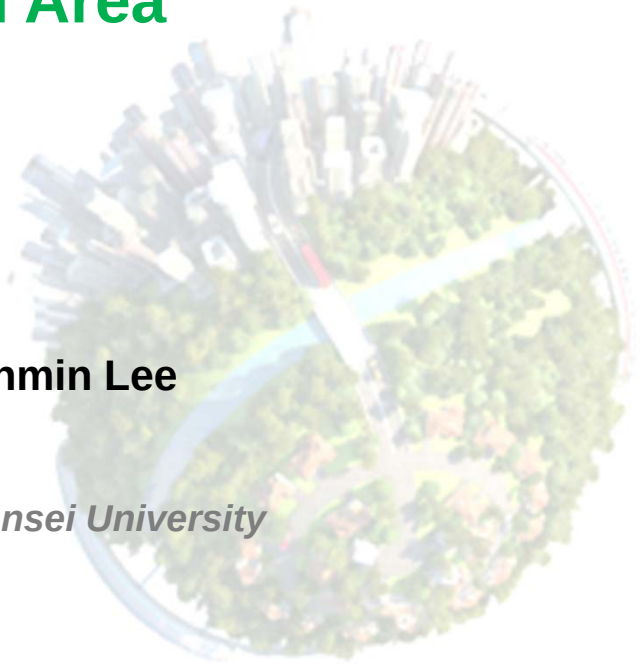
Measurements of Surface Energy and CO_2 Exchanges at City-Atmosphere Interface:

Case Study at Highrise Residential Area and Urban Park in Seoul Metropolitan Area



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Motivation

◆Rapid growth of megacities in Asia

1) Only 2% of the world land but >50% in the population in cities
2) 1.3 million people into cities each week
3) 75% of the world's resource are used by cities
4) 1.2kg of solid waste per person every day
5) Strong greenhouse gases emission in and around cities.
   - ✓ Only **17%** of land cover
   - ✓ **91.0%** of population ... (in 2012)
6) Eco- & Energy-Friendly urban development

◆**Urban Forest**: Debate on benefits of urban forest

1) Changes in microclimate and air quality
2) Impacts on urbanites (UHIs, air pollution, heat wave)
3) Mitigation and adaptation for environmental change (carbon uptake of trees)

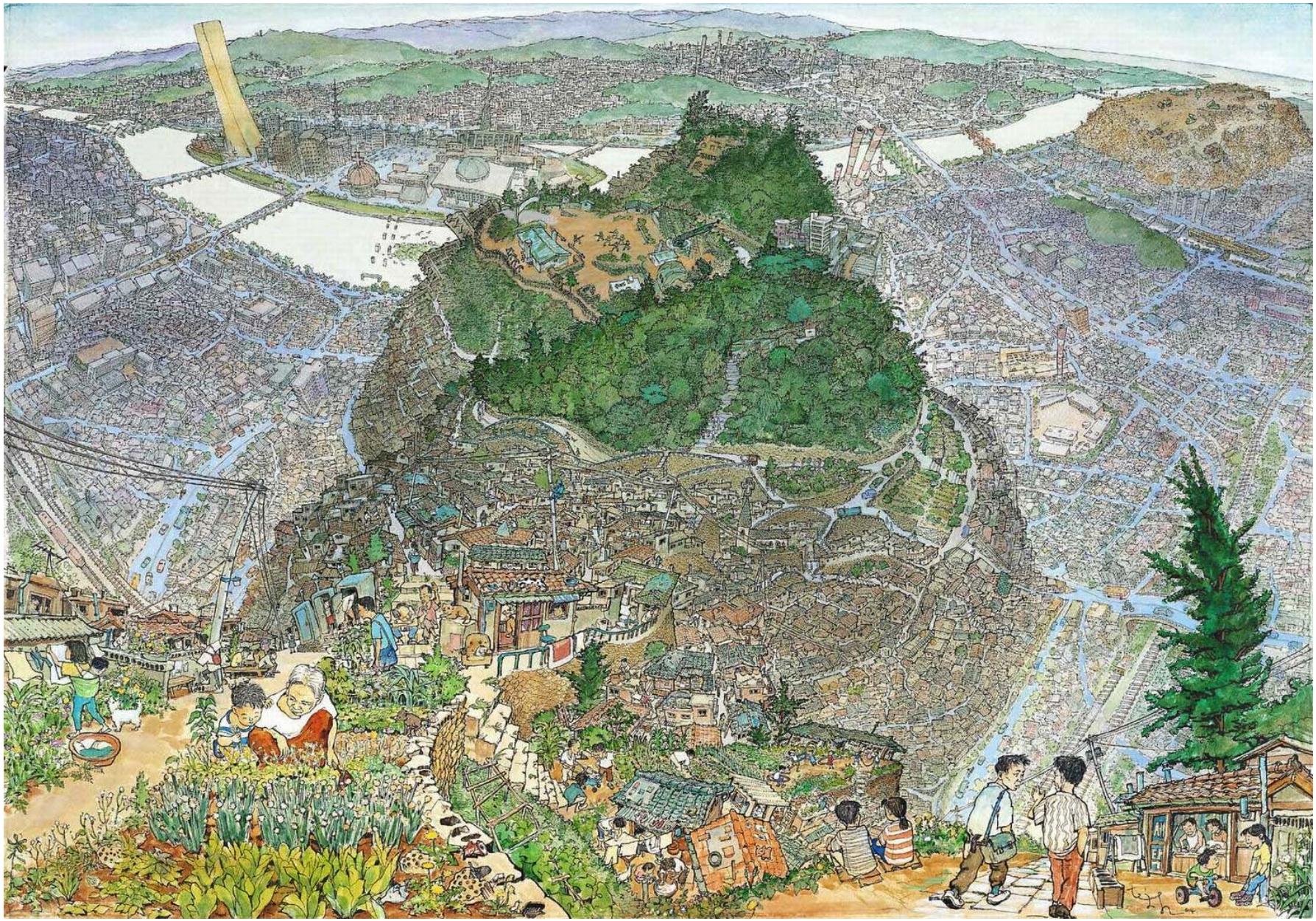
Research Objectives

In two distinct urban land cover (compact highrise residential area and **urban park**)

- Quantification of carbon uptake and surface energy balance

- Understanding of micrometeorological and urban re-development perspectives of green areas in Seoul

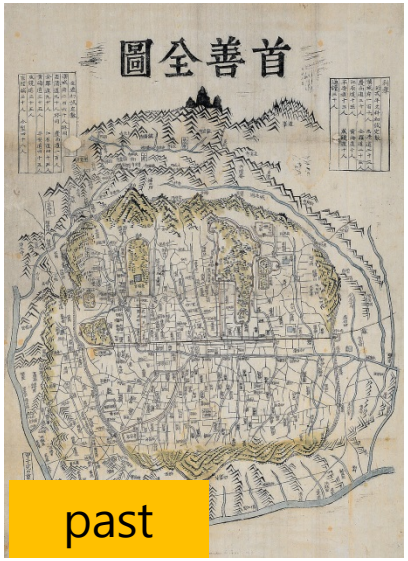
Seoul Metropolitan Area

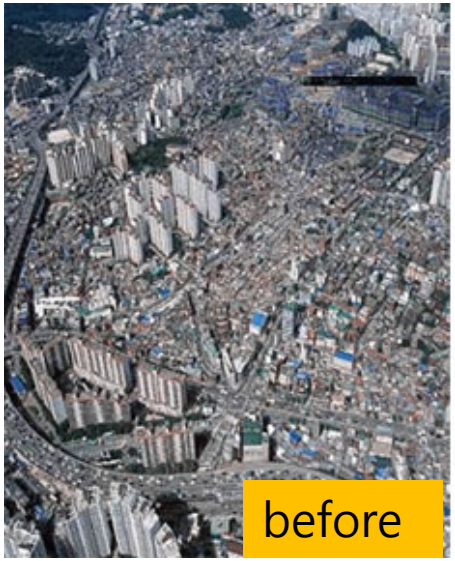


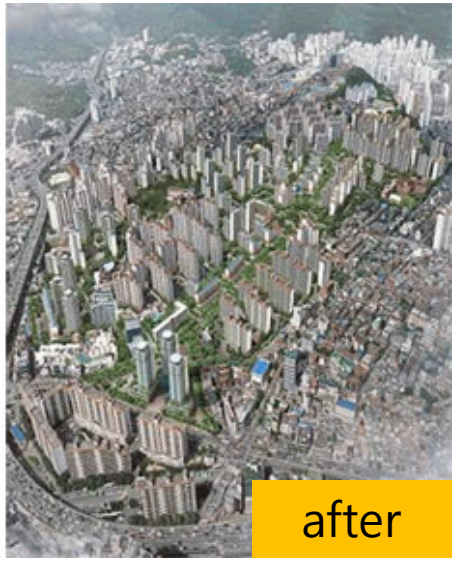
Mt. Wau by H.-C. Choi (1994)

Seoul Metropolitan Area

- Started in 1394 as the new capital of the *Choseon* Dynasty
- Population statistics
  - ✓ Seoul: 10 million in ~600 km^2 / 17,000 km^{-2}
  - ✓ Seoul metropolitan area : 25 million in ~1200 km^2 / 2100 km^{-2}
- Land use
  - ✓ Forest: 24% / River: 9% / Crop: 4%
  - ✓ Road: 13% / Urban Park: 3% (Natural park: 0.6%)
  - ✓ Roadside trees: 4.7 ha^{-1} (*ginko biloba* 40% / *Platanus occidentalis L.* 25%)
- Re-development stage: ~40% of buildings is older than 20 years





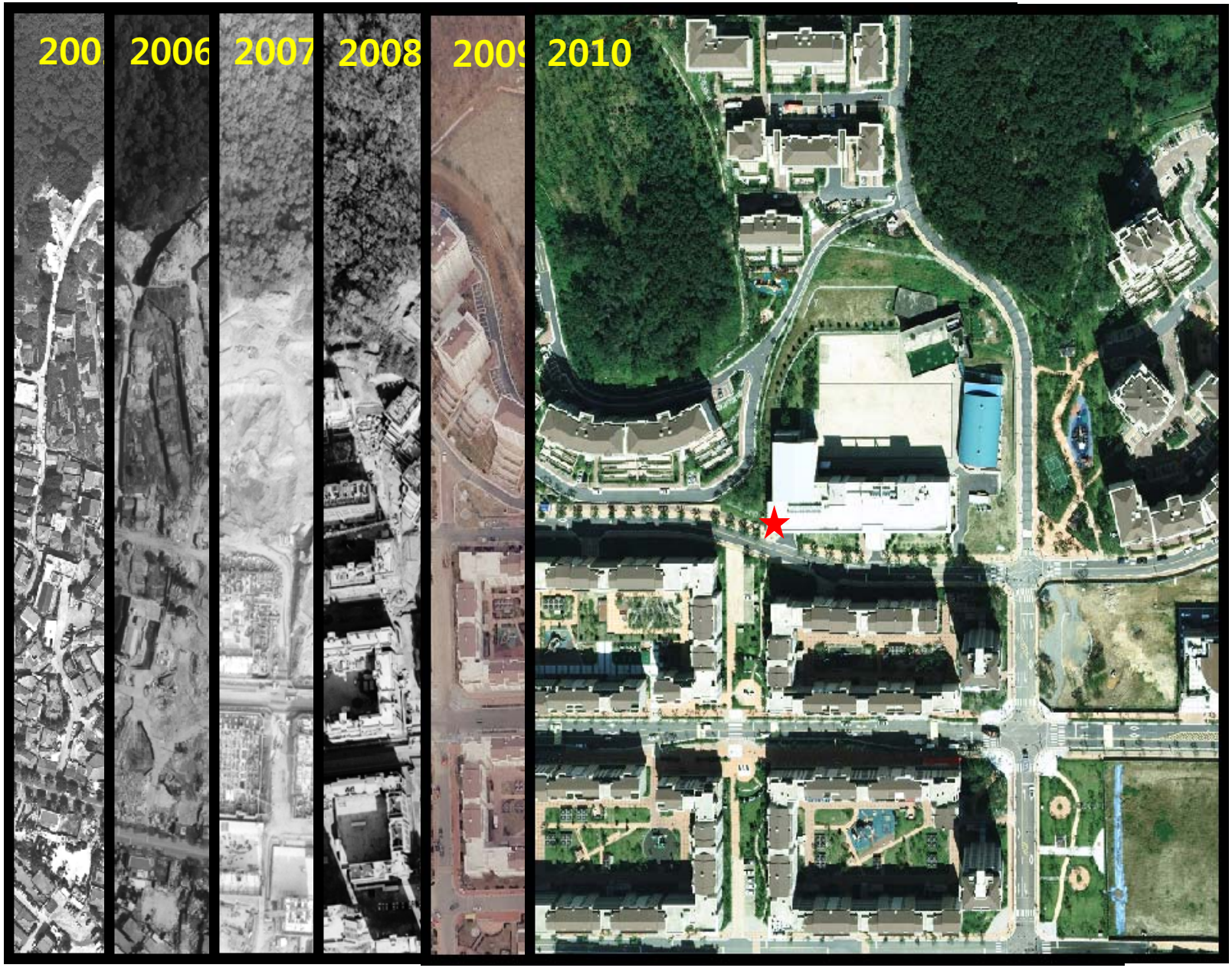


Site Description

Site Description

1. Compact Highrise Residential Area

- EunPyeong New-Town district (N 37.64˚, W 126.93˚), situated northern west part of Seoul metropolitan city
- Urban re-development since 2008
  - ✓ Compact high-rise apartment from low-rise apartment and bare soil
  - ✓ Roadside trees are transplanted cherry tree (*Prunus serrulata var. spontanea*).
  - ✓ Population increase from 3,646 (317 km^{-2}) in 2008 to 49,524 (4,299 km^{-2}) in 2012
  - ✓ About 30% vegetated surface (tree, turf grass)
  - ✓ 1500mm annual precipitation / 14°C annual mean temperature

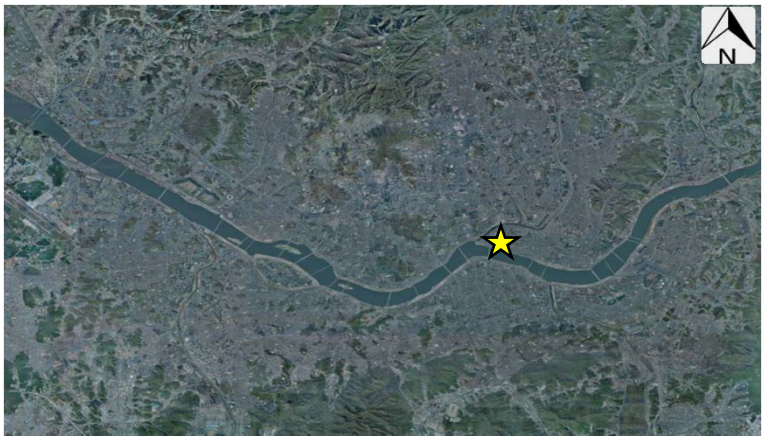


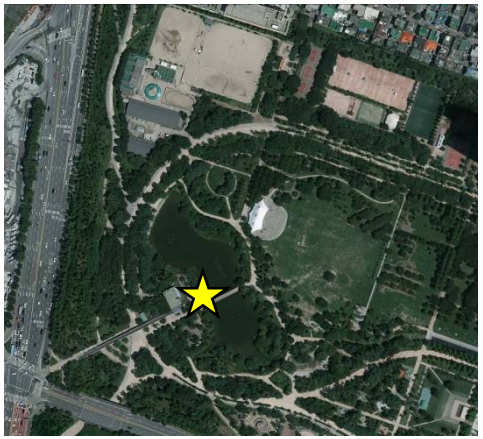
Aerial Photograph of EunPyeong Newtown (from Seoul metropolitan government)

Site Description

2. Urban Park

- Seoul Forest (N 37.54˚, W 127.04˚), situated central part of Seoul metropolitan city (Area ~ 1.2 km^{-2})
- Artificially Created Park in 2005
  - ✓ Urban park from golf course and racecourse
  - ✓ Human management (Regular irrigation / litterfall removal)
  - ✓ Mixed forest (pine, ginkgo, zelkova trees), pond, and turf grass
  - ✓ Canopy height is about 10m
  - ✓ Similar synoptic environment with the compact highrise residential area





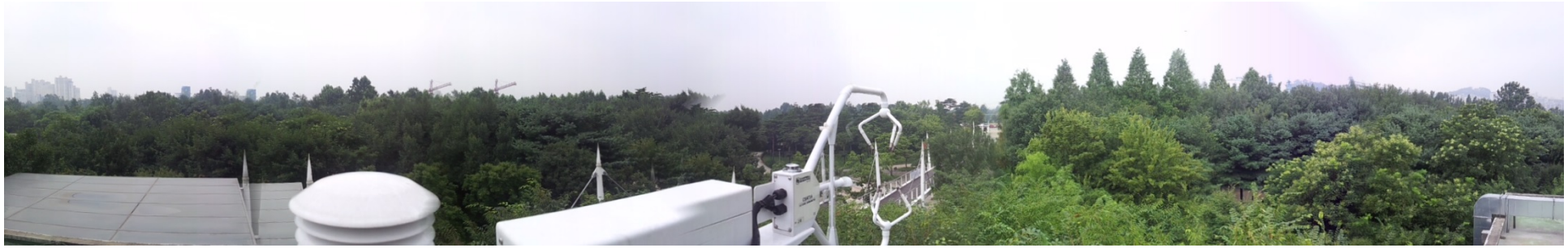
Micrometeorological Measurements

Compact Highrise Residential Area

- Eddy covariance measurement
  - Measurement since 2008
  - CPEC200 (Campbellsci)
  - CNR1 (Kipp&Zonnen)
  - Automatic weather station
- Footprint Analysis
  - Schmid(1999) / Hsieh et al. (2000)
- Building morphology
  - Airborne lidar building information
  - Mean horizontal building fraction: ~ 0.35
  - Mean building height: 20 m
  - roughness length: 1.7 m
  - zero-plane displacement height: 12 m
  - Skyview factor: 0.5

Urban Park

- Eddy covariance measurement
  - Measurement since 2013
  - CPEC200 (Campbellsci)
  - NR Lite2 (Kipp&Zonnen)
  - Automatic weather station
  - Soil temperature/moisture probes
- Footprint Analysis
  - Schmid(1999) / Hsieh et al. (2000)
- Vegetation canopy
  - Mixed forest (pine, ginkgo, zelkova trees)
  - Canopy height : ~10m

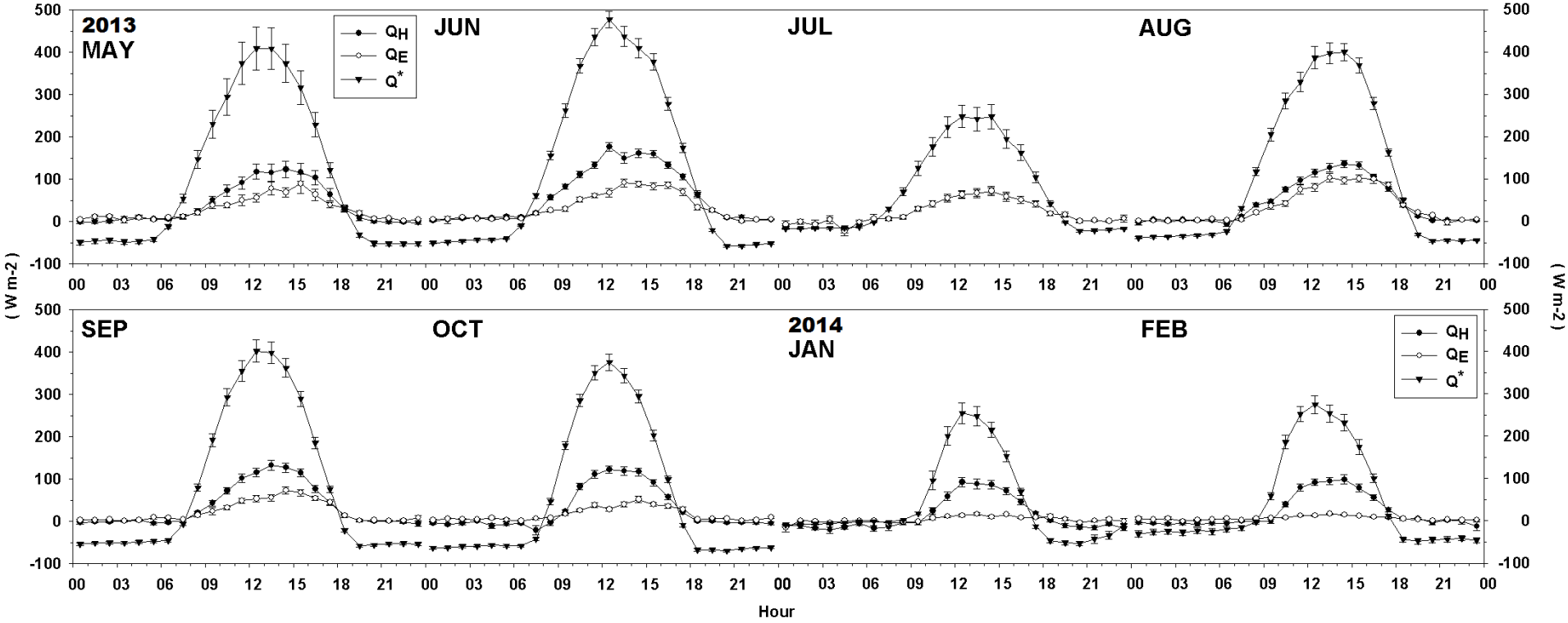


Results

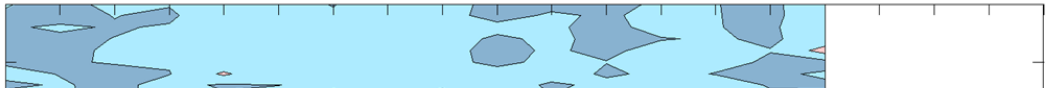
Compact Highrise Residental Area

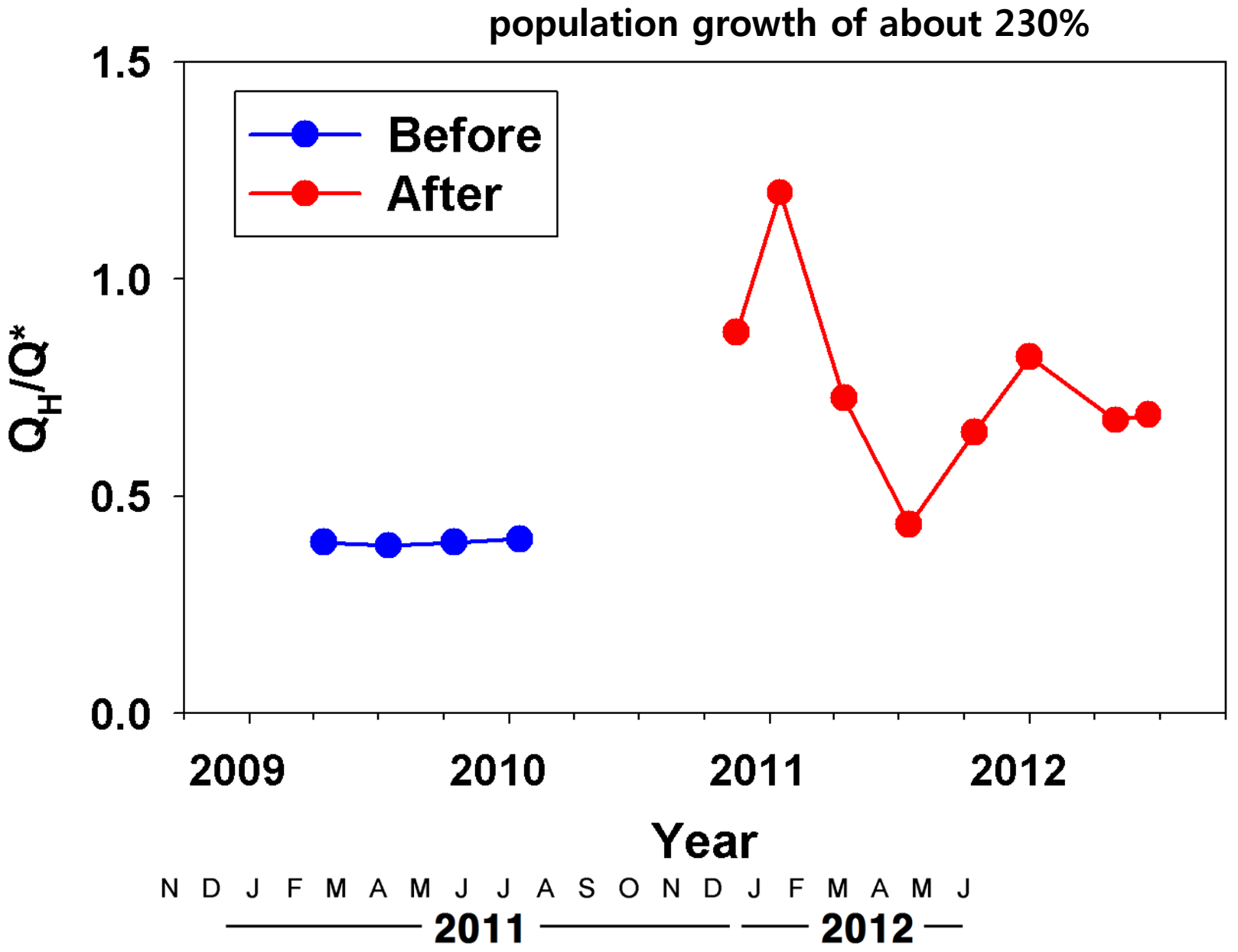
(Extensive Apartment Complex)

Surface Energy Fluxes



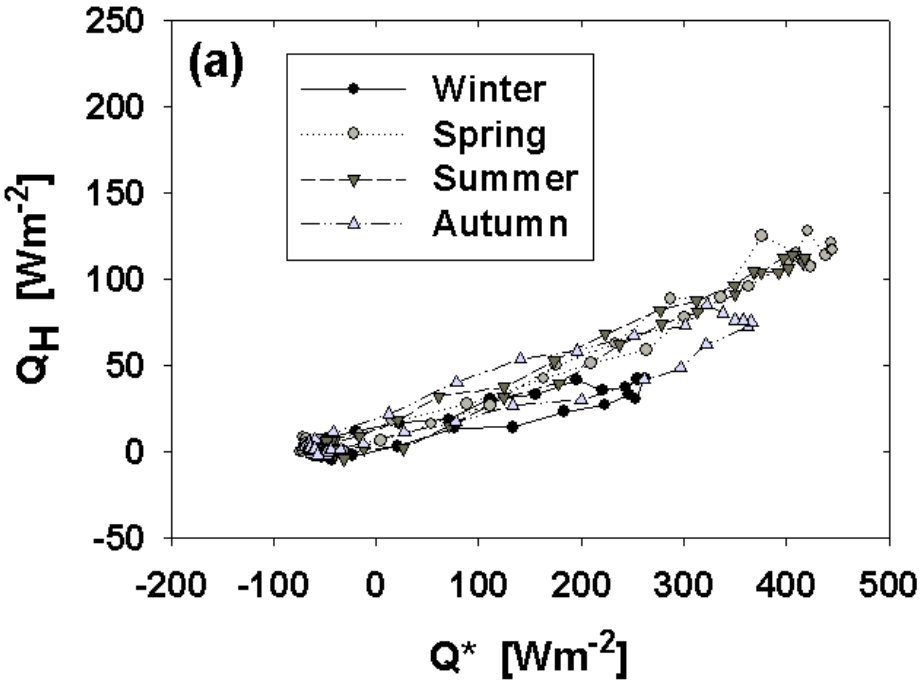
- ✓ Bowen ratio (Q_H/Q_E) : 1.7 (total), 5.7 (winter), 0.9 (Jul)
  : Sources of LE are roadside trees, turf, and soil.
- ✓ Time-lag between the peak of Q_H,Q_E ↑ and Q^* ↓
  : the role of heat storage (ΔQ_S) by urban structure.



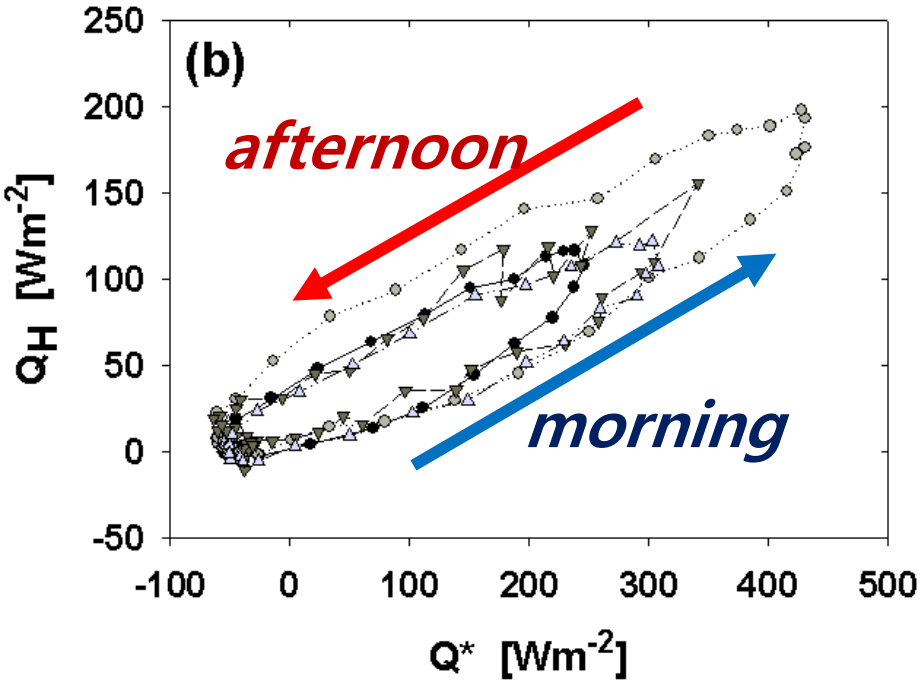

population growth of about 230%
Before
After
Q_H/Q^*
1.5
1.0
0.5
0.0
2009
2010
2011
2012
Year
N D J F M A M J J A S O N D J F M A M J
2011
2012

Heat Storage: Hysteresis of sensible heat fluxes

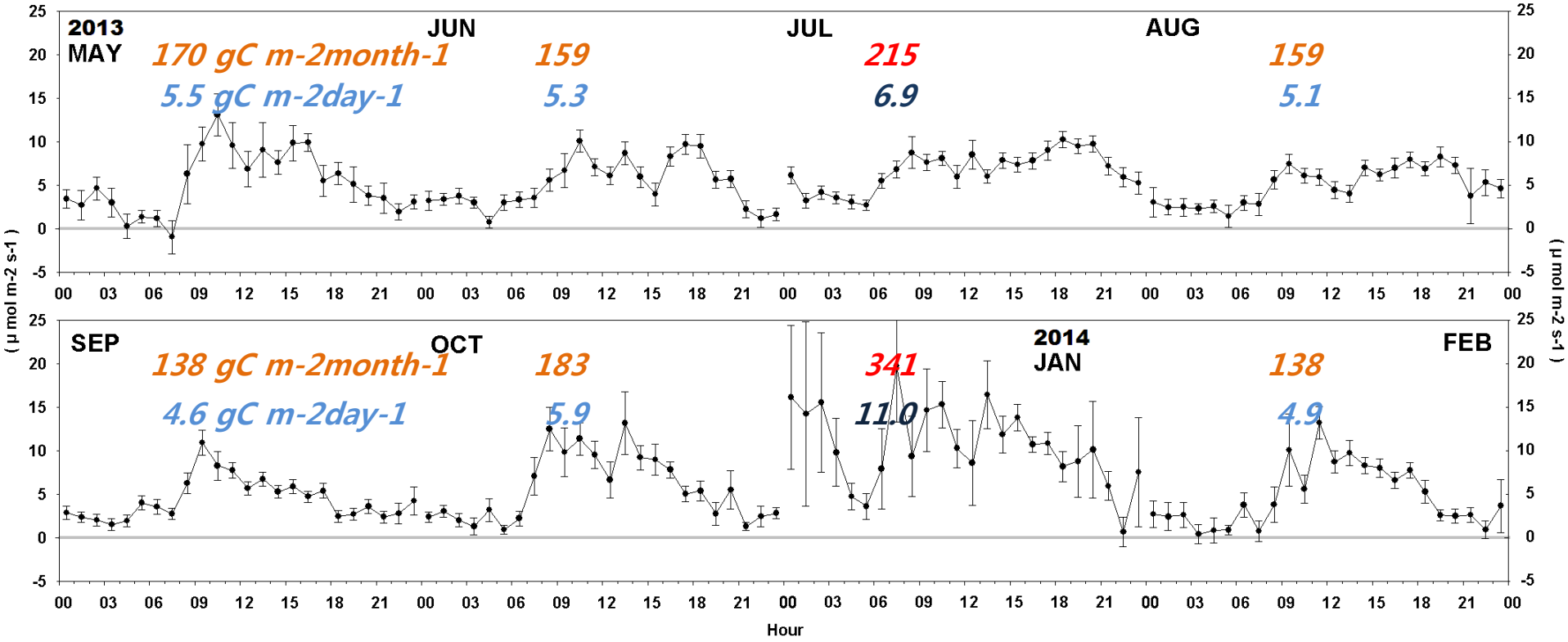
Before re-development



After re-development



- CO_2 Flux

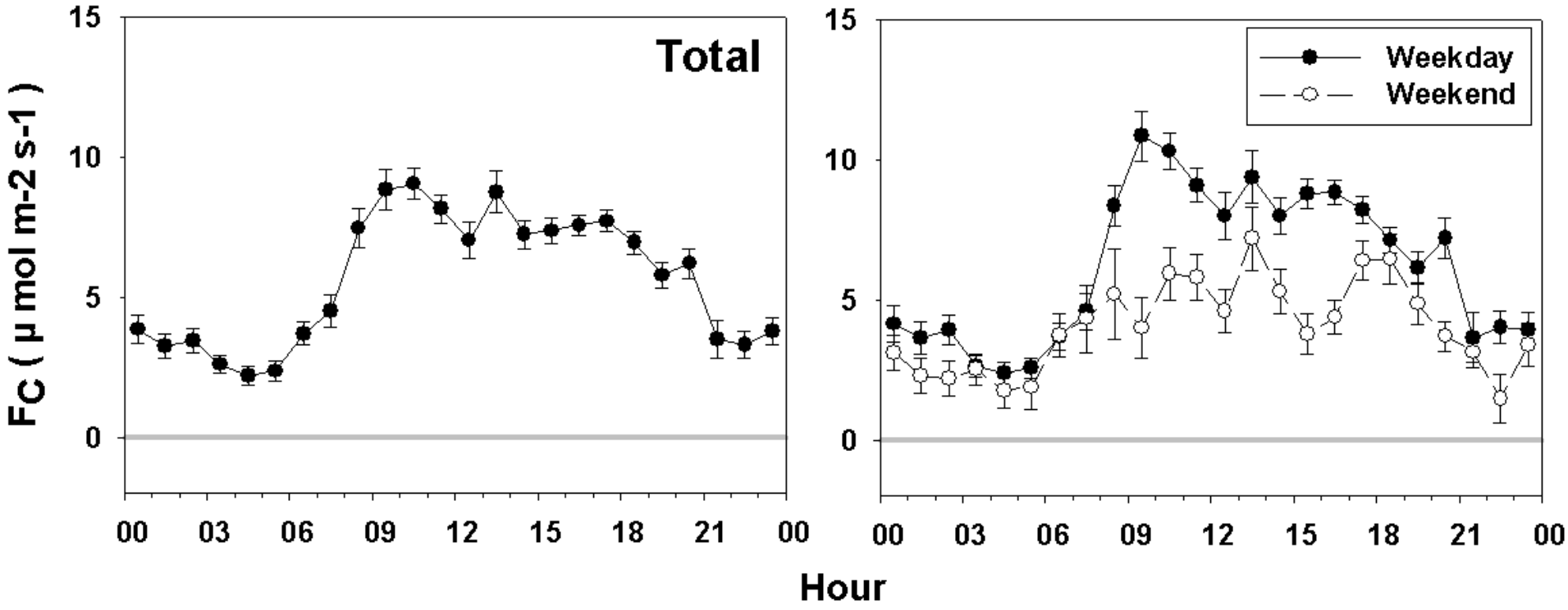


✓ Fc : **4.6 ~ 11.0** *gC m^{-2}day^{-1}* (**138 ~ 341** *gC m^{-2}month^{-1}*)

✓ Main sources of Fc : traffic, local heating (winter)
vegetation effects (Jul)

- CO_2 Flux

  - ✓ **Weekday :** 6.5 *gC day^{-1}*
  - ✓ **Weekend :** 4.2 *gC day^{-1}*
  - ✓ **Mean :** 5.8 *gC day^{-1}*

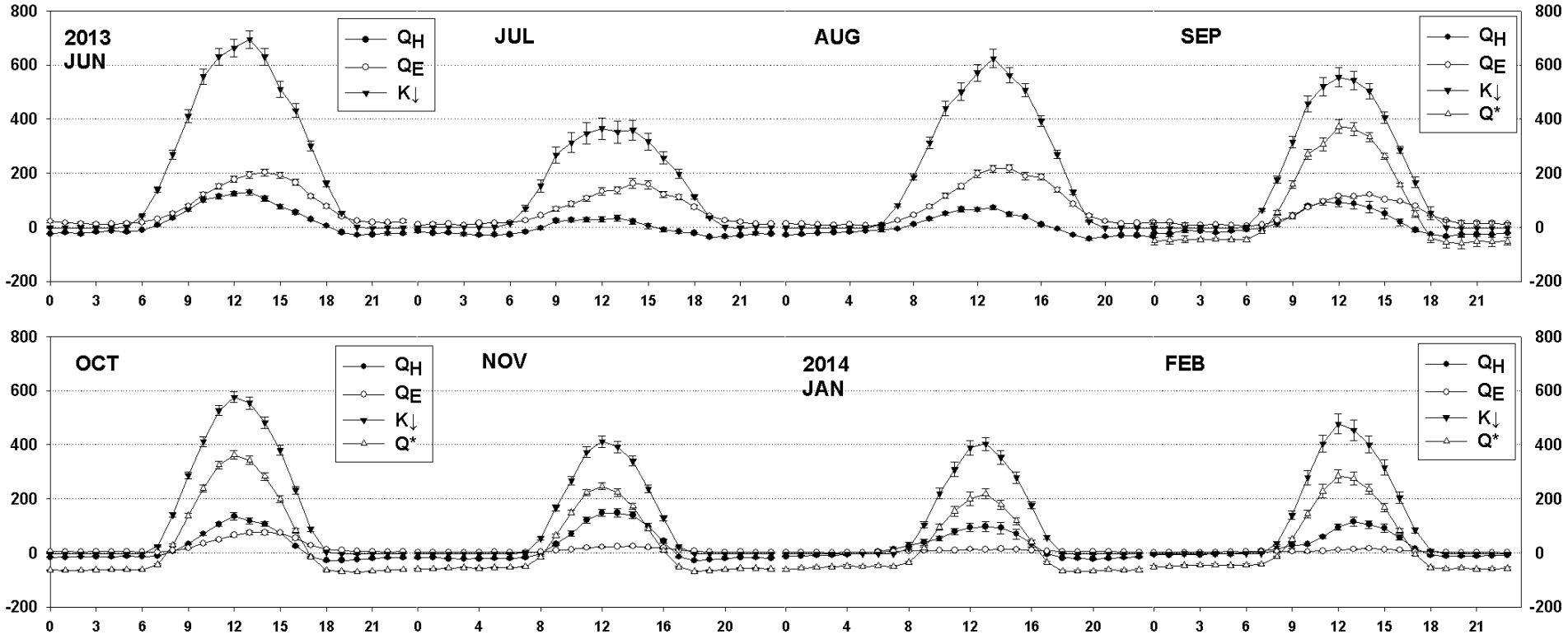


Results

Seoul Forest

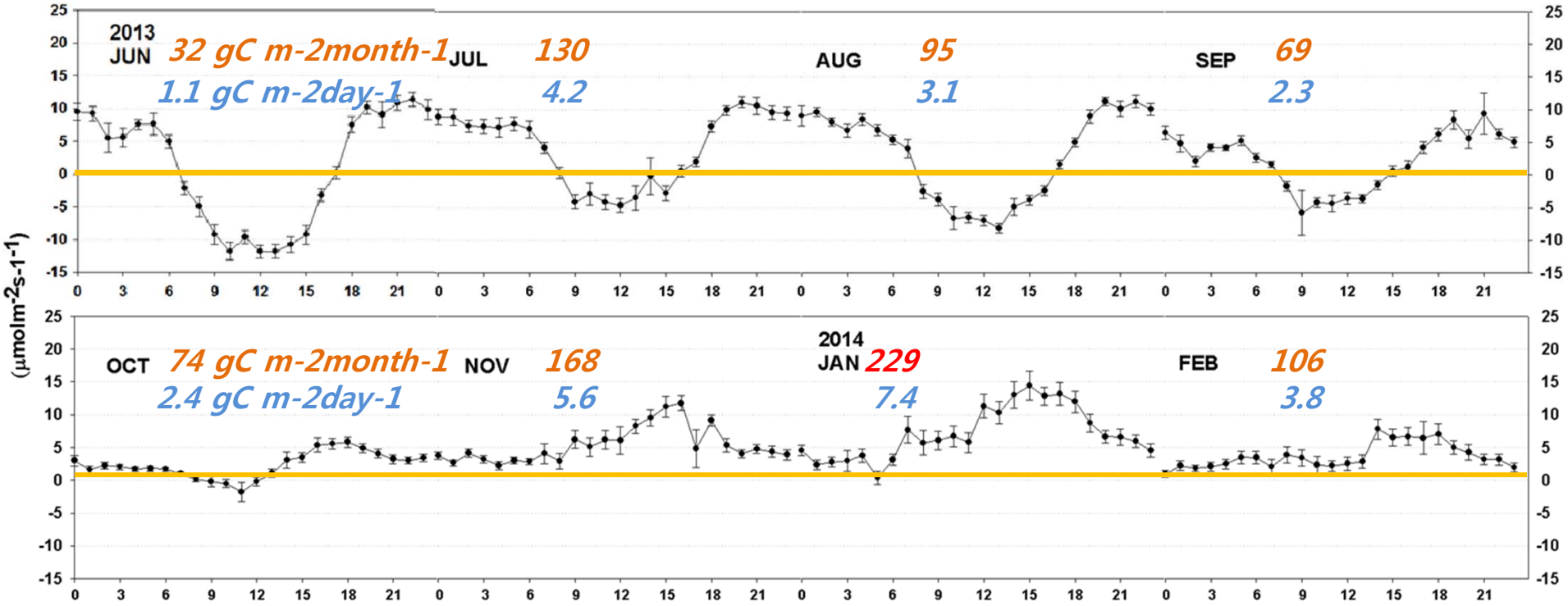
(Artificially Created Park)

Surface Energy Fluxes



- ✓ Bowen ratio (Q_H/Q_E) : 0.8 (total), 6.3 (winter), 0.4 (Jul)
- ✓ Latent heat flux is dominant except winter.

CO_2 Flux

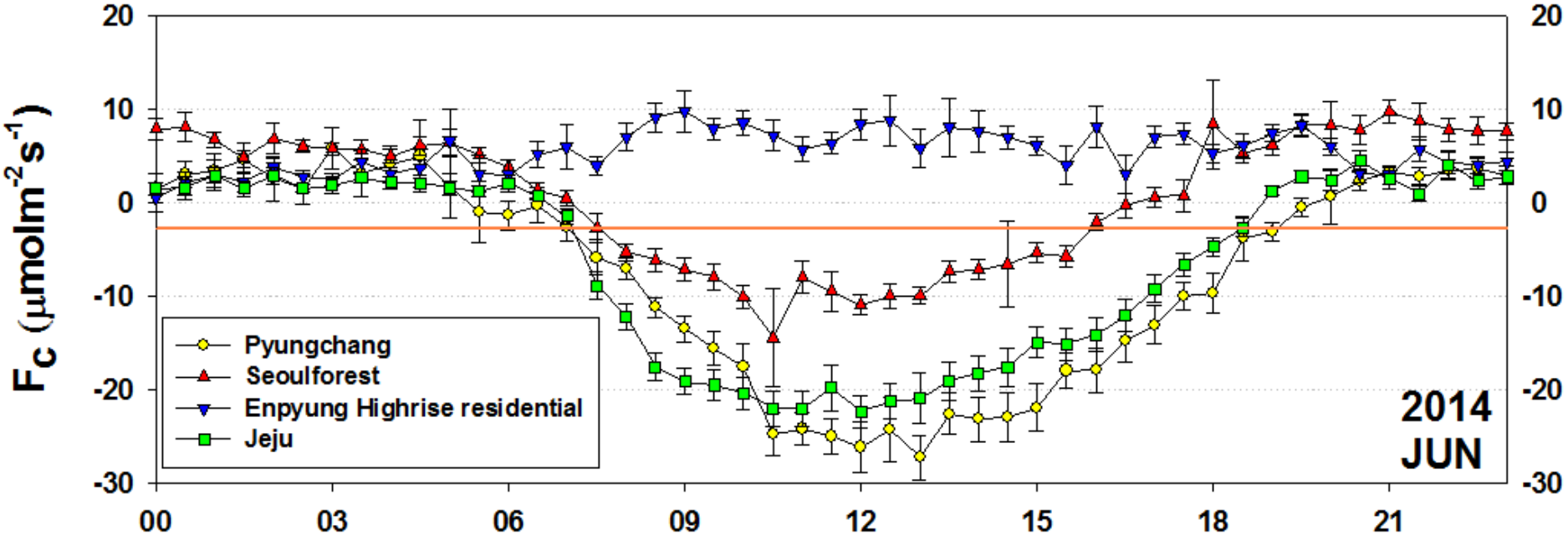


- **Fc : 1.1 ~ 7.4 *gC m^{-2}day^{-1}* (32 ~ 229 *gC m^{-2}month^{-1}*)**
- **Clear diurnal and seasonal variations**

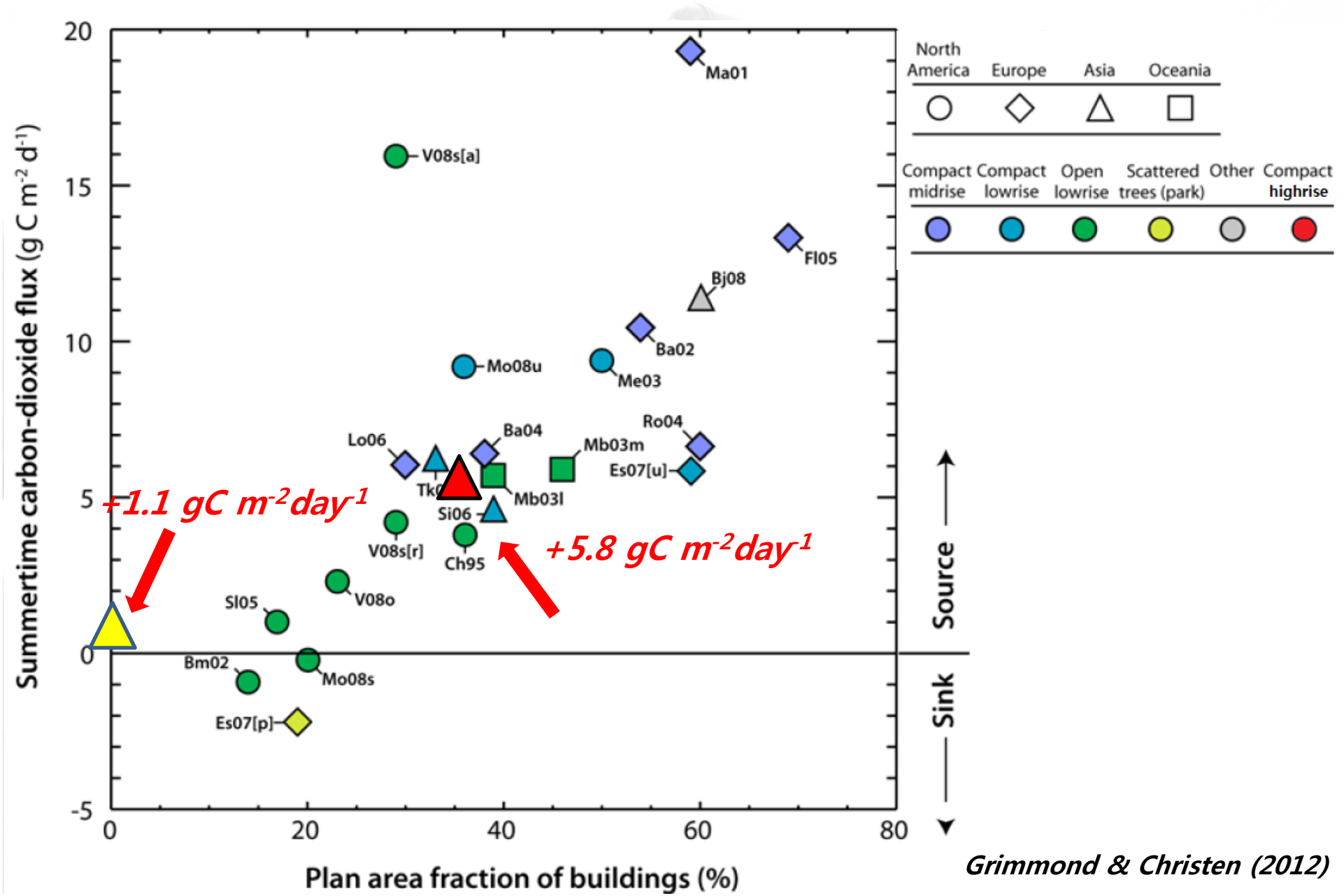
* During the same period @ Eunpyeong Newtown
: 4.6 ~ 11.0 gC m^{-2}day^{-1} (138 ~ 341 gC m^{-2}month^{-1})

Diurnal Variation of CO_2 Flux

- ✓ **Comparison of CO_2 Flux with Natural forest stations exposed to the similar climate in Korea**



Summer-time CO_2 Flux



Grimmond & Christen (2012)

Summary (1)

- Turbulent fluxes are first measured at recently re-developed compact highrise urban area in Seoul .
  - ✓ **Carbon source** of 138 ~ 341 *gC* m^{-2}*month*$^{-1}$ (1.3 *tC* ha^{-1} yr^{-1})
  - ✓ CO_2 emission shows **clear diurnal variations** following traffic volume but its **seasonal change is weak** **(heating in winter)**.
  - ✓ It is a **relatively weak carbon source** considering **high population density and traffic volume**.
  - ✓ Bowen ratio is larger than 1 except the monsoon seasons. shows significant seasonal variations despite significant portion of **impervious surface.**
  - ✓ Daytime QE and increased FC in July consistently attract attention to **the role of urban vegetation.**
  - ✓ **Heat storage** and **anthropogenic** heat emission become significant after the re-development with **the footprint of the Asian monsoon**.

Summary (2)

- Turbulent fluxes is measured at urban park in Seoul and unique features are observed.
  - ✓ **Carbon source** of 32 ~ 229 *gC* m^{-2}*month*$^{-1}$ (21 *tC* ha^{-1} yr^{-1})
  - ✓ CO_2 uptake shows **strong diurnal and seasonal variations** (maximum carbon uptake in summer).
  - ✓ Even summer growing season, **daily Net Ecosystem Exchange is positive** despite of human management such as irrigation and litterfall removal.
  - ✓ **Ecosystem respiration is pretty large** compared to natural forest around Seoul.
  - ✓ **Similar to natural forest, Latent heat flux** is bigger than **sensible heat flux** from Jun to Sep, but **Latent heat flux** is almost 0 during winter season.

Thank you for your attention

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