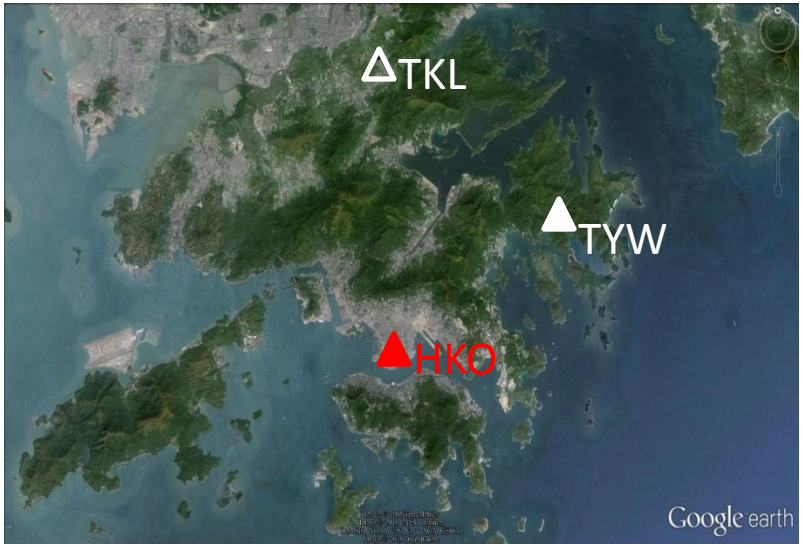


- Change 1 --- Mean Temperature: Higher in the urban area.
- Change 2 --- Daily Maximum Temperature: Lower in the urban area.
- Change 3 --- Daily Minimum Temperature: Higher in the urban area.
- Change 4 --- Time when Daily Maximum Temperature occurs: Delayed in the urban area.

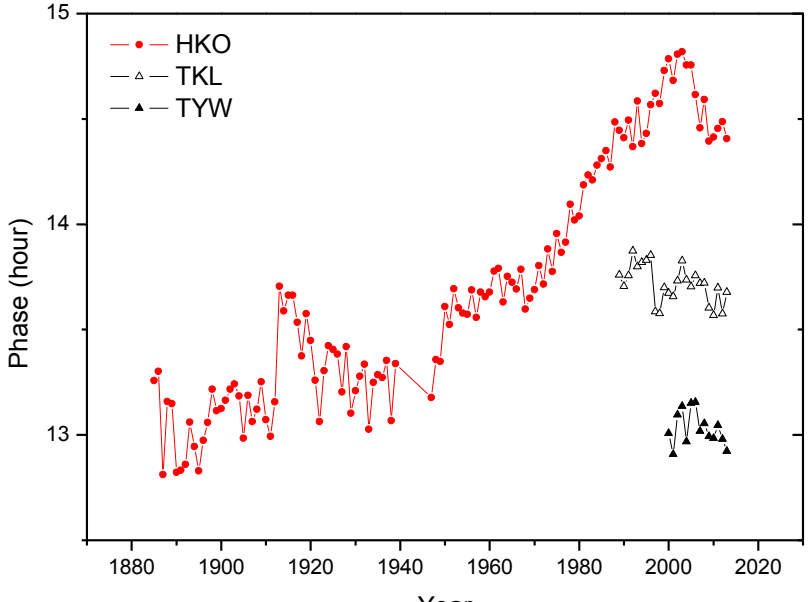
Decadal change of daily air temperature cycle in Hong Kong







β_i / ω



Summary

- We observe that the night time is warmer, day time is cooler and phase (timing for the peak temperature) delays in a compact stone forest and a high rise compact city Hong Kong.
- We hypothesis that the phase delay may be explained by the increased thermal storage and reduced wind in the stone forest and in the cities.

Thank you very much!