# Contribution of urban park to thermal comfort and $CO_2$ mitigation in a hot-humid environment


**Keunmin Lee[1], Je-Woo Hong[2], Jeongwon Kim[1], Jinkyu Hong[1,*]**

[1] Ecosystem-Atmosphere Process Laboratory, Department of Atmospheric Sciences, Yonsei University, Seoul, Republic of Korea,

[2] Korea Environment Institute, Sejong, Republic of Korea (Corresponding author* : jhong@yonsei.ac.kr, http://eapl.yonsei.ac.kr)



Reference

- Lee, K.M., Hong, J-W., Kim J.W. & Hong, J. (2020). Contribution of urban park to thermal comfort and CO2 mitigation in a hot-humid environment. In preparation.
- Hong, J.-W., J. Hong, J. Chun, Y. Lee, L. Chang, J. Lee, K. Yi, Y. Park, Y. Byun, and S. Joo (2019). Comparative assessment of net CO2 exchange across an urbanization gradient in Korea based on in situ observation, Carbon Balance and Management, https//doi.org/10.1186/s13021-019-0128-6.
- Hong, J. W., Lee, S. D., Lee, K., & Hong, J. (2020). Seasonal variations in the surface energy and CO2 flux over a high-rise, high-population, residential urban area in the East Asian monsoon region. International Journal of Climatology, https://doi.org/10.1002/joc.6463.



Acknowledgement

This research was supported by a National Research Foundation of Korea Grant from the Korean Government (MSIT) (NRF-2018R1A5A1024958), and the Korea Meteorological Administration Research and Development Program under Grant KMI2018-03512.


## Motivation

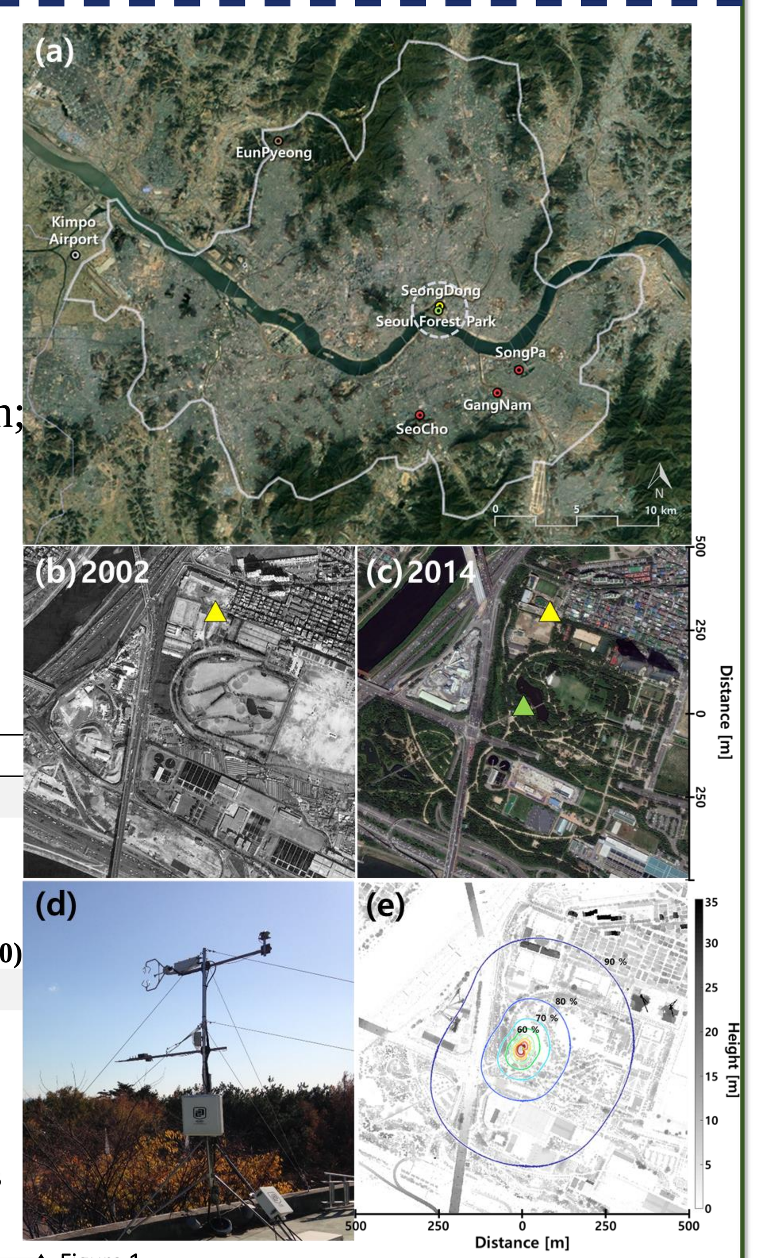
- ✓ Today, cities are recognized as a key driver of climate change mitigation efforts and such efforts include the increase of **green urban infrastructure** in cities for the purpose of thermal comfort and $CO_2$ mitigation.
- ✓ We observed surface turbulent fluxes at an artificially constructed Seoul Forest Park (SFP) in Seoul, for two years from June 2013 to May 2015.
- ✓ The objectives of the study are to 1) quantify water, energy and $CO_2$ exchanges from urban park into the atmosphere and 2) quantify the effect of the urban park on microclimate through comparison before and after the park construction and comparison with urbanized surrounding areas and 3) identify abiotic and biotic factors controlling the temperature reduction and CO2 offset.

## Site Description

✓ **Seoul Forest Park**

- the third biggest park in Seoul (1.16 km²)
- Artificially created park in 2005
- Mixed forest, pond, and turf grass (120~390 stem/ha, EVI ; 0.1 ~ 0.5)
- Annual mean temperature and precipitation; 13.9°C / 1094 mm
- **road ($\lambda_R$) : 11% (south~west)** ~ 150,000 vehicles/day
- **vegetation ($\lambda_V$) : 48%**
- $\bar{Z}_H \cong 7.5$ m (canopy)

| Sites | Location | LCZ | |
|---|---|---|---|
| **Eddy covariance station** | | | |
| **SFP (Seoul Forest Park)** | 37.55°N, 127.04°E | $LCZ_{A9}$ | urban park |
| **EP (EunPyeong)** | 37.64°N, 126.93°E | $LCZ_1$ | residential area **(Hong et al., 2020)** |
| **Automatic weather station** | | | |
| **SD (SeongDong)** | 37.55°N, 127.04°E | $LCZ_{5B}$ | urban park |
| **AVG** | | | high-density central business district |
| - **GangNam** | 37.51°N, 127.05°E | $LCZ_{21}$ | |
| - **SeoCho** | 37.49°N, 127.02°E | $LCZ_{21}$ | |
| - **SongPa** | 37.51°N, 127.10°E | $LCZ_{15}$ | |
| **Aerodrome meteorological observation station** | | | |
| **KP (KimPo)** | 37.57°N, 126.78°E | $LCZ_D$ | rural (airport) |



▲ Figure 1.
(a) The location of stations in Seoul and (b) aerial photographs around Seoul Forest Park station in 2002 before the creation of the park, and (c) in 2014 during observation period (modified from map data ©2019 Google). The location of SFP station (green triangle) and SD automatic weather station (yellow triangle). (d) The photograph of SFP station (e) and footprint climatology with height of surrounding obstacles around SFP station.

## Materials and methods

### *Urban Heat Island Intensity*

$$UHIi = T_{air\ (SFP\ or\ AVG)} - T_{air\ (KP)} \quad [°C]$$

### *Surface Carbon Balance*

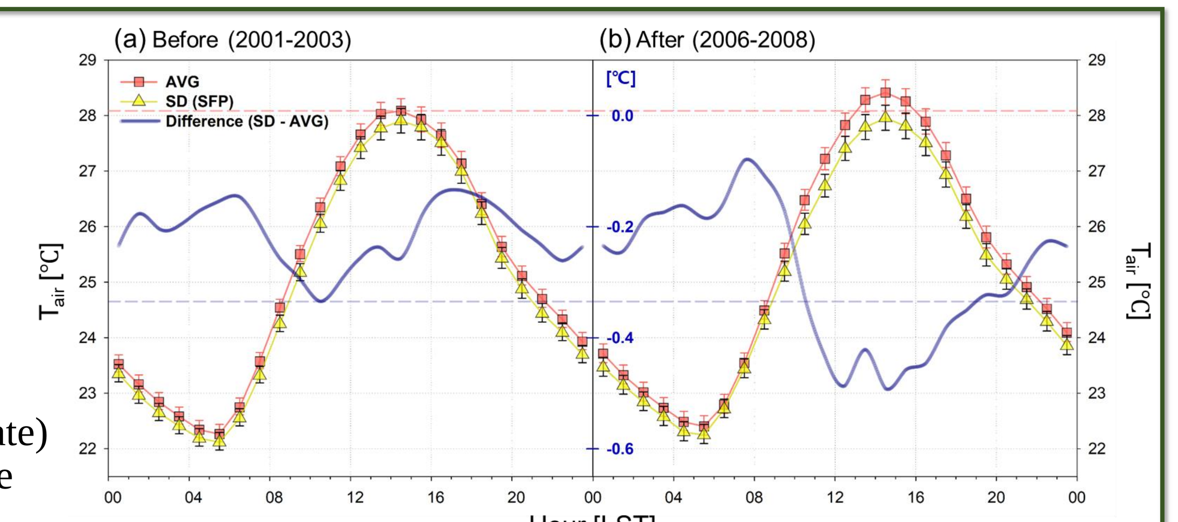
$$F_C + \Delta S = RE + E_R + E_B - P + \Delta A \quad [\mu mol\ m^{-2}\ s^{-1}]$$

✓ $F_C$ : net $CO_2$ flux, $RE$ : ecosystem respiration (vegetation + soil),
$E_R$ : emissions from vehicles of roads, $E_b$ : emissions from heating of buildings
$P$ : carbon sequestration by vegetation
ΔS : carbon storage (assume zero), $\Delta A$ : horizontal and vertical advection (assume zero)

## Results

✓ **Temperature reduction by park creation**

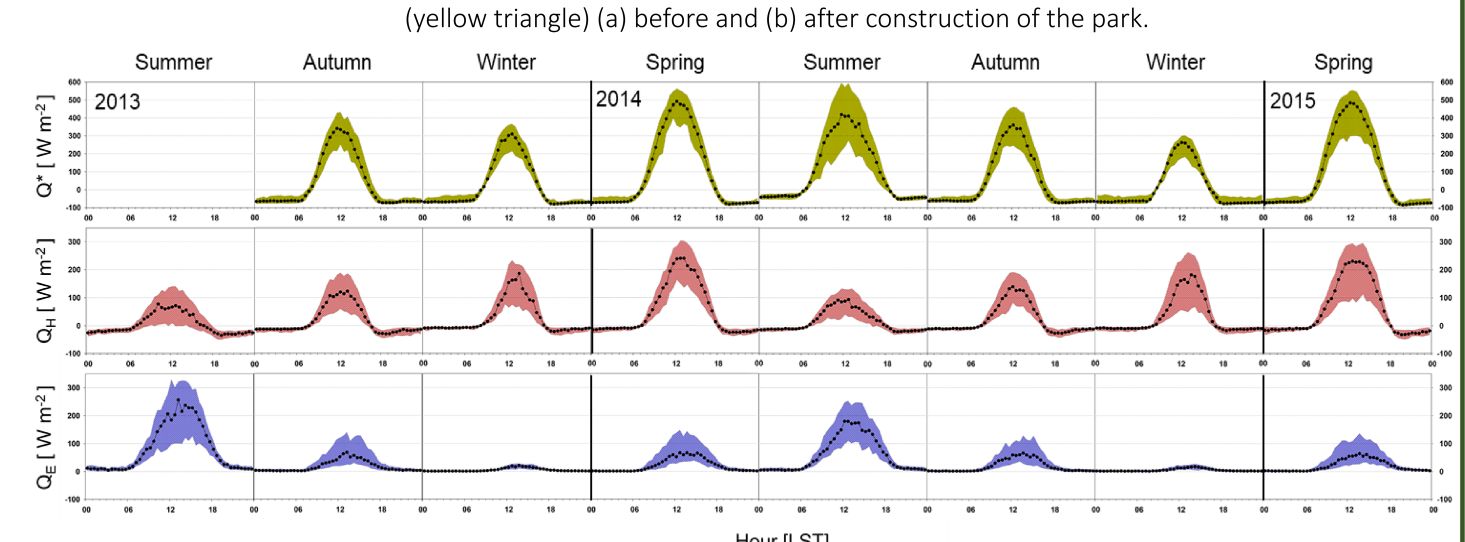
- Maximum $T_{air\ (After-before)}$
  - AVG : 0.3°C ↑
  - SFP (SD) : 0.1°C ↑
- Mean $T_{air\ (After-before)}$
  - AVG : 0.2°C ↑
  - SFP (SD) : 0.1°C ↑ (~global mean warming rate)
- $T_{air\ (SD-AVG)}$ peak moves from the morning to the afternoon because $Q_E$ increases



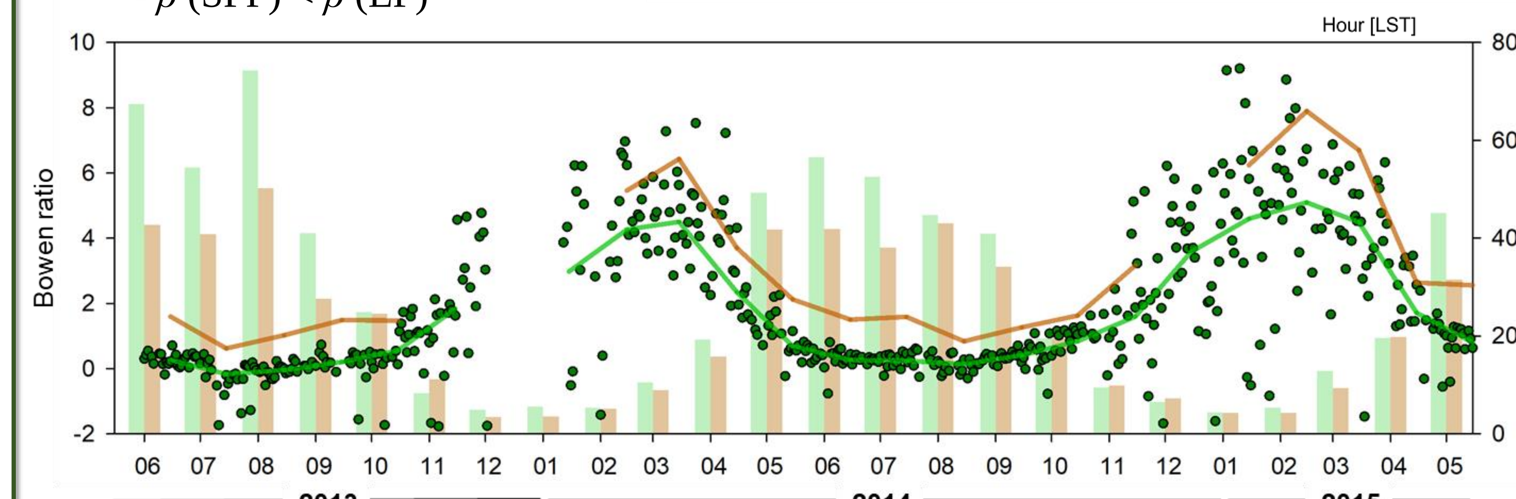
▲ Figure 2.
Mean diurnal pattern of air temperature during **summer** in AVG (red square) and SD (yellow triangle) (a) before and (b) after construction of the park.

✓ **Surface energy balance in urban park**

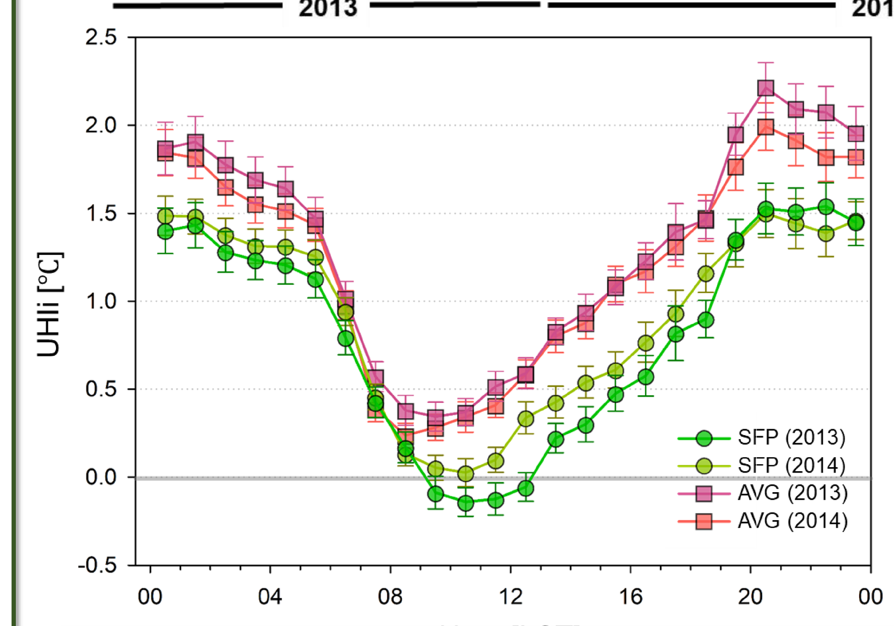
- In summer, $Q_E$ (2013) > $Q_E$ (2014) because of the interannual variation of the East Asian monsoon activity
- Bowen ratio ($\beta$)
  - 0 (summer) ~ 4 (winter)
  - $\beta$ (SFP) < $\beta$ (EP)



▲ Figure 3.
Seasonal median diurnal variations (points) and interquartile ranges (shaded) of 30-min sensible heat flux ($Q_H$), latent heat flux ($Q_E$) and net radiation (Q*) for two years.



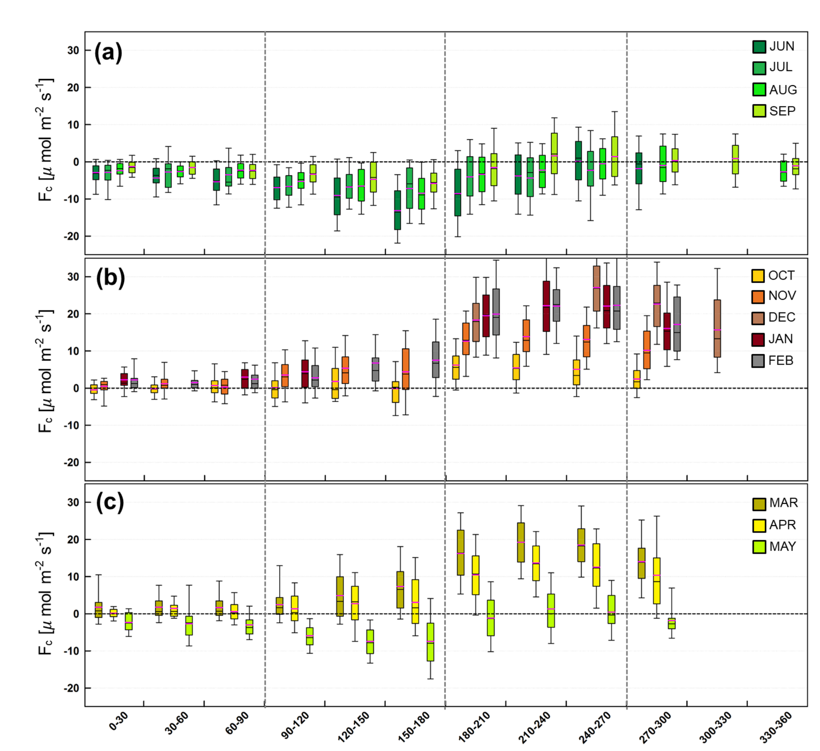
◀ **Figure 4.**
Daily Bowen ratio ($\beta = \sum Q_H / \sum Q_E$; green dot), monthly Bowen ratio of SFP (green line) with EP (brown line) and monthly evapotranspiration of SFP (green bar) with EP (brown bar) during two-year.



◀ Figure 5.
Hourly mean diurnal variation of urban heat island intensity of SFP and AVG in 2013 and 2014 **in summer.** The error bars represent standard errors.

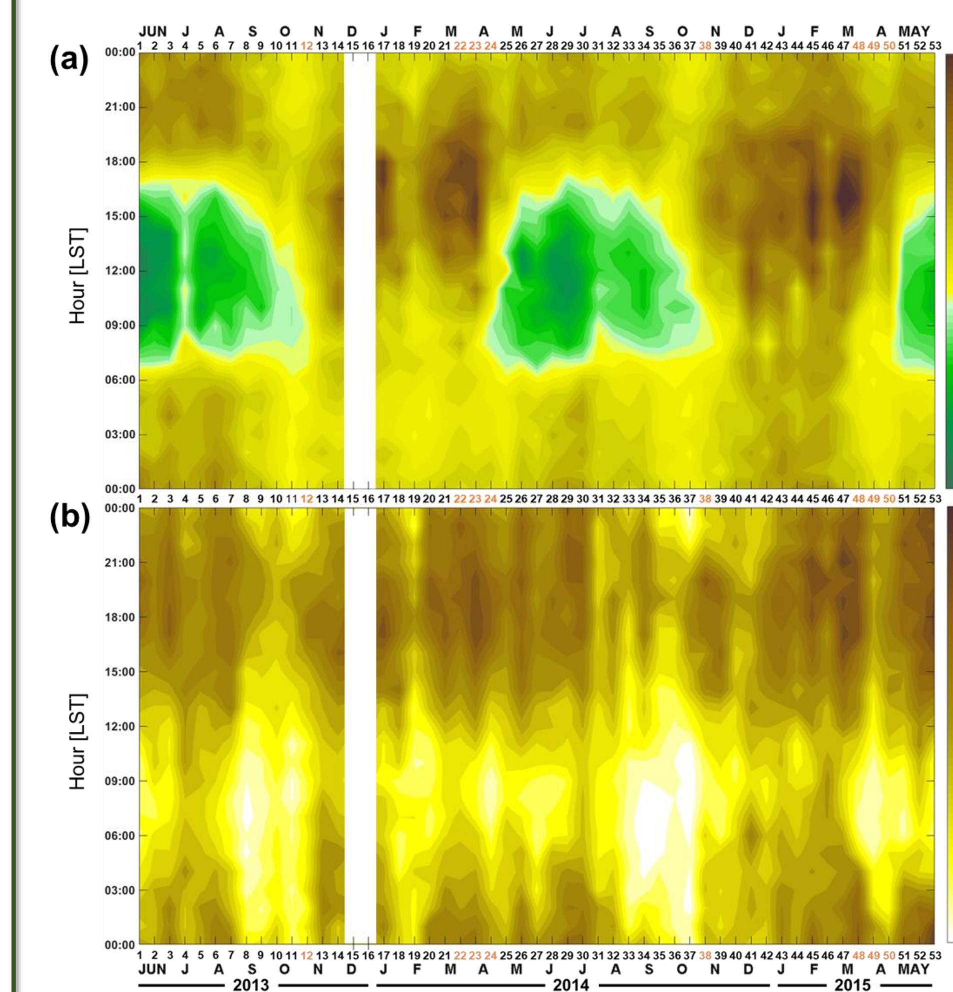
✓ **Urban heat island intensity (UHIi)**

- UHIi of the AVG and SFP : UHIi$^A$ / UHIi$^S$
- UHIi$^A$ (0.2 – 2.2 °C) > UHIi$^S$ (0 – 1.5 °C)
- Minimum UHIi$^A$ : 0.3 °C (2013) at 09:30 and 0.2 °C (2014) at 08:30
  Minimum UHIi$^S$ : – 0.1 °C (2013) and 0.0 °C (2014) at 10:30
  → slow minimum UHIi peak in SFP
  → higher thermal capacity (soil ↑, impervious surface↓)
- UHIi$^A$ (2013) ≅ UHIi$^A$ (2014)
  UHIi$^S$ (2013) < UHIi$^S$ (2014) ← $Q_E$ (2013) > $Q_E$ (2014)



▲ Figure 6.
Monthly boxplots of daytime ($K_\downarrow$ > 120 W m$^{-2}$) $F_C$ by wind direction. Boxes have a minimum of 20 samples. Medians are indicated by black horizontal lines; means are indicated by pink horizontal lines.

✓ **Surface $F_C$ over park with heterogeneous urban landscape**



◀ Figure 7.
(a) Temporal variation of hourly averaged $F_C$ and (b) road fraction ($\lambda_R$, %) for every two-week from Jun 2013 to May 2015. The horizontal axis indicates the number of the two-week for two years and vertical axis is the time of day. In December 2013, there are a gap for about 4 weeks due to the power system failure.

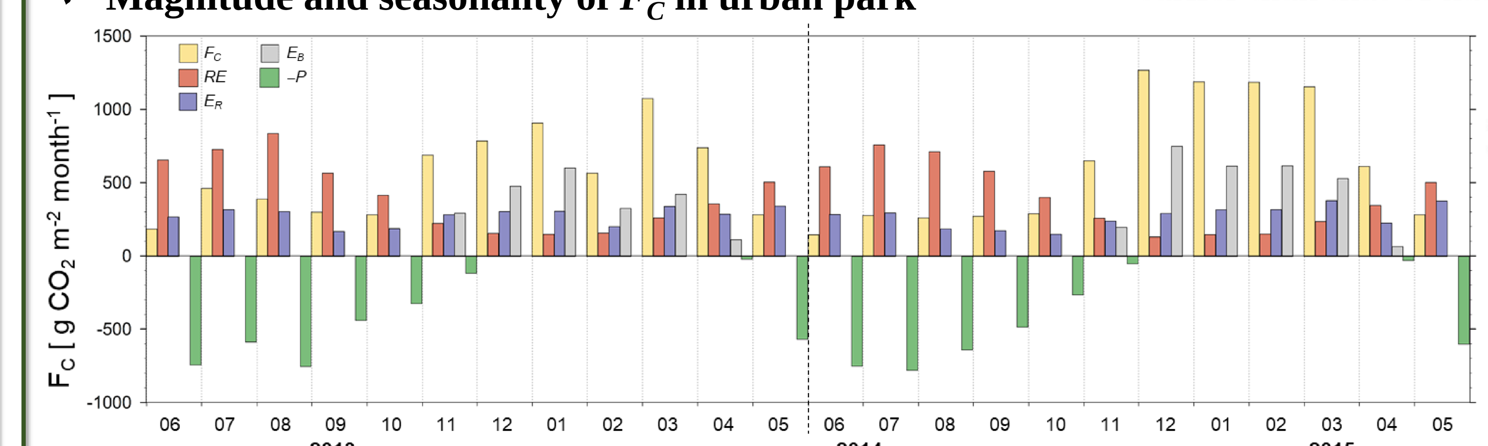
(Fig.6)

- During the summer daytime (from June to August), the mean $F_C$ < 0 in all sectors because of $P$
- the highest tree cover fraction (150-180°) → strongest $CO_2$ uptake but some positive values of $F_C$ ← emissions from vehicles on the roads, $E_R$
- Largest emissions at western sector in winter and late spring because of $E_R + E_B$

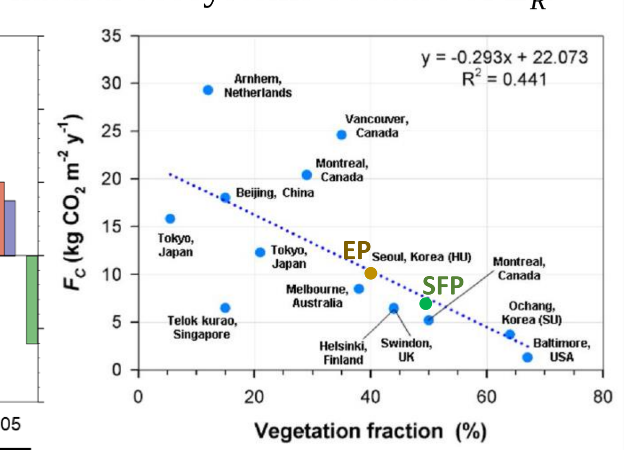
(Fig.7)

- the highest $CO_2$ uptake in June
- significantly reduced $CO_2$ uptake in the middle of summer (4th and 31st two-week) ← reduced $K$↓ because of East Asian monsoon activity
- the clear relationship between $F_C$ and $\lambda_R$
  → $F_C$↑ & $\lambda_R$↑ (23rd, 45th and 47th two-weeks)
  → $F_C$↓ & $\lambda_R$↓ (19th and 46th two-weeks)
- $CO_2$ uptake becomes neutral between 16:00-17:00 earlier than that of natural ecosystems because of $E_R$.

✓ **Magnitude and seasonality of $F_C$ in urban park**



▲ Figure 8.
Monthly sums for $F_C$ (observed; *yellow bar*) and its components, indicating ecosystem respiration (*RE; red bar*), vehicle emissions from the road ($E_R$; *blue bar*), building emissions ($E_B$; *gray bar*) and photosynthetic uptake by vegetation (*P, green bar*).



▲ Figure 9.
Relationship between annual $CO_2$ flux and vegetation fraction (Fig.12a of Hong et al., 2019)

- Lowest $F_C$ in June
  ← absorption by $P$ (in summer)
  ← small $RE$ (compared with Jul, Aug)
- On a monthly basis, $P$ offsets $RE$ in only June.
- $RE > E_R$ (Apr to Oct) / $RE < E_R$ (Nov to Mar)
- in summer; $F_C$ ← biogenic component ($P$, $RE$)
  in winter; $F_C$ ← anthropogenic component ($E_B$, $E_R$)
- The annual mean total $F_C$, $RE$ and $P$: **7.1**, 4.9, **3.7** kg $CO_2$ m$^{-2}$ year$^{-1}$
- On an annual basis, vegetation in SFP absorbs more than 30% of the $CO_2$ emitted from or around the park.

## Summary

- ✓ SFP, the artificially developed urban forest park, acts to offset the increase in temperature, reducing the temperature by up to 0.6 °C, compared to the surrounding high-density residential area. This cooling effect is closely related to more evapotranspiration compared to the impervious surface.
- ✓ We partition the net $F_C$ at urban park into biogenic and anthropogenic $F_C$ components by analyzing the relationship between road fraction and $CO_2$ emission.
- ✓ Vegetation in SFP absorbs 3.7 kg $CO_2$ m$^{-2}$ year$^{-1}$, corresponding to about 1/3 of $CO_2$ emission from soil, vehicles and buildings around the park.
- ✓ The annual mean total $F_C$ is 7.1 kg $CO_2$ m$^{-2}$ year$^{-1}$. It is consistent with the scaling between annual $CO_2$ fluxes and vegetation fraction. It is about 3 kg $CO_2$ m$^{-2}$ year$^{-1}$ less than that in typical residential area in Seoul.