Multi-year energy balance and carbon dioxide fluxes over a residential neighborhood in a tropical city

Matthias Roth[(1)], Christer Jansson[(2)] and Erik Velasco[(3)]

[(1)] Department of Geography, National University of Singapore, Singapore
[(2)] Swedish Meteorological and Hydrological Institute, Norrköping, Sweden
[(3)] Singapore-MIT Alliance for Research and Technology, Singapore

Research context

- Vast majority of past energy balance and carbon flux work has been carried out outside the (sub)tropics

- Only very few studies are available from low latitudes: Miami (Newton *et al* 2007), Ouagadougou (Offerle *et al* 2005), Mexico City (Oke *et al* 1992 and 1999 and Velasco *et al* 2011), Singapore (Velasco *et a*l 2013); of these cities only Singapore has truly tropical climate with extended wet season

- Understanding of energy and mass exchange in an important region of the world is therefore extremely poor

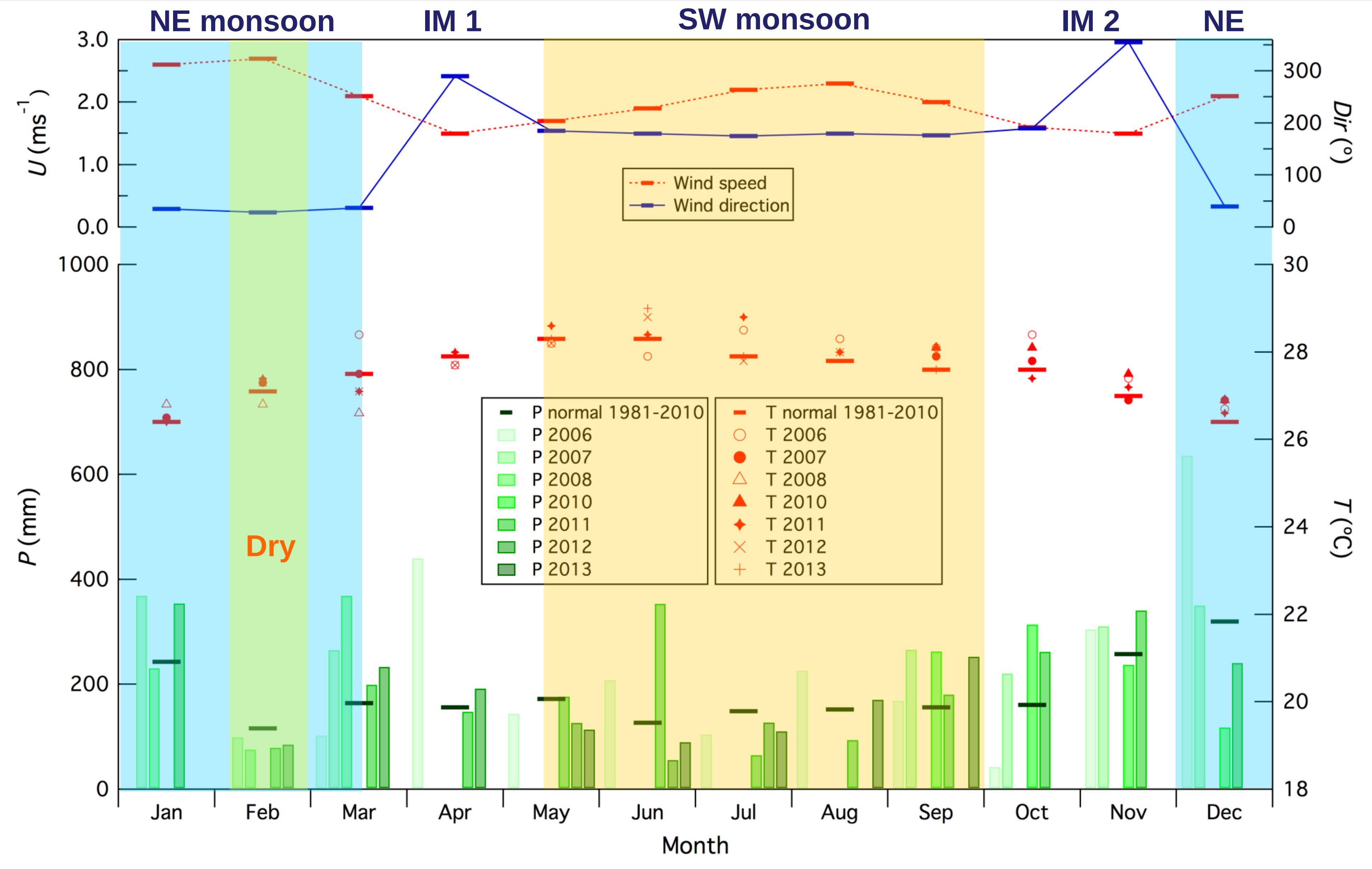
- Goal of present study is to quantify the energy balance and CO_2 fluxes for a residential neighborhood in a modern city located in a tropical-wet climate

- Focus on temporal variability (diurnal, seasonal and inter-annual)

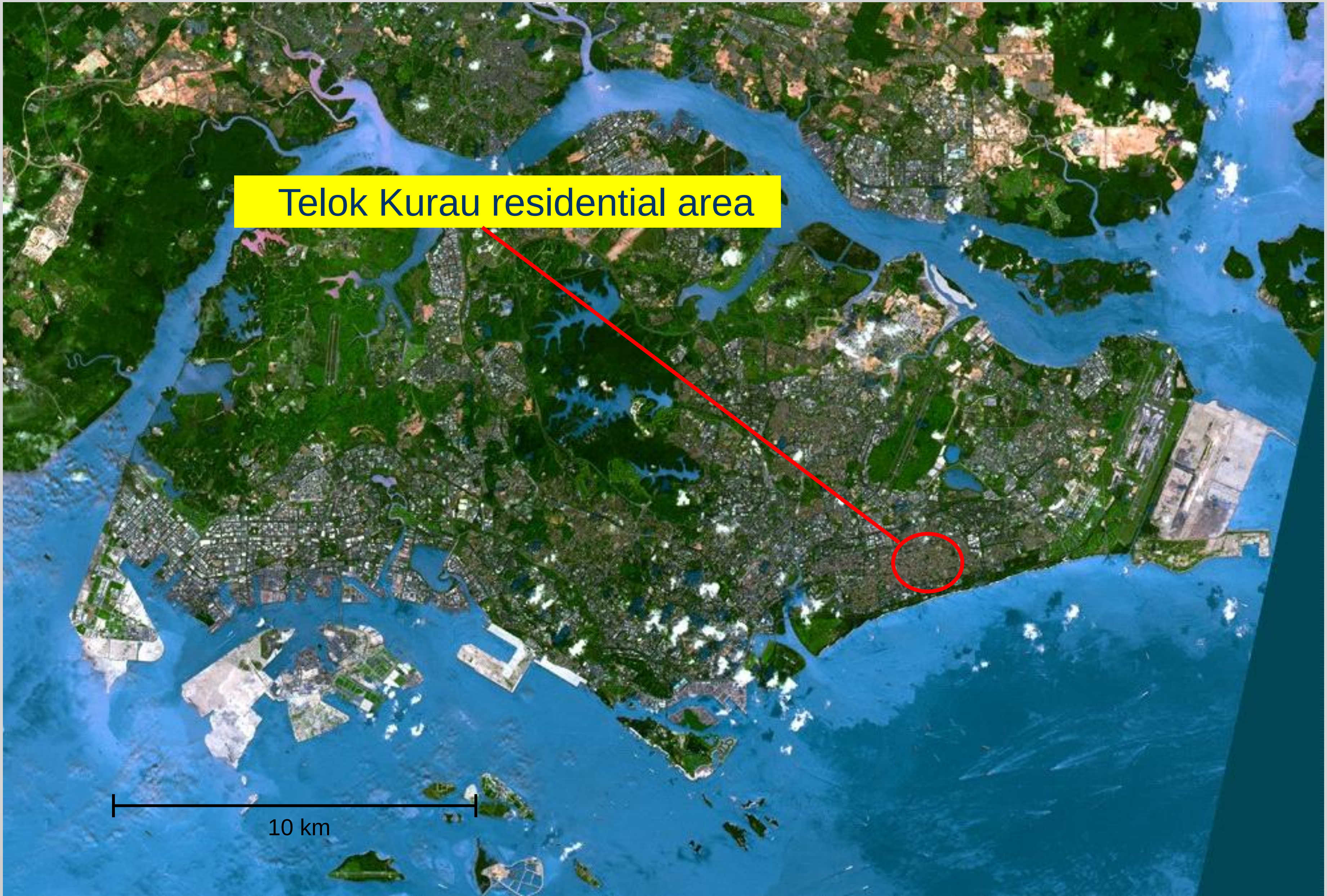
- Attempt to understand controls on the surface energy and mass exchange and elucidate differences (if any) to those from temperate cities

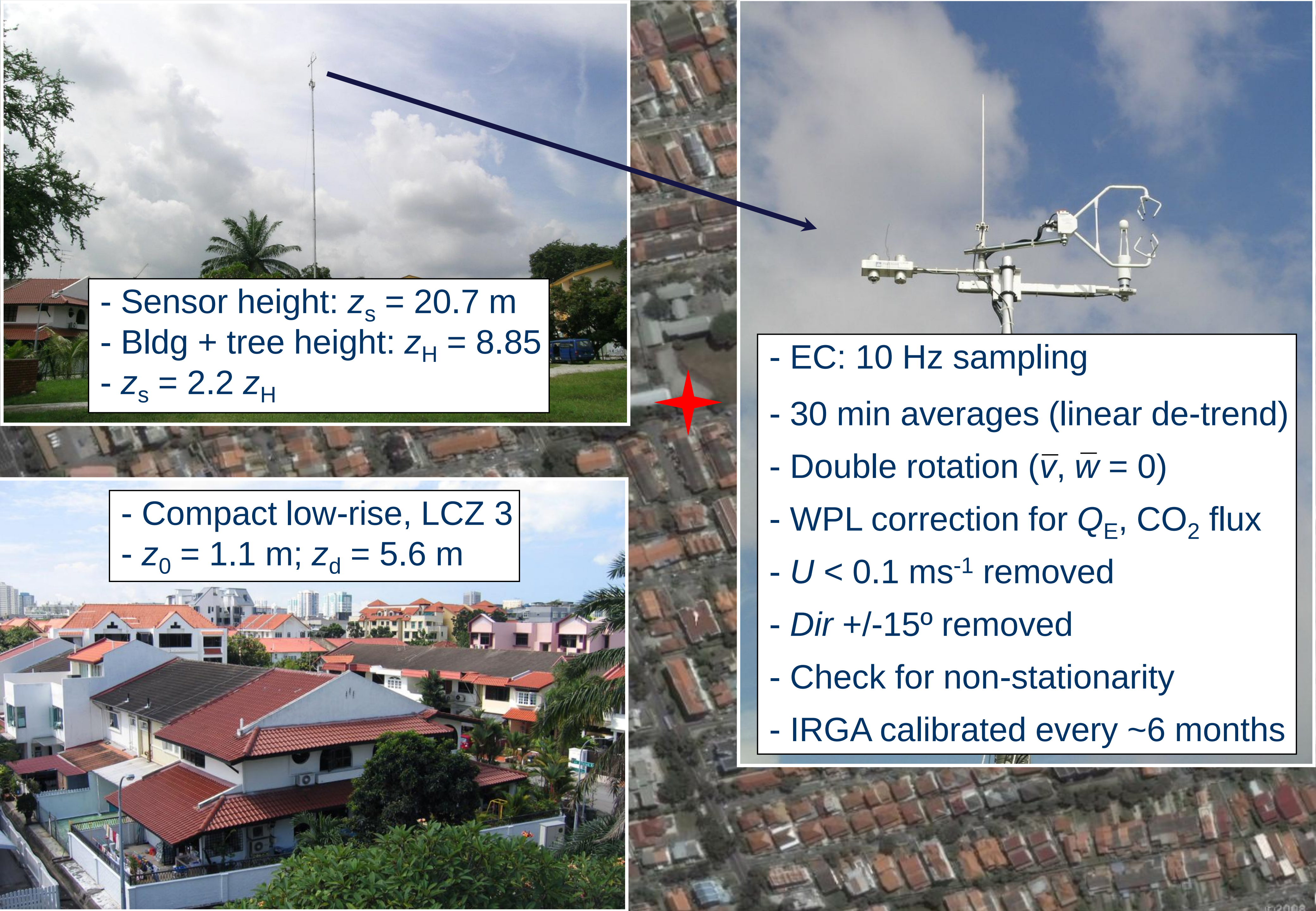
Geographical setting of Singapore

Mean monthly long-term climate normals

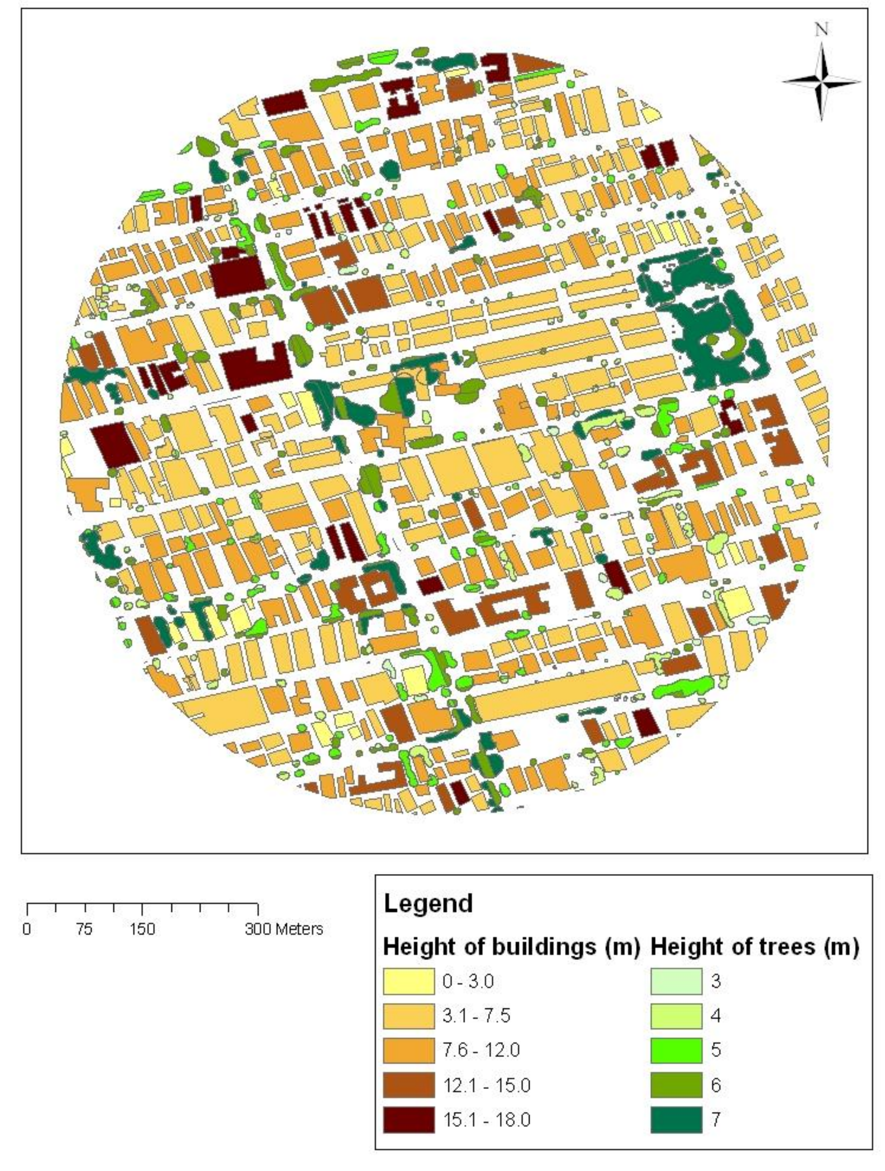


Location of EC measurement site

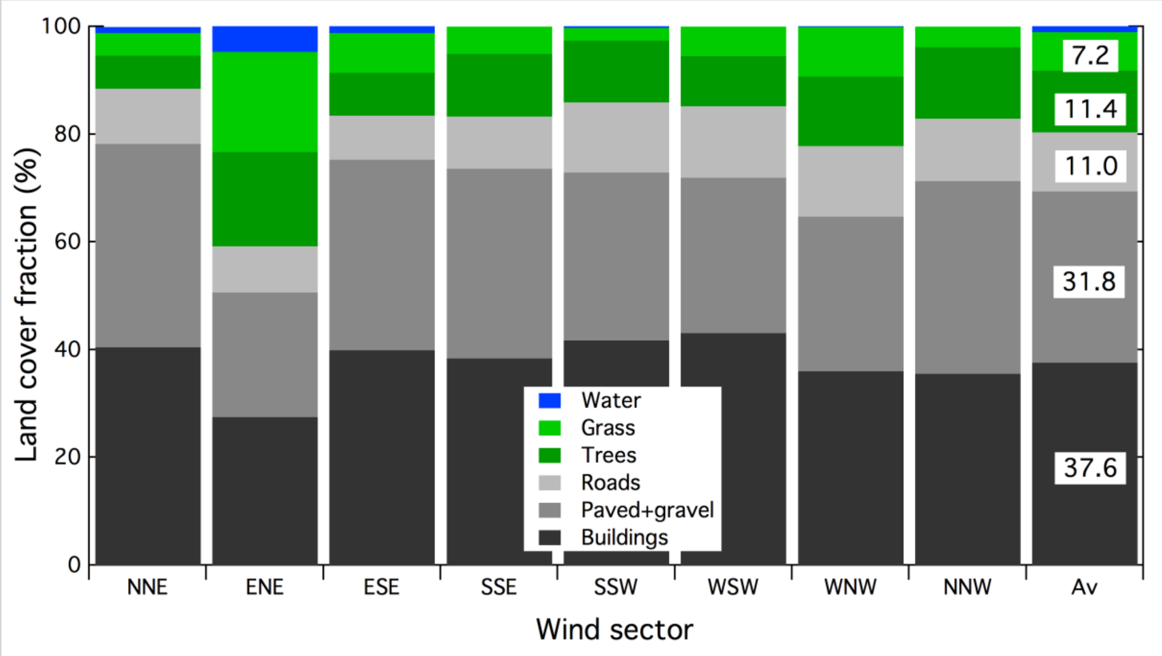



- Sensor height: z_s = 20.7 m
- Bldg + tree height: z_H = 8.85
- $z_s = 2.2\ z_H$
- EC: 10 Hz sampling
- 30 min averages (linear de-trend)
- Double rotation ($\bar{v}$, $\bar{w}$ = 0)
- WPL correction for Q_E, CO_2 flux
- U < 0.1 ms^{-1} removed
- *Dir* +/-15^o removed
- Check for non-stationarity
- IRGA calibrated every ~6 months
- Compact low-rise, LCZ 3
- z_0 = 1.1 m; z_d = 5.6 m

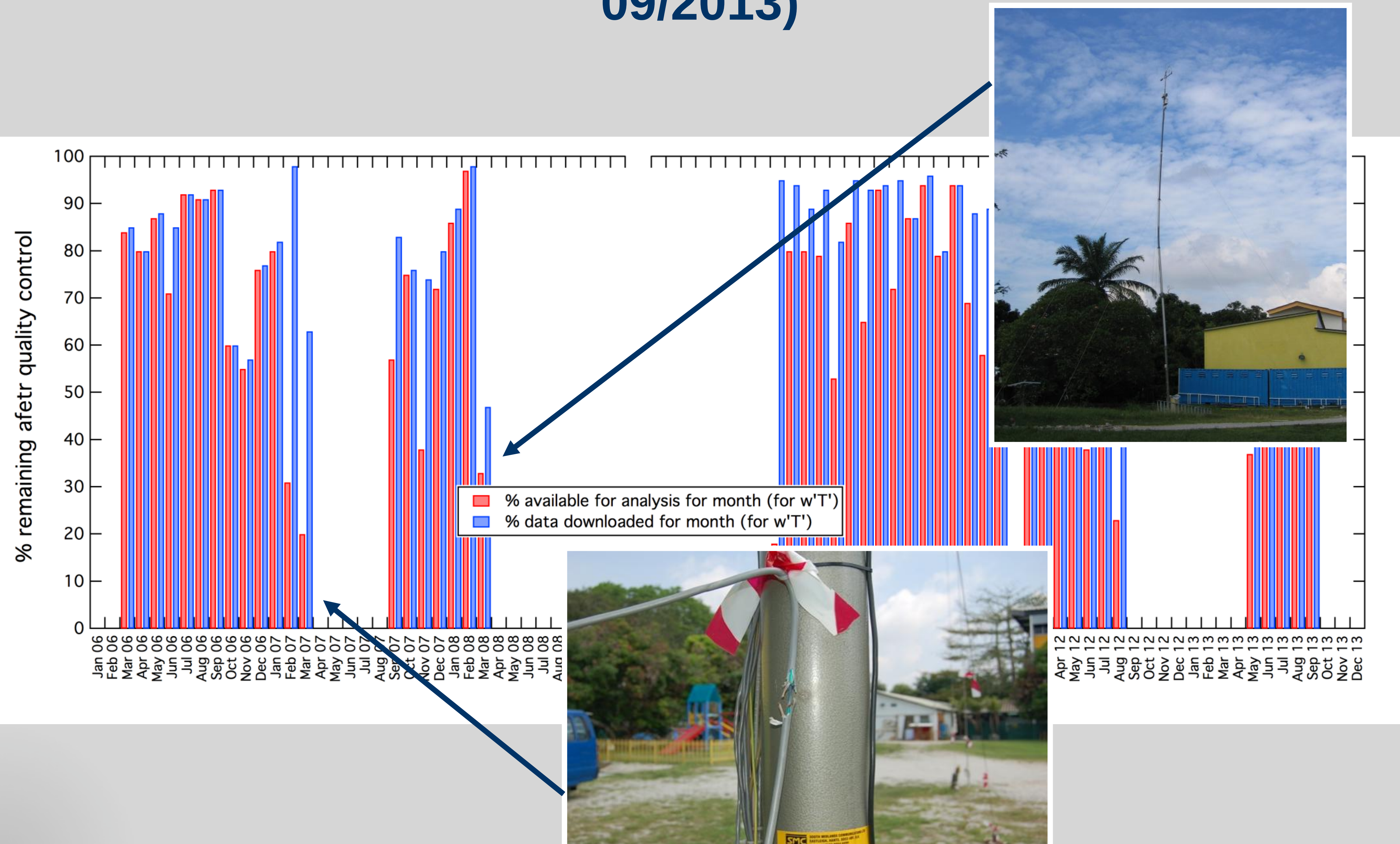
Site characteristics



Uniform land cover in all directions:

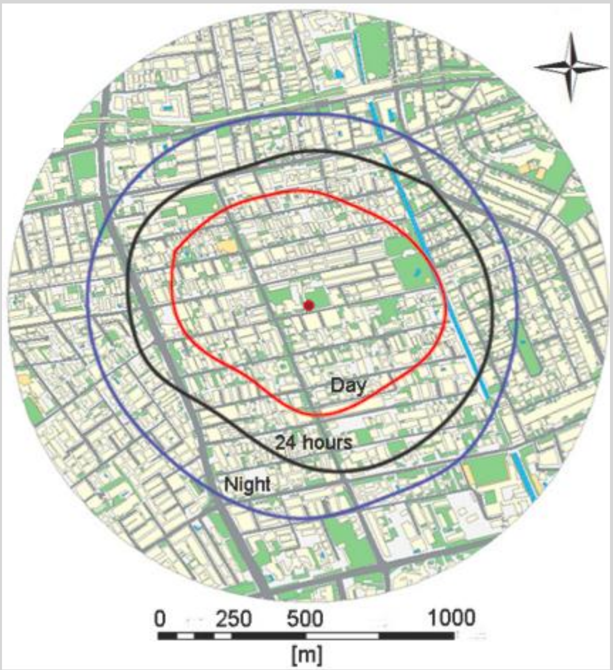


Data availability during measurement period (03/2006-09/2013)



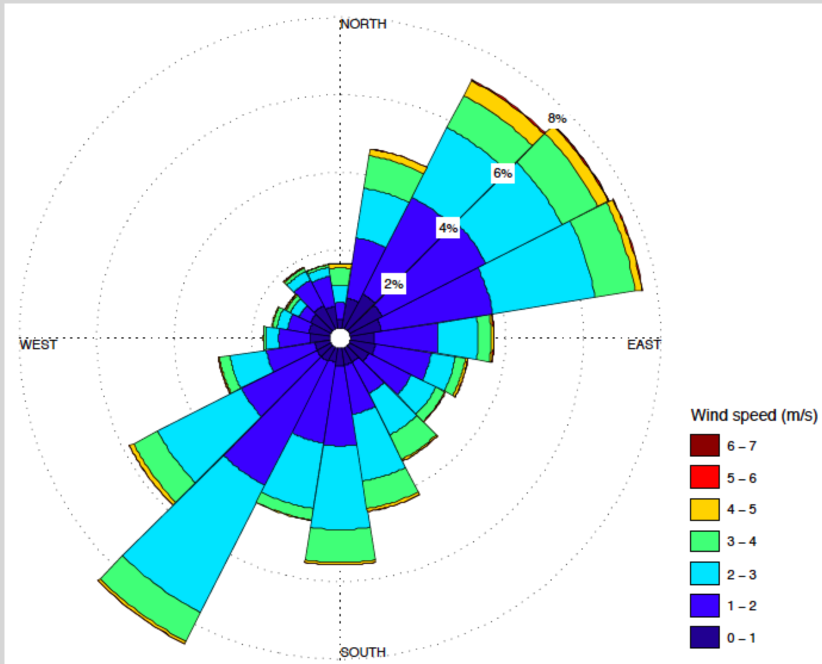
Measurement characteristics

80% footprint* <1000 m:



Velasco *et al* (2013)

Wind regime and
# of 30-min periods:



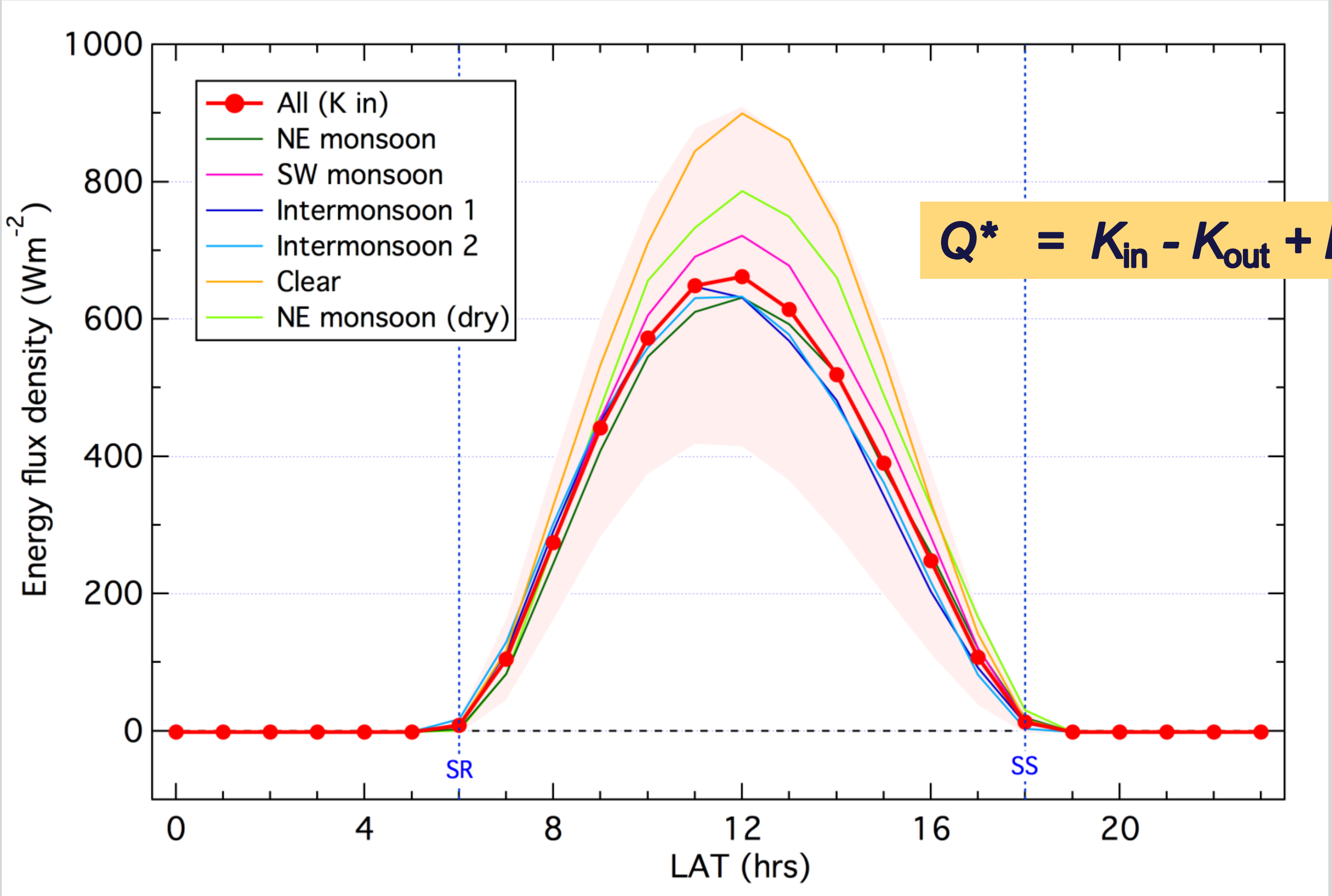
Stable (*z'/L* > 0.1): 9%
Neutral (-0.1 < *z'/L* <0.1): 62%
Unstable (*z'/L* < -0.1): 29%

NE: ~16,400
SW: ~18,300
NE (dry): ~3,800

IM1: ~12,300
IM2: ~13,500
Clear: ~2,500

* Calculated using analytical model by Hsieh *et al* 2000 (*Adv Water Res*)

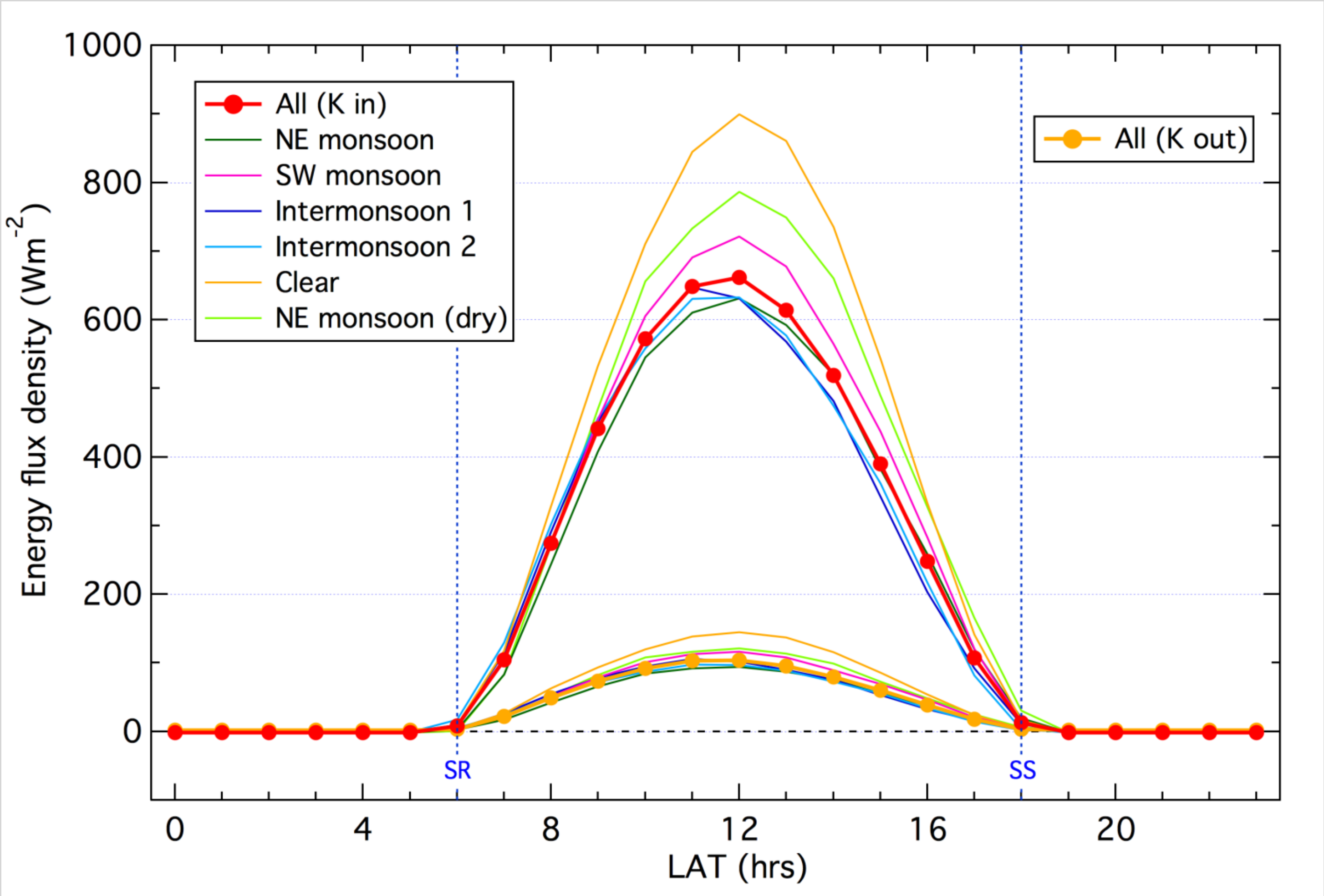
Ensemble diurnal radiation balance



$$Q^* = K_{in} - K_{out} + L_{in} - L_{out}$$

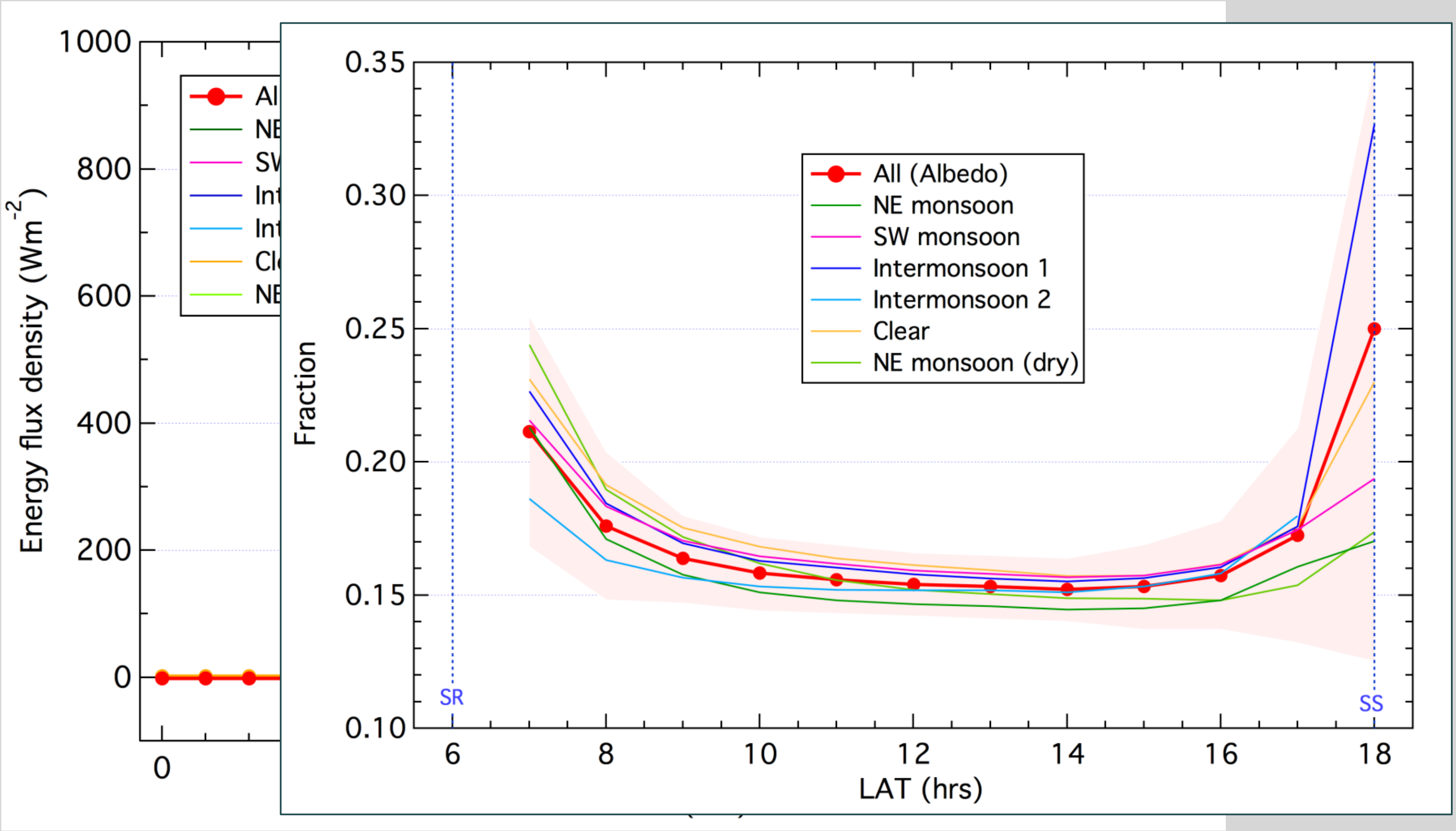
- Little seasonal variability; NE monsoon (cloudy) and IM (≠ Eqx) values are lowest
- K_{in} values during clear conditions >1000 W m^{-2}

Ensemble diurnal radiation balance



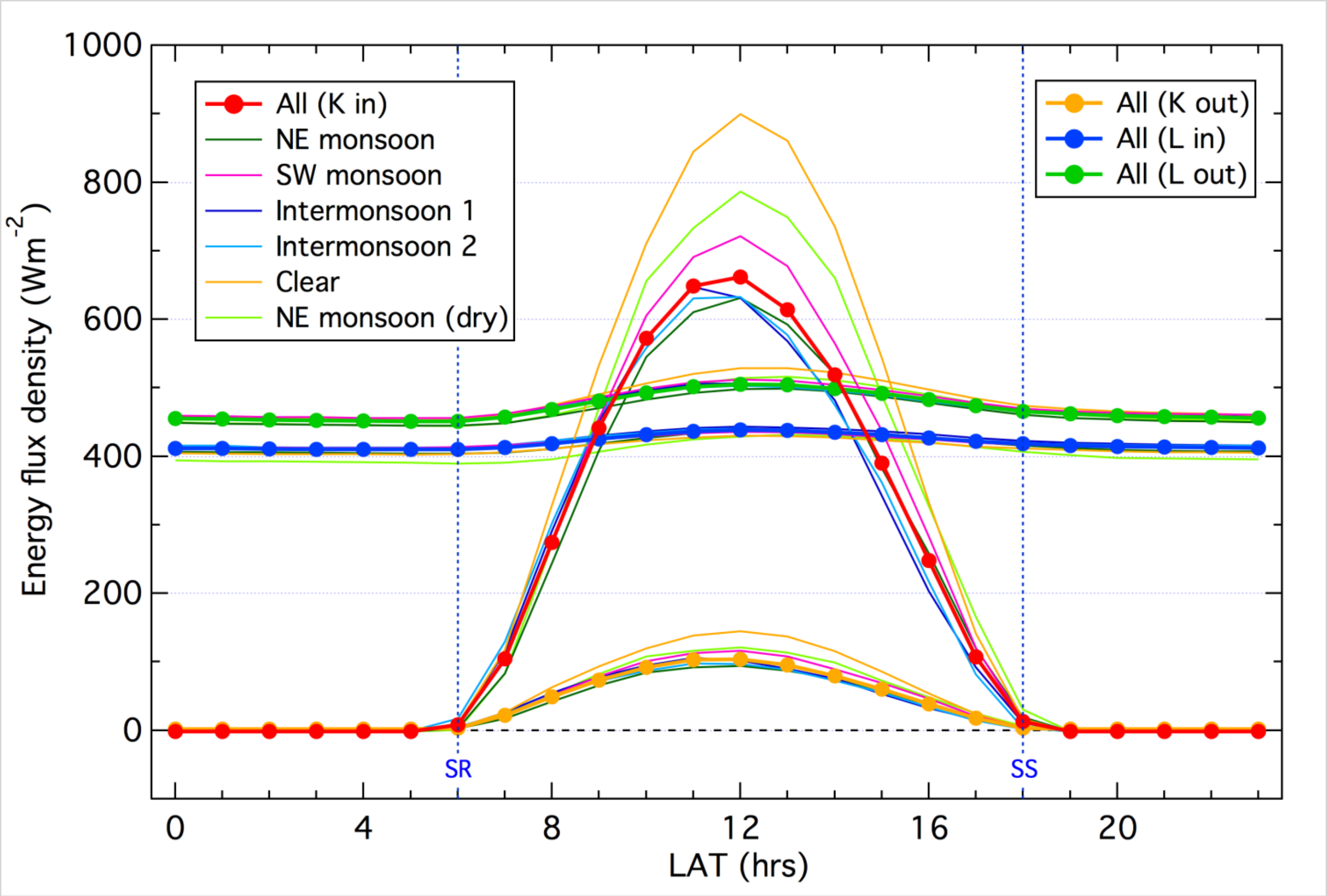
- K_{out} mirrors K_{in} as expected

Ensemble diurnal radiation balance



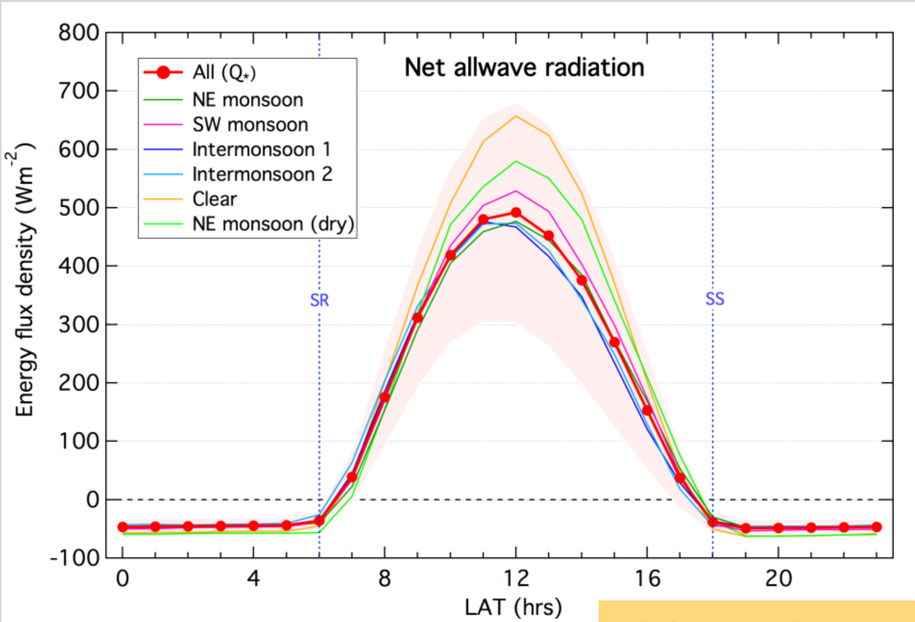
- Average albedo: 0.16
- Lowest during the NE monsoon season (wet); strong diurnal variability for “dry”

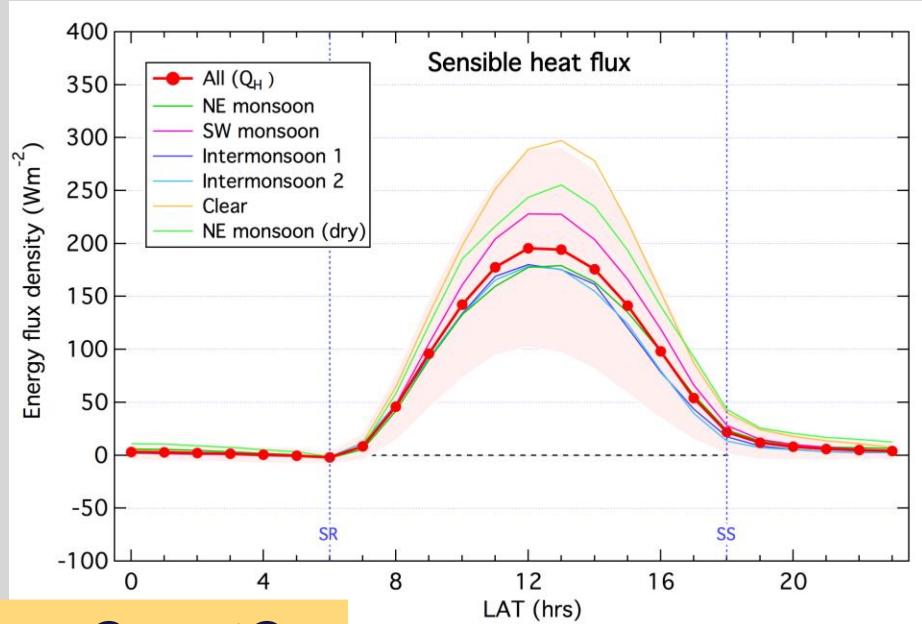
Ensemble diurnal radiation balance



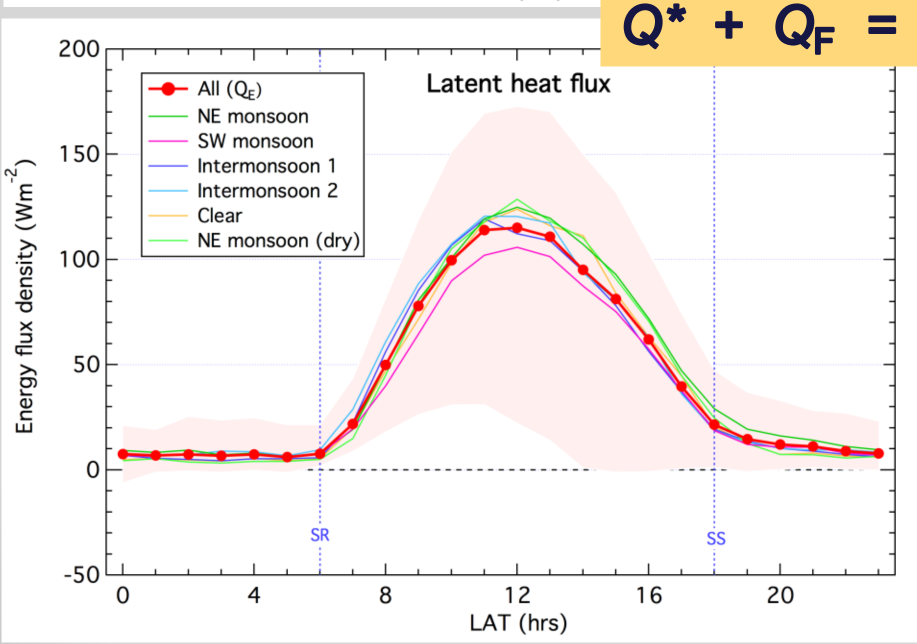
- High L_{in} and L_{out} values (role of temperature and moisture)
- Very little seasonal variability for L

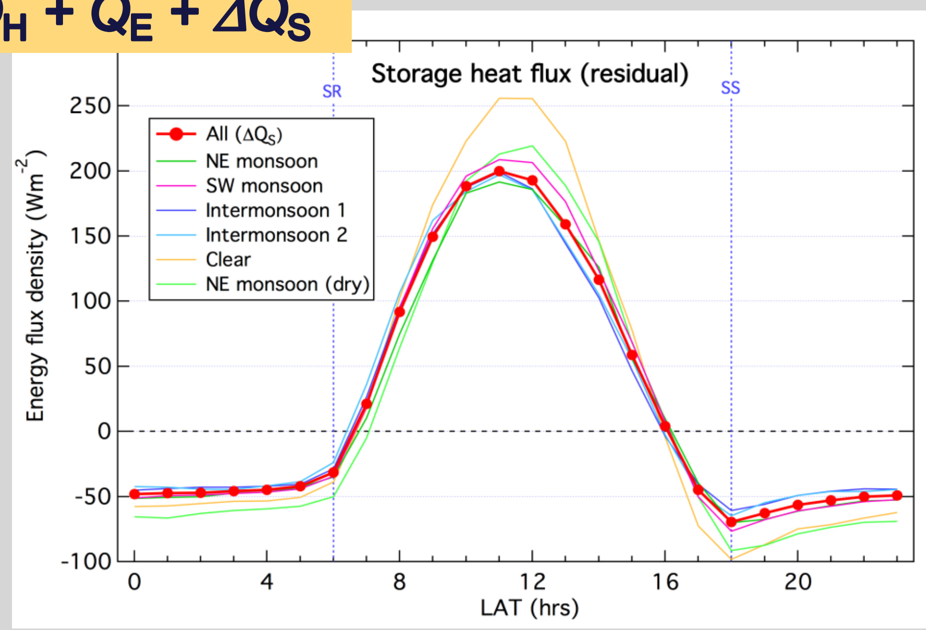
Ensemble diurnal energy balance components



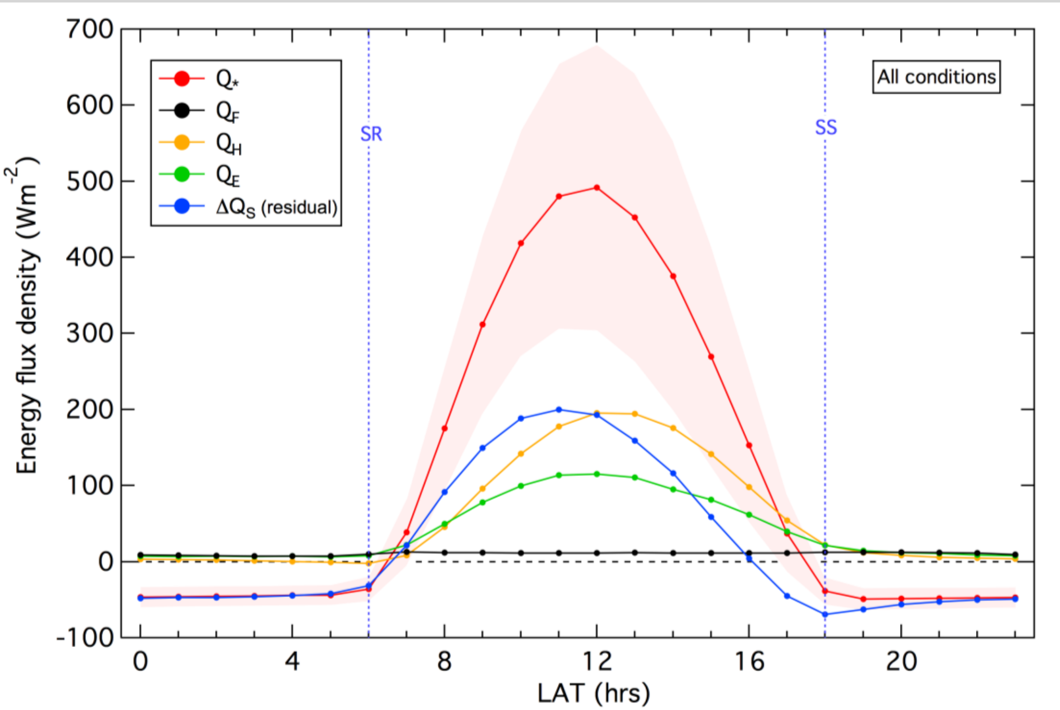


$$Q^* + Q_F = Q_H + Q_E + \Delta Q_S$$



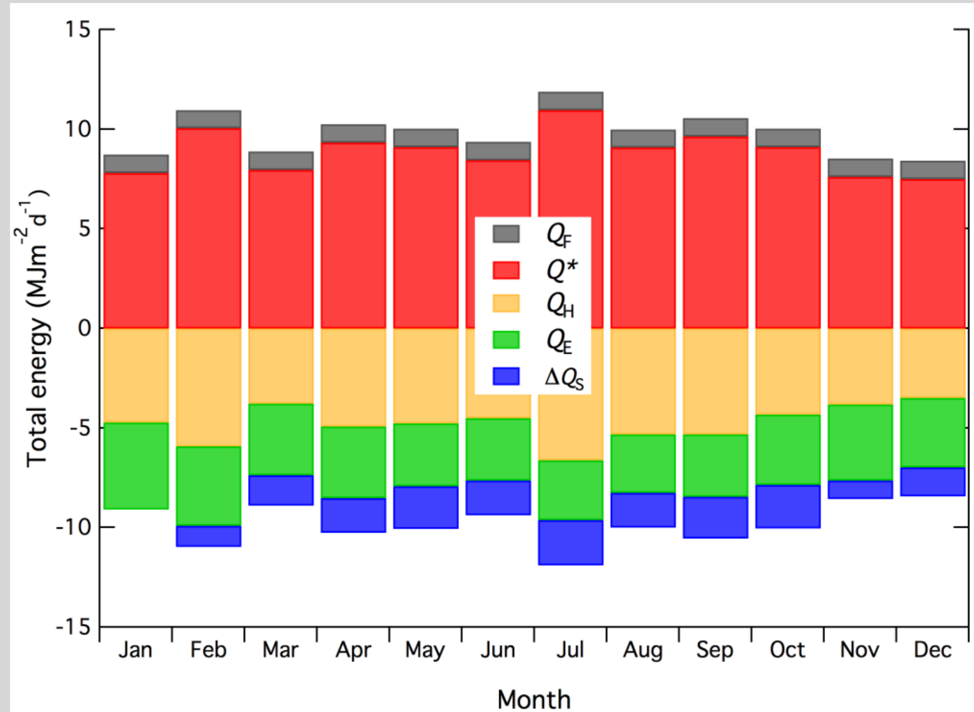


Ensemble diurnal energy balance



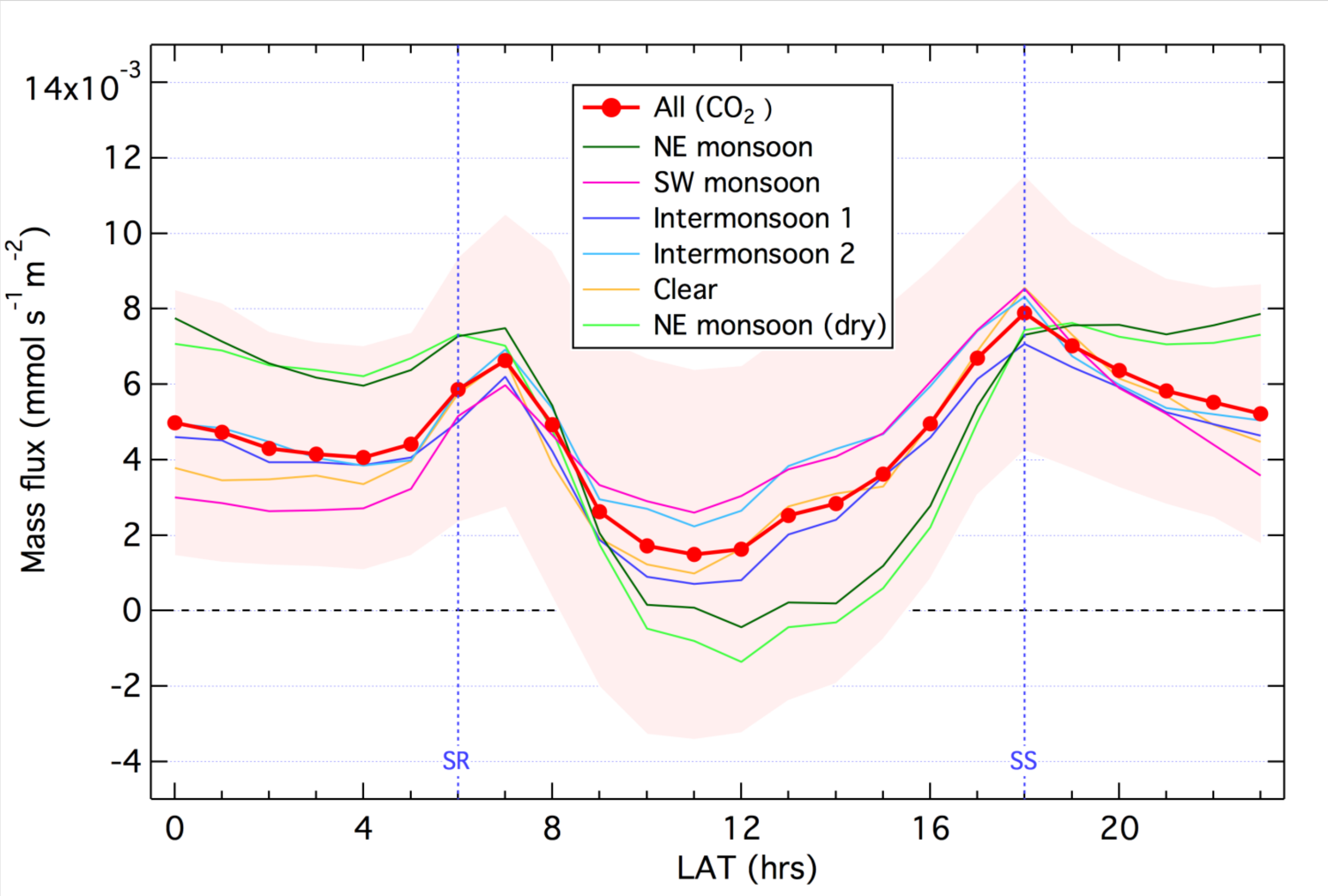
- Overall features same as those of suburban sites in *eg* temperate regions

Annual variability of energy balance terms



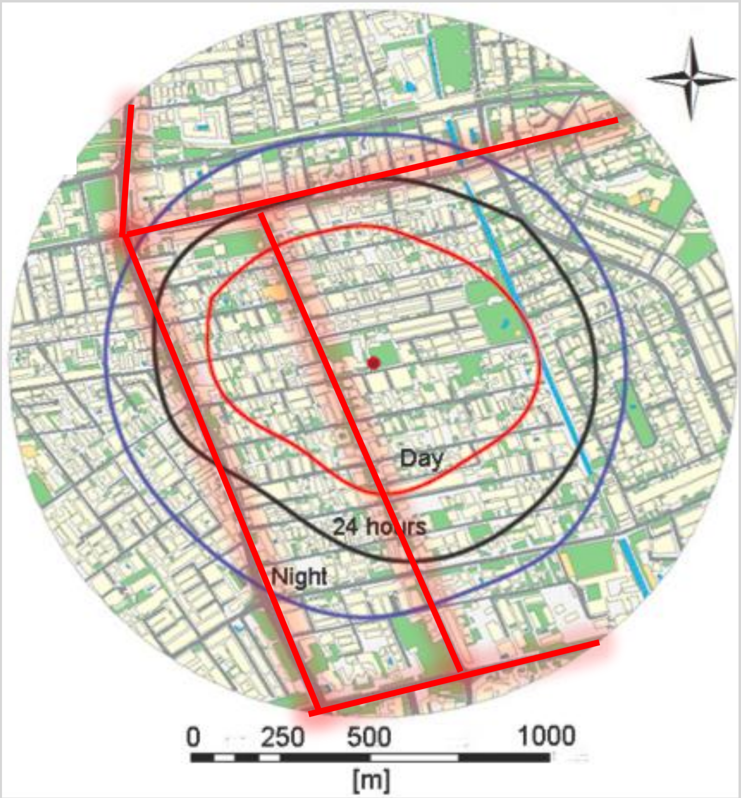
- Little month-to-month variability
- Year-round loss into substrate; artifact of energy balance closure?

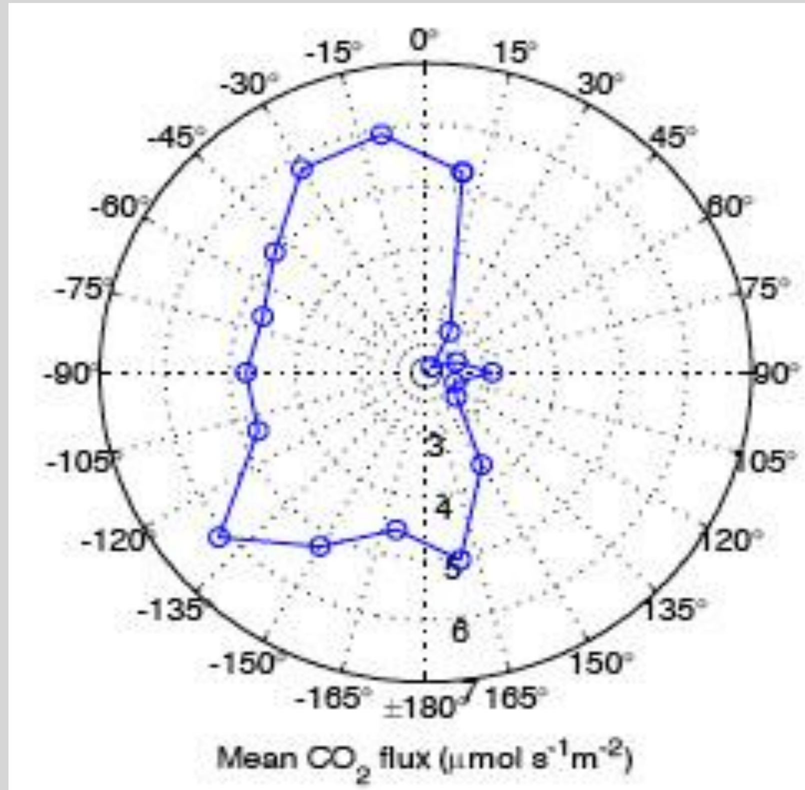
Ensemble diurnal CO_2 flux



- Generally positive, but vegetation has clear effect during daytime
- Strong seasonal variability with larger sequestration/uptake during NE winds

Directional variation of CO_2 flux





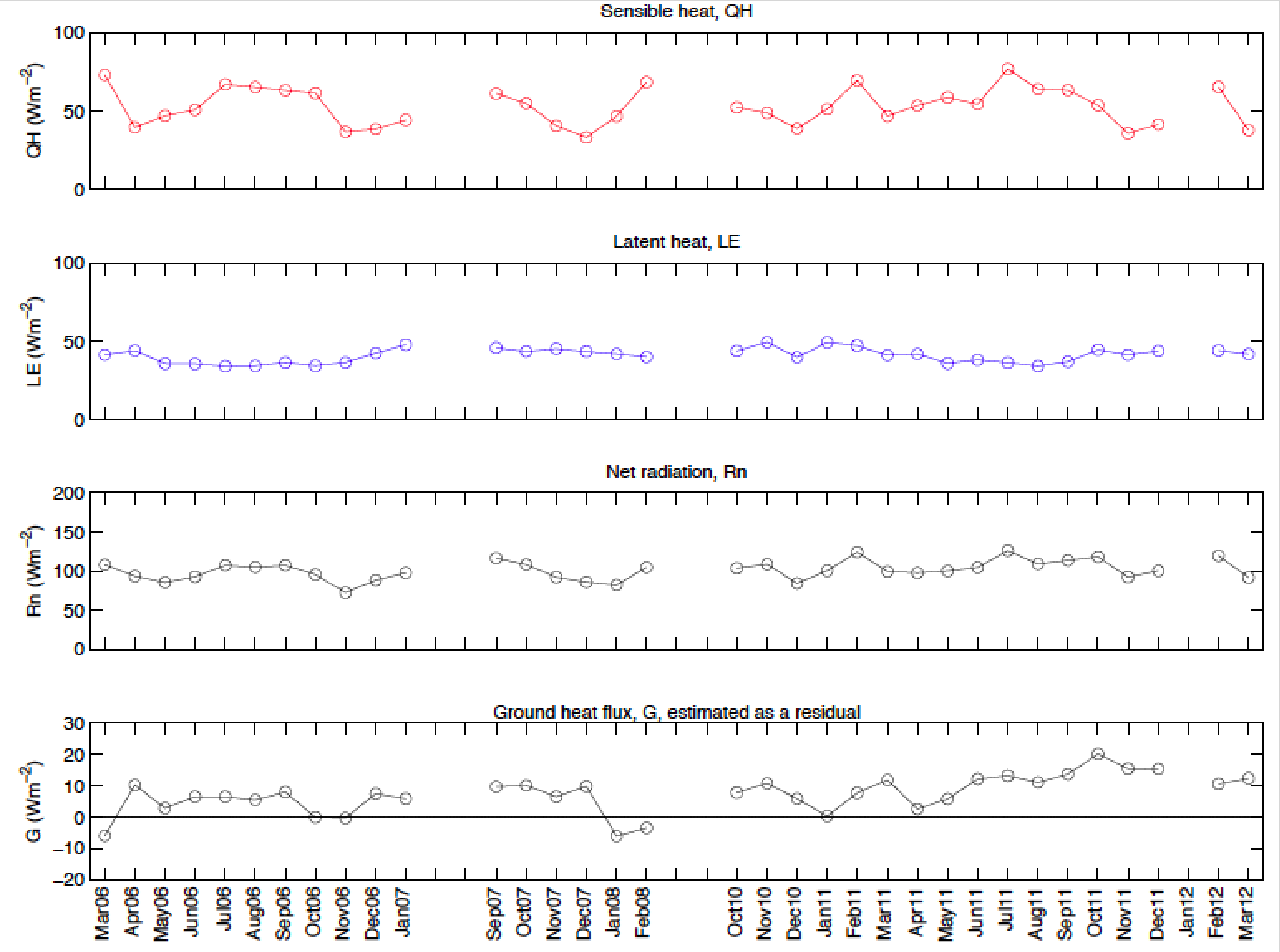
- CO_2 flux is strongly modulated by the presence of local sources, i.e. road traffic in upwind source area during SW monsoon conditions

Final remarks

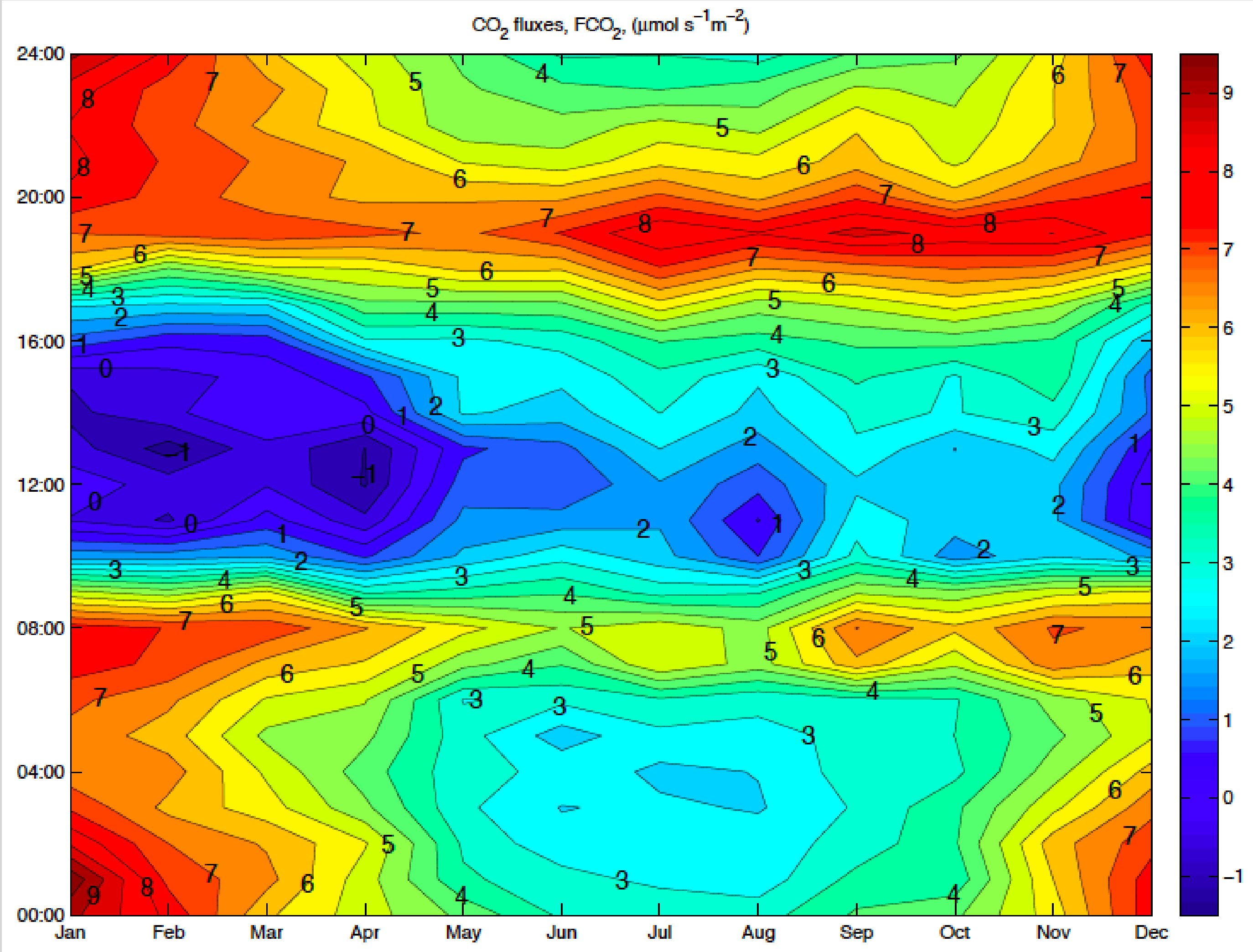
- Data presented enhance the geographic range of similar work to a grossly understudied region
- Diurnal variation and relative partitioning of energy balance fluxes at suburban site is similar to observations from cities in other climate regions
- Little seasonal variability in energy balance fluxes; higher (lower) Q_H and lower (higher) Q_E during relatively drier (wetter) SE (NE) monsoon period
- Suburban surface is a constant source of CO_2: magnitude of flux related to traffic emissions but also modulated by presence of vegetation
- Seasonality of CO_2 flux determined by emission sources in source area and therefore dependent on wind direction (no local heating/cooling sources which would emit CO_2)
- Present data are useful resource for evaluating models validation in a different climatic context

Thank you!

Monthly mean flux values



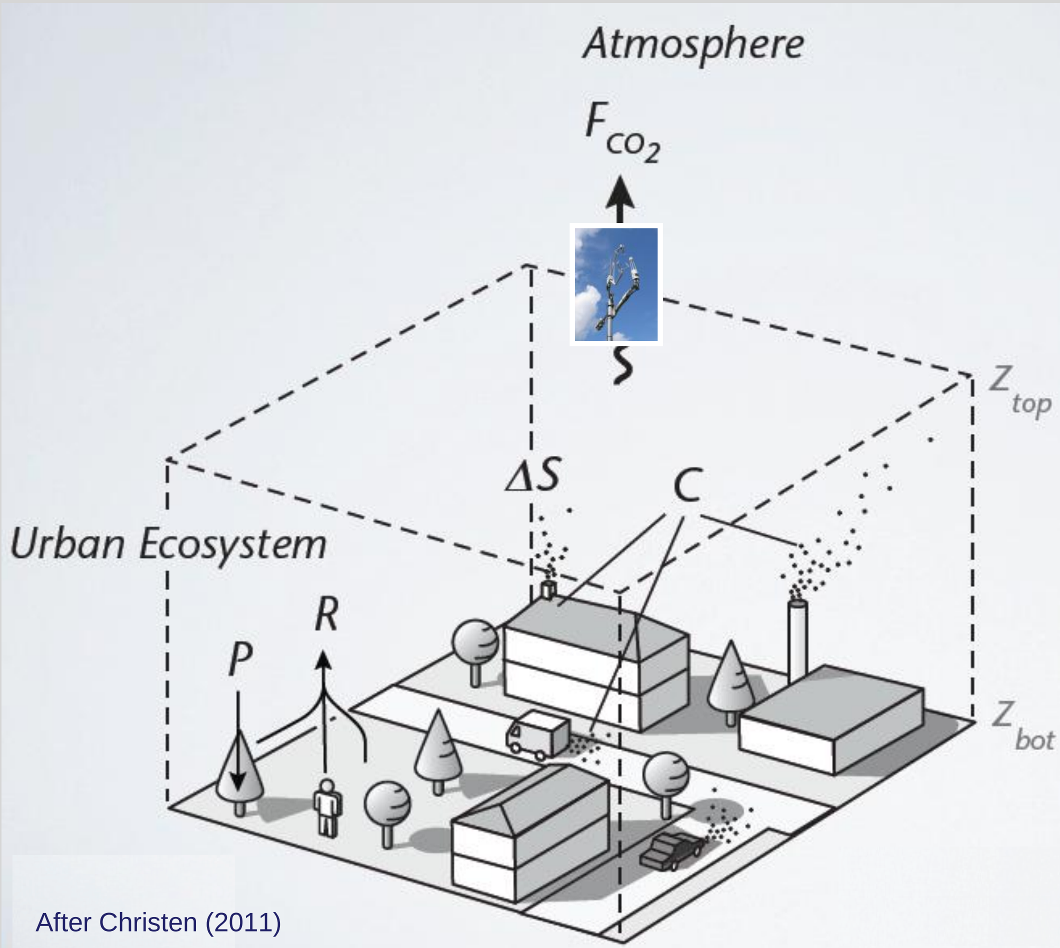
Temporal variation of 30-min CO_2 flux values



- Largest amplitudes during NE monsoon season (less traffic, more vegetation in footprint); highest values during SW monsoon evening rush hour

Measurement approach

Eddy covariance (EC) approach - most direct and defensible way to obtain fluxes



$$F_{CO2} = C + R - P + \Delta S$$

C - Combustion

R - Respiration

P - Photosynthesis

ΔS - Storage change in air within balancing volume

$$Q^* + Q_F = Q_H + Q_E + \Delta Q_S$$

Q^* - Net allwave radiation

Q_F - Anthropogenic heat flux

Q_H - Sensible heat fux

Q_E - Latent heat flux

ΔQ_S - Storage heat flux (res)

Local-scale approach: Climate of neighborhoods with similar type of urban development; urban ecosystem of interest is represented within flux footprint