Seasonal controls on urban-rural differences of the surface radiation budget

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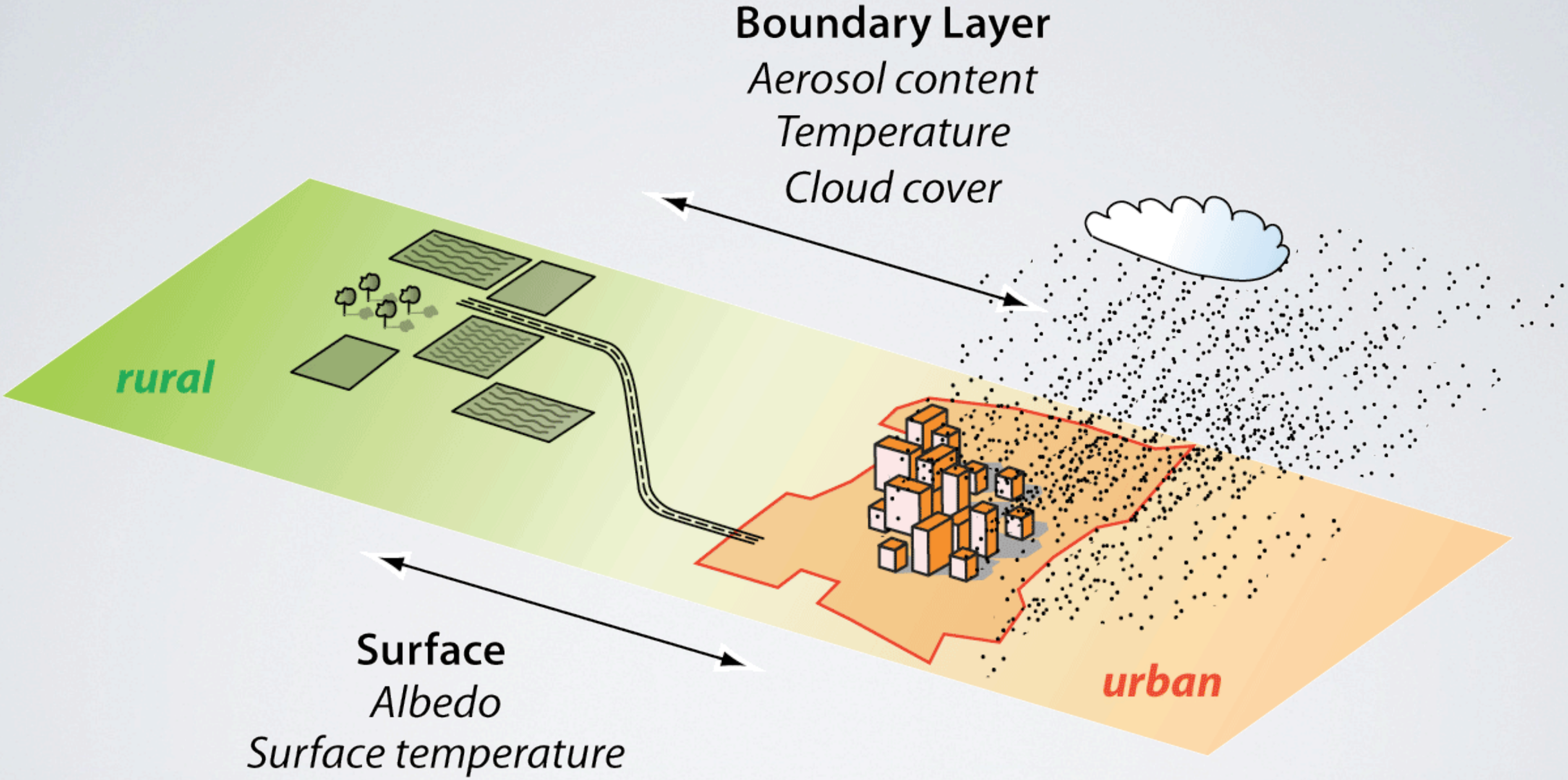
EPiCC

Canadian Foundation for Climate and Atmospheric Sciences (CFCAS)
Fondation canadienne pour les sciences du climat et de l'atmosphère (FCSCA)

UBC a place of mind

$$Q^* = K_\downarrow - K_\uparrow + L_\downarrow - L_\uparrow$$



seasonal effects?

Forest
Built
Tidal mudflats
Other (agricultural, park)

Vancouver

Vancouver-Sunset
(urban)

YVR

Strait of Georgia

Sturgeon
Bank

Richmond

Fraser River

Westham Island
(rural)

Ladner

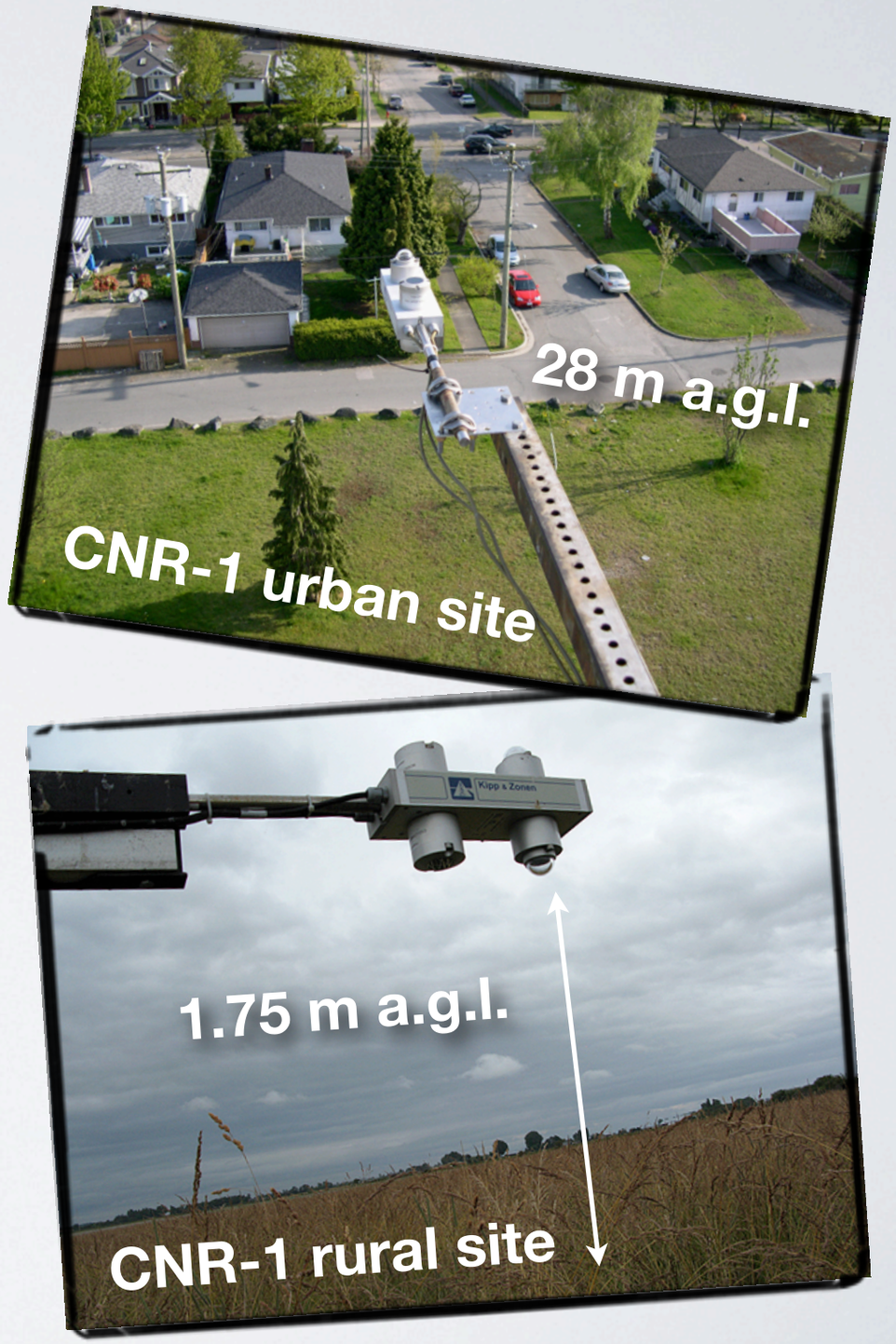
Roberts
Bank

Instrumentation and data processing

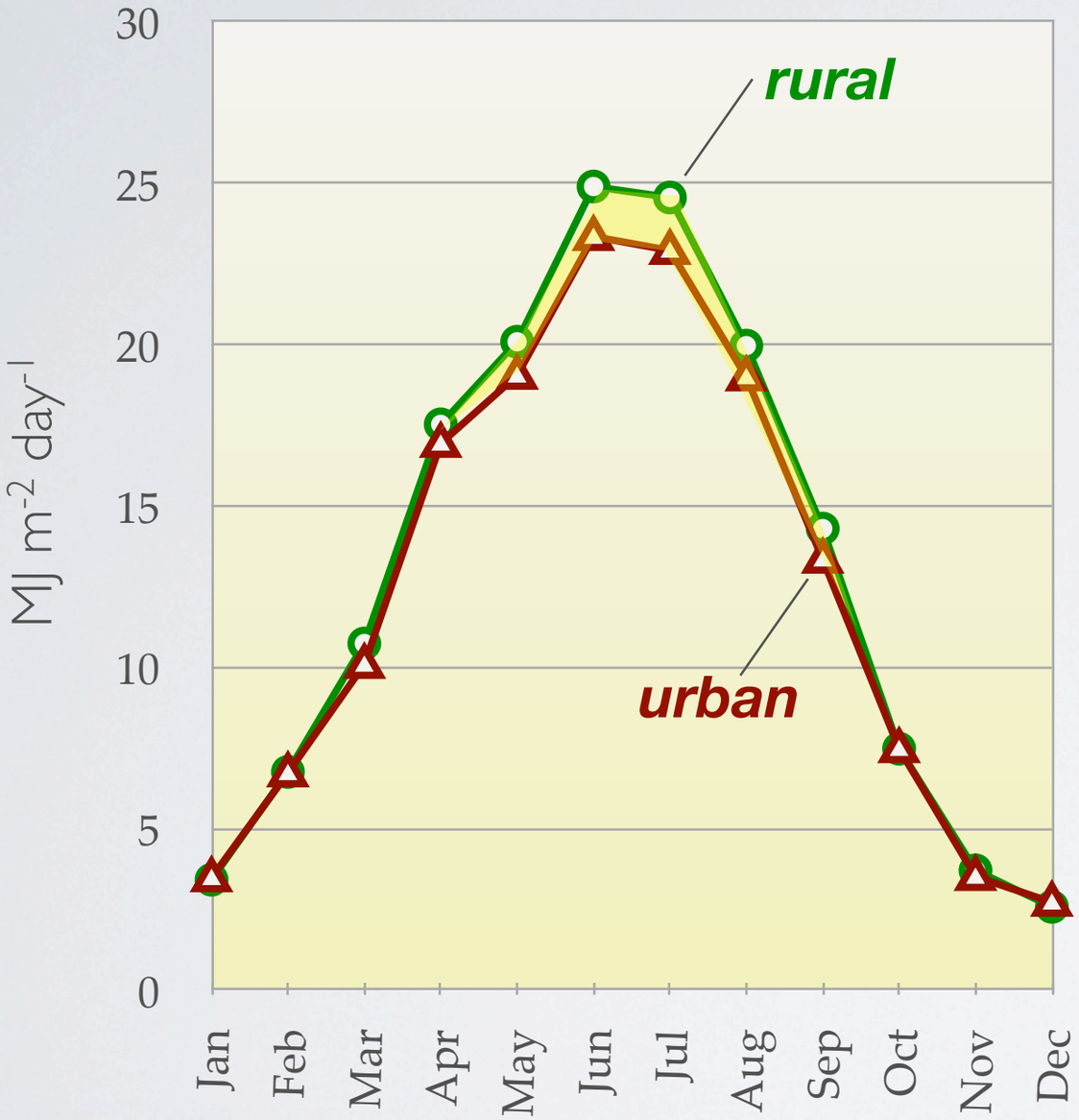
- Data from October 1, 2008 to September 30, 2009 when **4-component net radiometers** (CNR-1) were simultaneously in operation at both sites.

- **Ensemble averages** of the diurnal course for each month.

- Complemented by METAR observations at YVR, midway between sites.



Results - Shortwave irradiance $K_{\downarrow}$

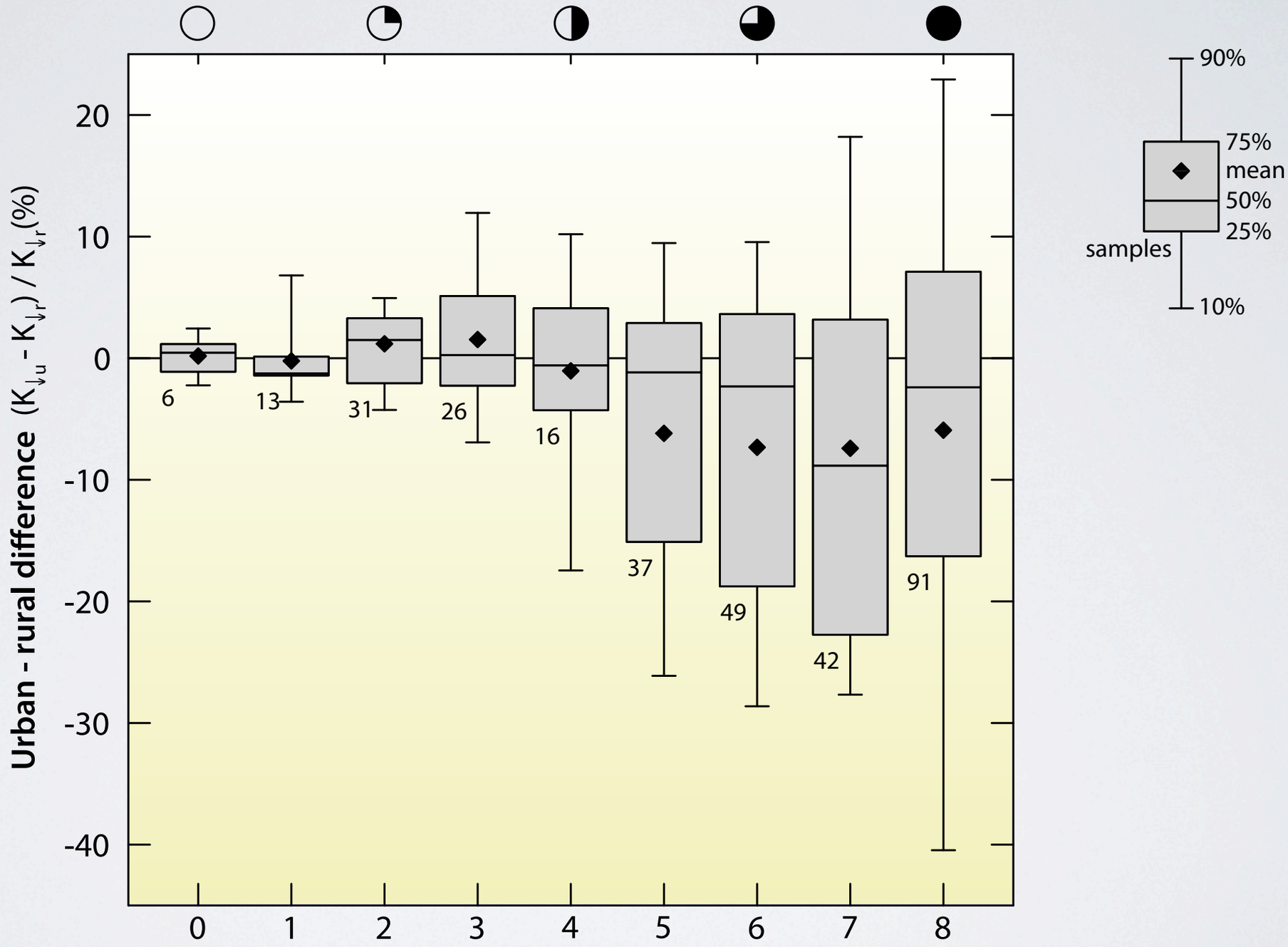


Less incoming shortwave at urban site (-4.5%)

Higher relative reduction in summer half year (-5.1%) compared to winter half year (-1.2%)

$$Q^* = K_{\downarrow} - K_{\uparrow} + L_{\downarrow} - L_{\uparrow}$$

Causation - Aerosols or cloud cover?



$$Q^* = K_{\downarrow} - K_{\uparrow} + L_{\downarrow} - L_{\uparrow}$$

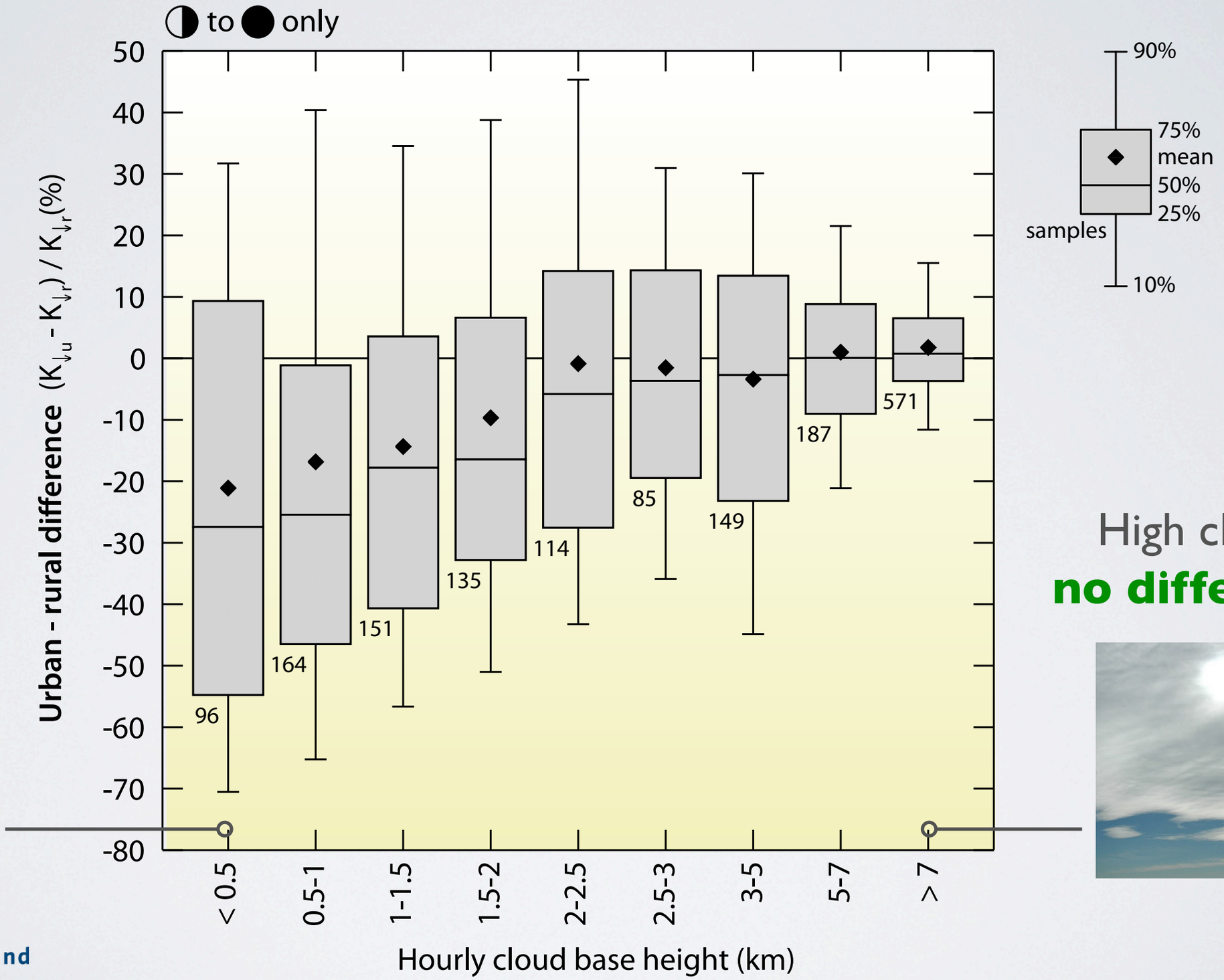
Vancouver’s urban atmosphere and clouds

North shore mountains

Downtown

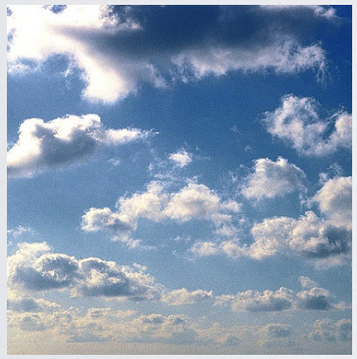
Vancouver, view towards North

The effect of cloud height on differences in $K_{\downarrow}$



Low clouds

reduction



High clouds

no difference

$$Q^* = K_{\downarrow} - K_{\uparrow} + L_{\downarrow} - L_{\uparrow}$$

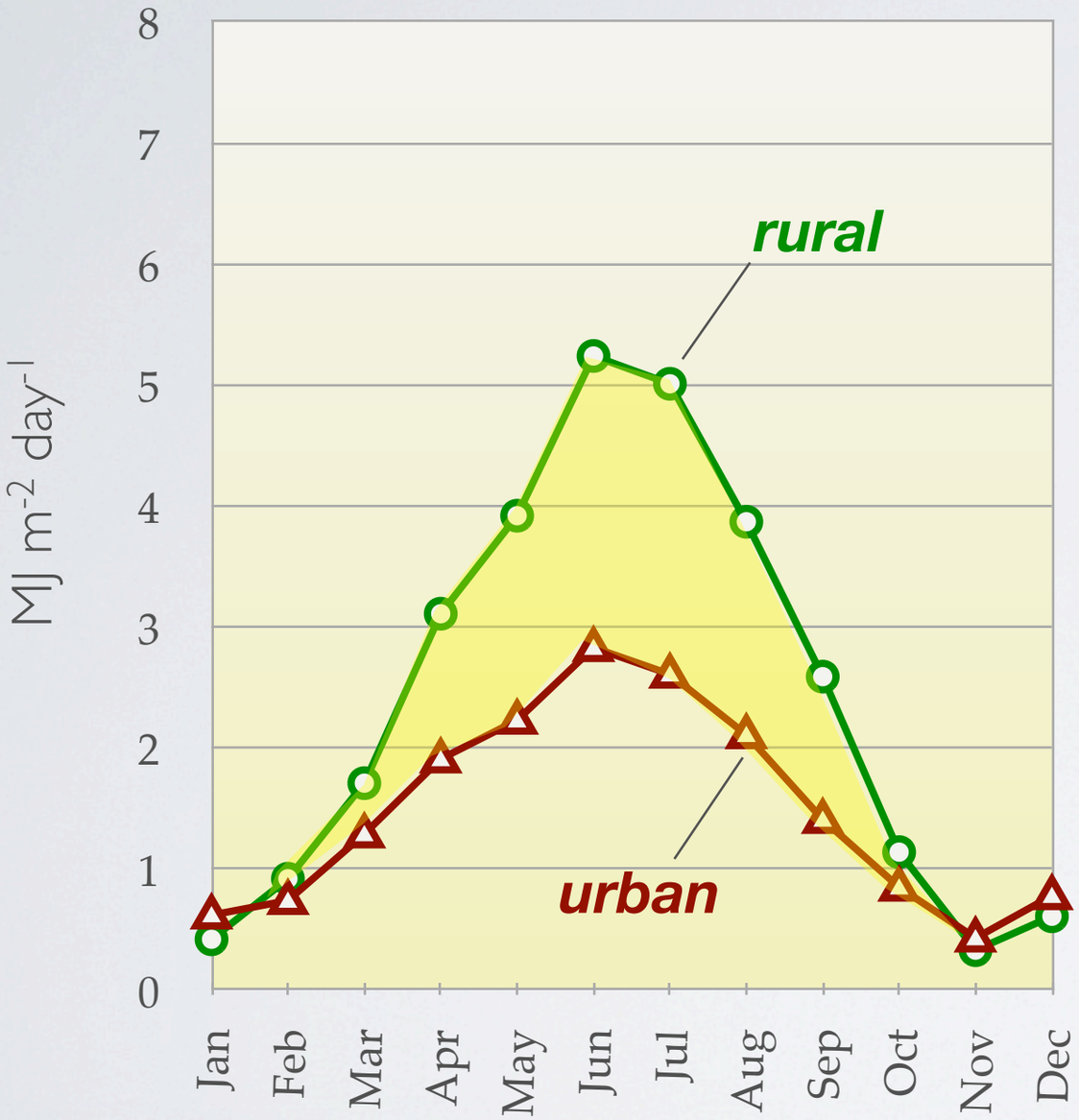
Key points: shortwave irradiance

- No significant attenuation was observed under clear-sky conditions, hence the **effect of aerosols is negligible** for the pair of sites selected. This is in agreement previous data from Vancouver's urban boundary layer (Hay, 1983).

- The observed attenuation of $K_{\downarrow}$ is rather **explained by differences in cloud cover** - strongest differences are found with broken, low boundary-layer clouds in the warmer half of year.

$$Q^* = K_{\downarrow} - K_{\uparrow} + L_{\downarrow} - L_{\uparrow}$$

Results - Shortwave reflectance $K_{\uparrow}$



Substantially less reflection (more absorption) of shortwave at urban site (-36%).

Albedo stays low and relatively constant throughout the year at urban site (10.8% to 13.1%)*

Rural albedo changes between a winter minimum of 14.0% and a summer maximum of 19.4%*

* excluding periods with snow cover

$$Q^* = K_{\downarrow} - K_{\uparrow} + L_{\downarrow} - L_{\uparrow}$$

Albedo - effect of vegetation and ground state

α = 11.3%
February

α = 11.5%
April

α = 11.7%
July

urban

α = 16.0%
February

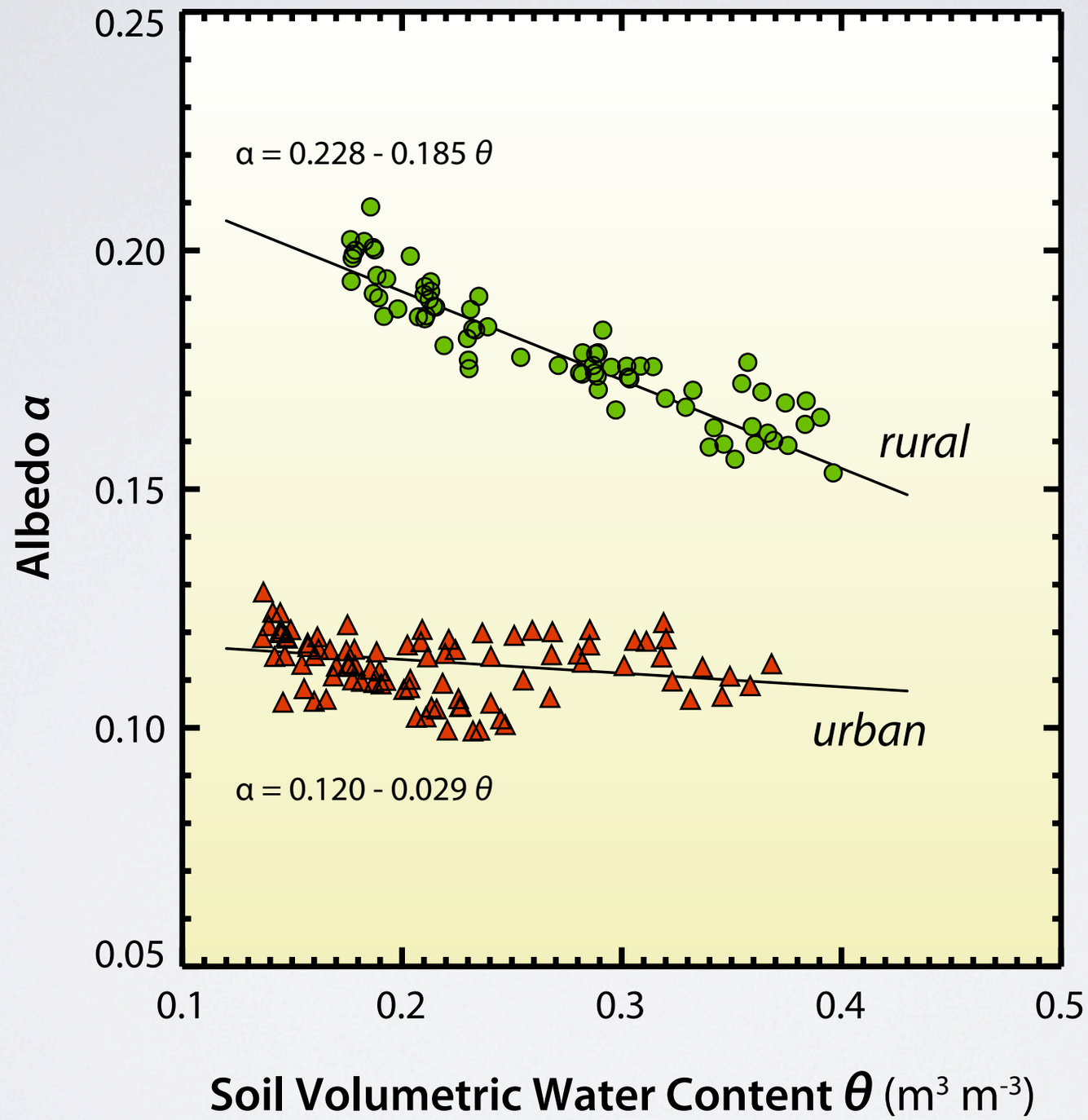
α = 16.6%
April

α = 19.0%
July

rural

$$Q^* = K_\downarrow - K_\uparrow + L_\downarrow - L_\uparrow$$

Albedo controlled by plant water availability



$$Q^* = K_\downarrow - K_\uparrow + L_\downarrow - L_\uparrow$$

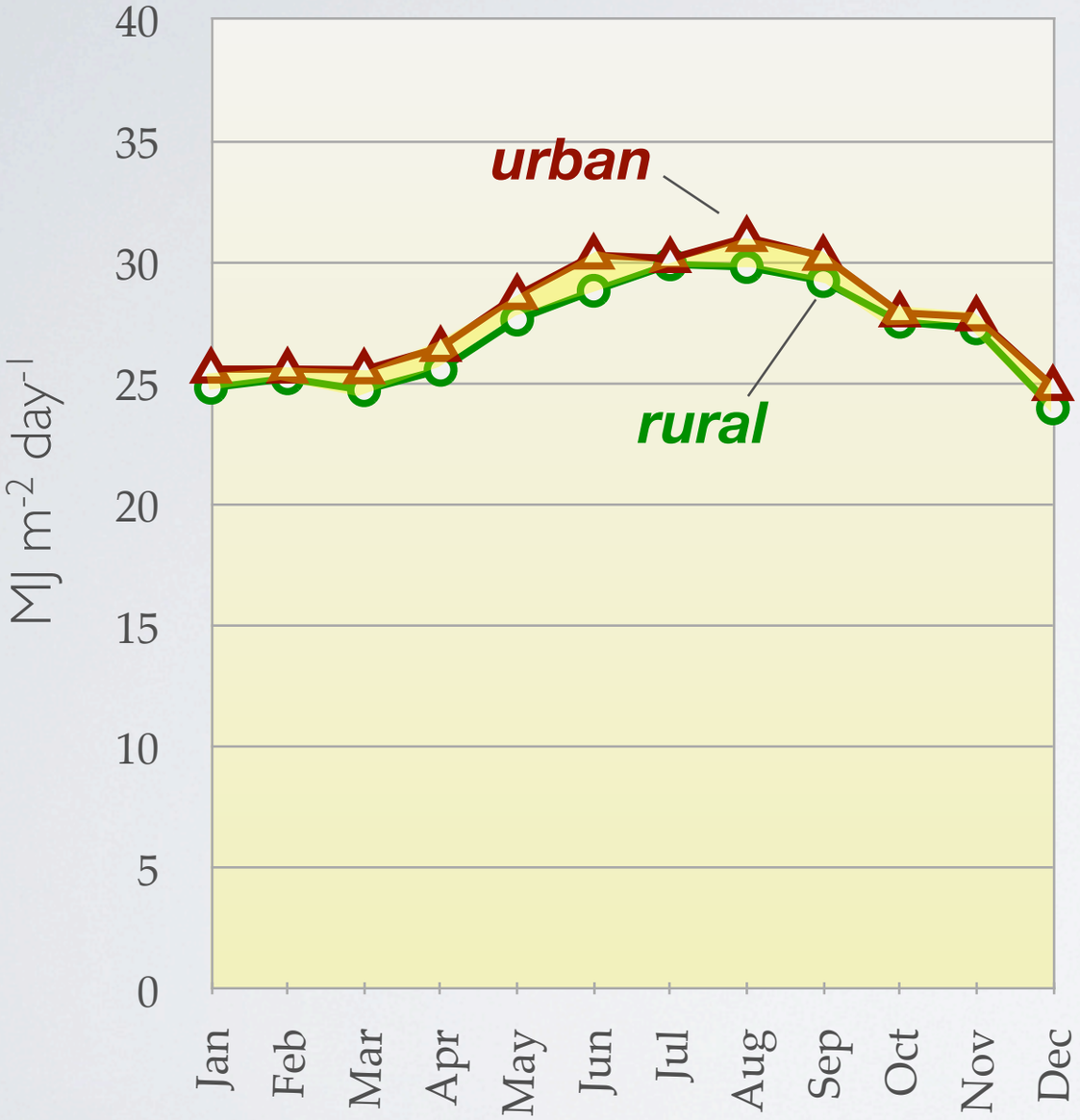
Key points: Shortwave reflectance

- Albedo changes over the year are small at the urban site compared to the rural environment.

- Albedo changes mostly controlled by plant water availability.

- Despite decreased $K_{\downarrow}$, **the urban site absorbs more shortwave energy** due to its lower albedo for most of the year. $K^* = K_{\downarrow} - K_{\uparrow}$ is 2% higher in the city.

Longwave incoming

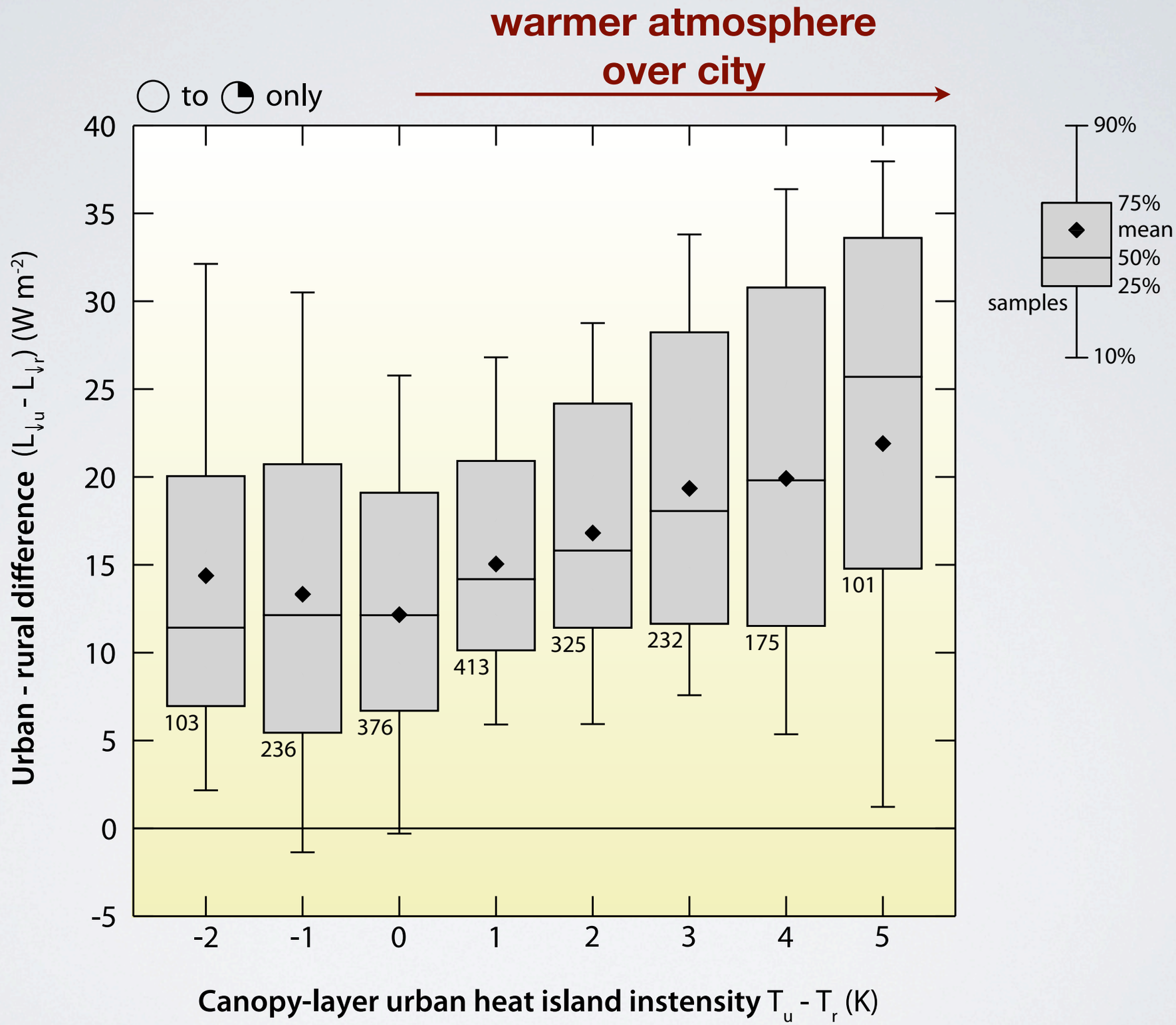


More longwave incoming radiation at urban site (+3%).

Difference is stronger in the warmer (+4.1% from Apr-Sep) rather than colder half of the year (+2.5% Oct-Mar).

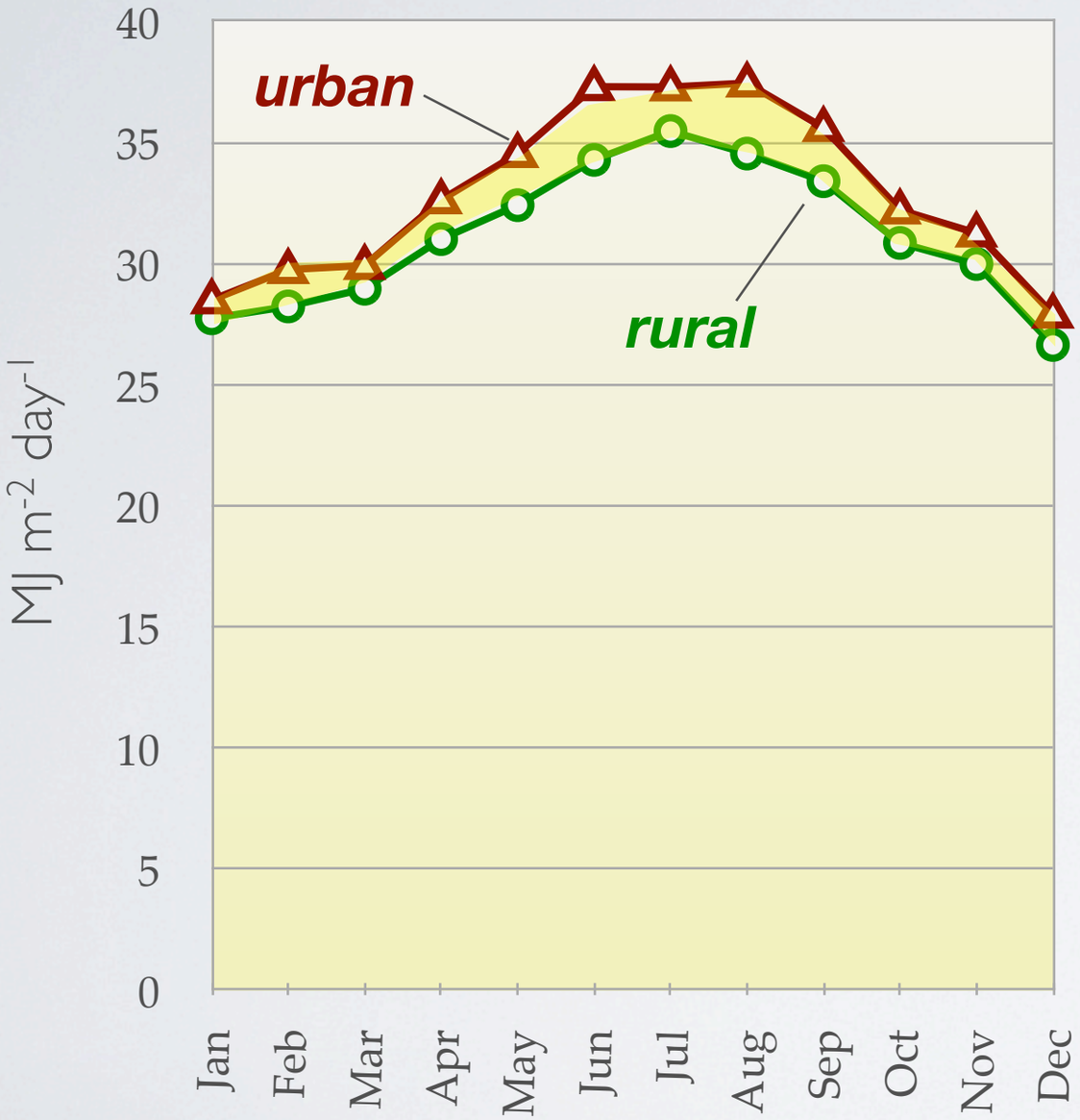
$$Q^* = K_\downarrow - K_\uparrow + L_\downarrow - L_\uparrow$$

$L_{\downarrow}$ controlled by urban heat island (UHI)



$$Q^* = K_{\downarrow} - K_{\uparrow} + L_{\downarrow} - L_{\uparrow}$$

Longwave fluxes



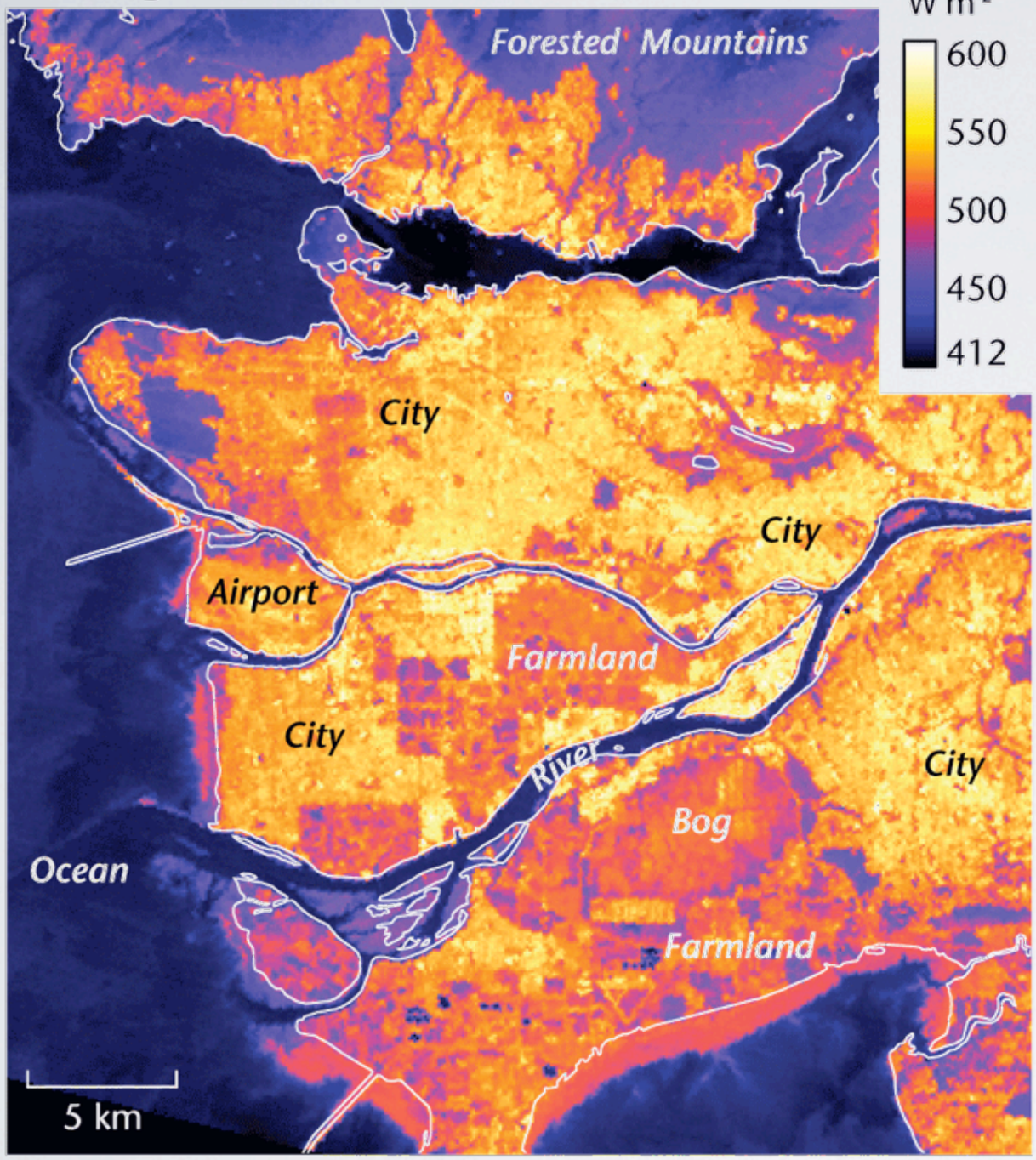
98% of the time, more longwave outgoing radiation at urban site (+6% on average).

In absolute numbers, $L_{\uparrow}$ shows the largest of all the urban-rural radiation component differences.

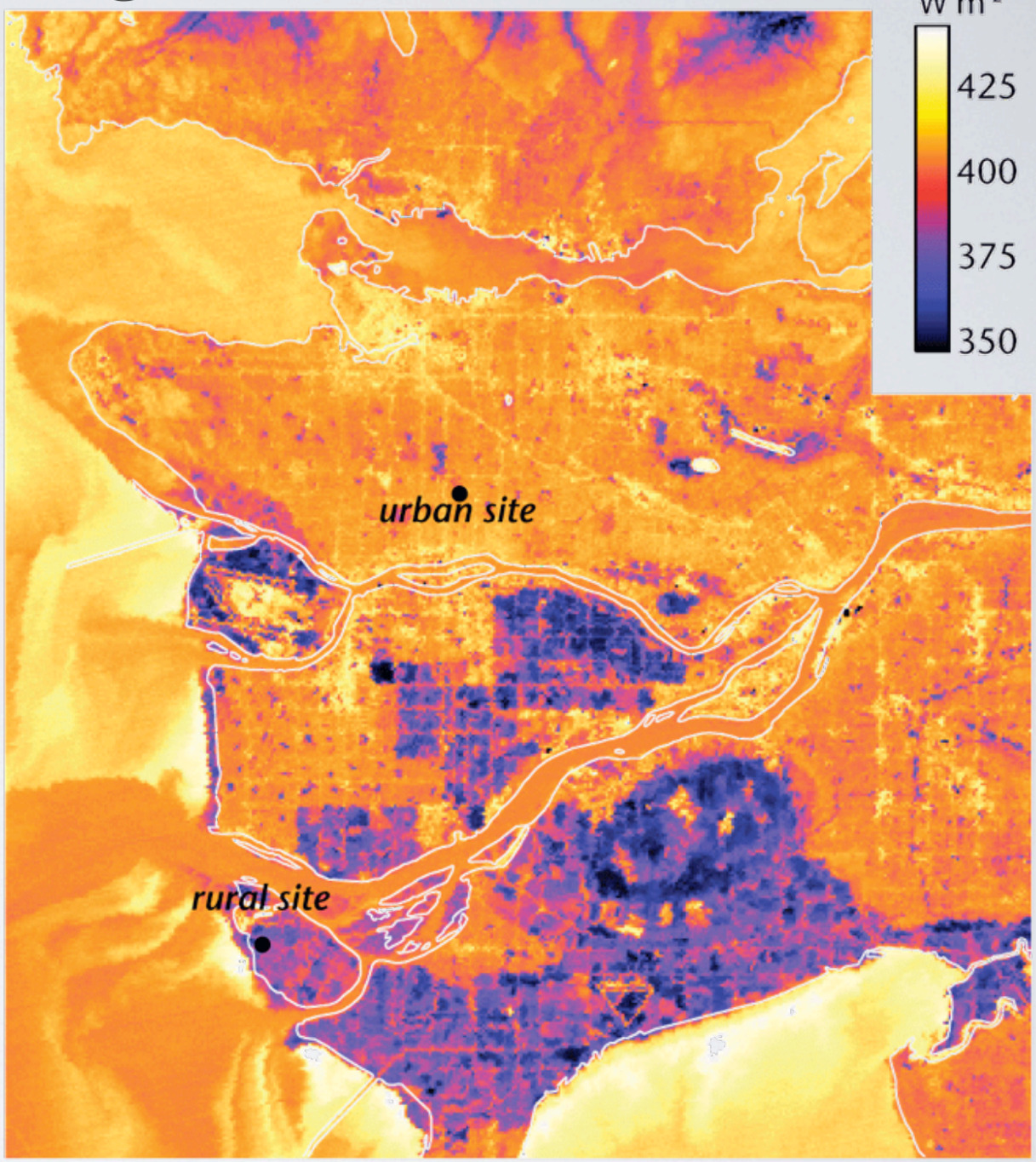
Controlled by reduced cooling rates of warmer urban surface elements (surface UHI)

$$Q^* = K_{\downarrow} - K_{\uparrow} + L_{\downarrow} - L_{\uparrow}$$

Day



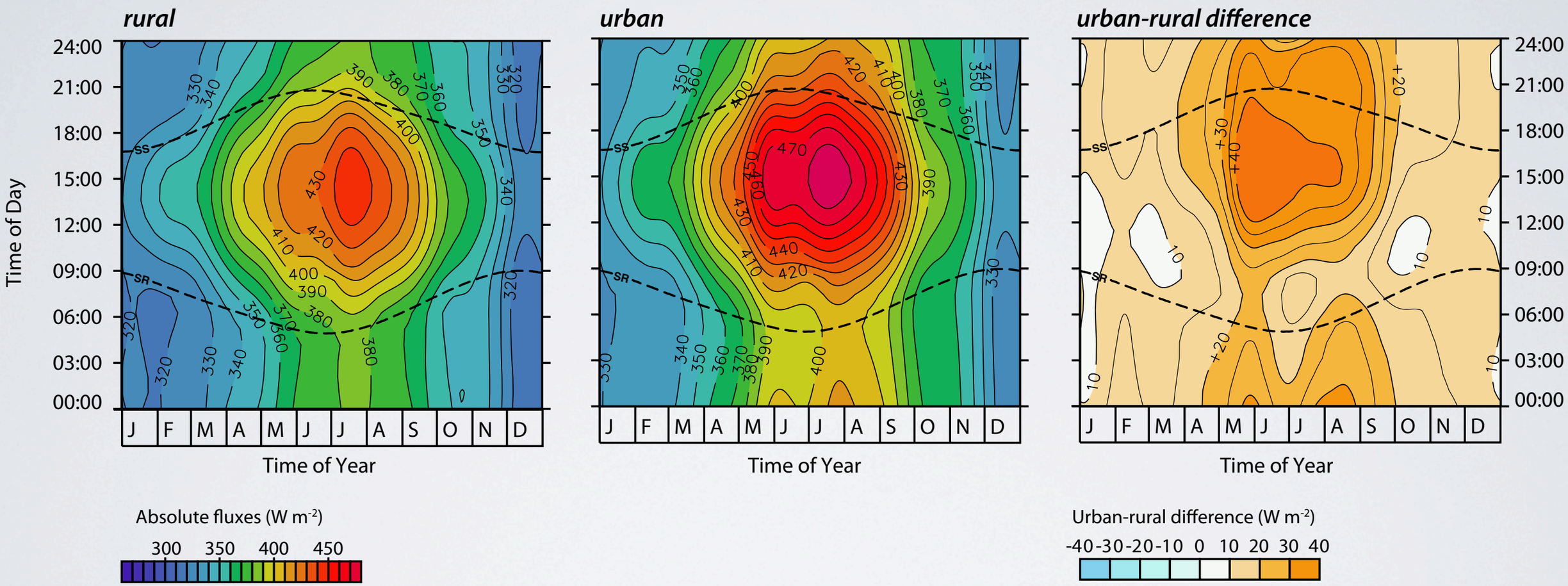
Night



ASTER / Data source: NASA/JPL

$$Q^* = K_\downarrow - K_\uparrow + L_\downarrow - L_\uparrow$$

Long-wave outgoing



$$Q^* = K_{\downarrow} - K_{\uparrow} + L_{\downarrow} - L_{\uparrow}$$

Key points: Longwave components

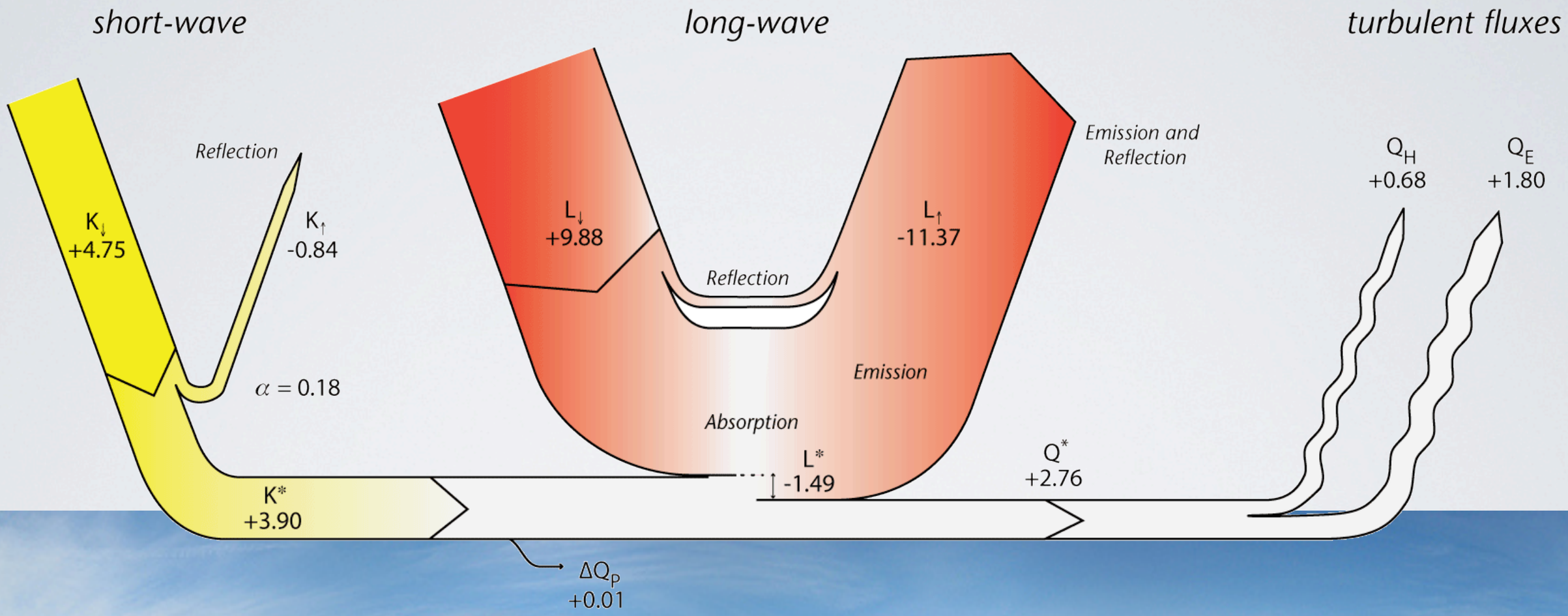
- Urban boundary layer heat island enhances $L_{\downarrow}$ over Vancouver.

- Surface urban heat island enhances $L_{\uparrow}$ with strongest differences in summer / afternoon or evenings (release of stored heat at night).

- The effect of enhanced $L_{\uparrow}$ at the urban site dominates over enhanced $L_{\downarrow}$. The **urban site loses more energy in the long wave** on an annual basis (23% of L^*)

Partition of rural energy balance

all values in GJ m^{-2} yr^{-1}



Urban energy balance and **urban-rural differences**

all values in GJ m^{-2} yr^{-1}