ICUC9, Friday, 24/Jul/2015, Toulouse, France

# *Comprehensive validation of a simulation system for simultaneous prediction of urban climate and building energy demand*

Osaka City
(population 2.7M)


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# Background & Purpose

## Progress in Urban Climate Modelling

### Heterogeneous LULC & surface geometry, and those parameterizations

**Slab models** (1990s) ➡ **UCPs** (Urban Canopy Parameterizations) with CFD (2000s-)

### Anthropogenic Heat (AH), and its implementation to urban climate models

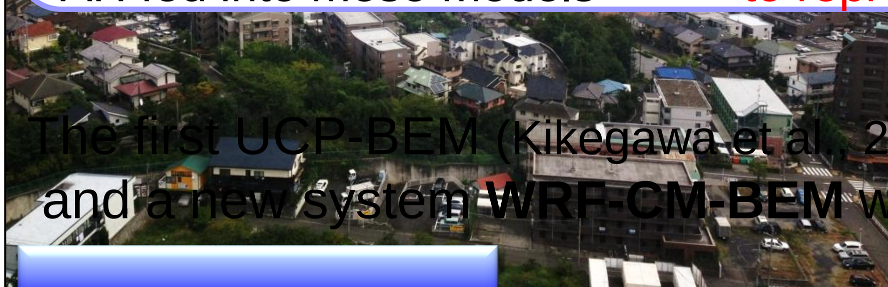
**Static approach** (1990s) ➡ **Dynamic modelling (UCP-BEM)** (2000s-)

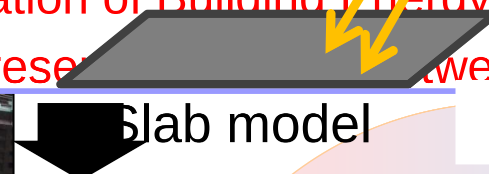
Energy inventory-based

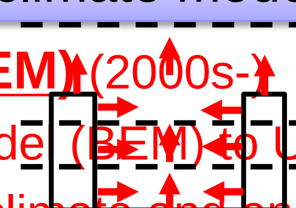
AH fed into meso models

Integration of Building Energy Model (BEM) to UCP

to represe... ...tween climate and energy.






The first UCP-BEM (Kikegawa et al., 2003) was implemented in the WRF model, and a new system **WRF-CM-BEM** was devel... ...014).


... AC ... and

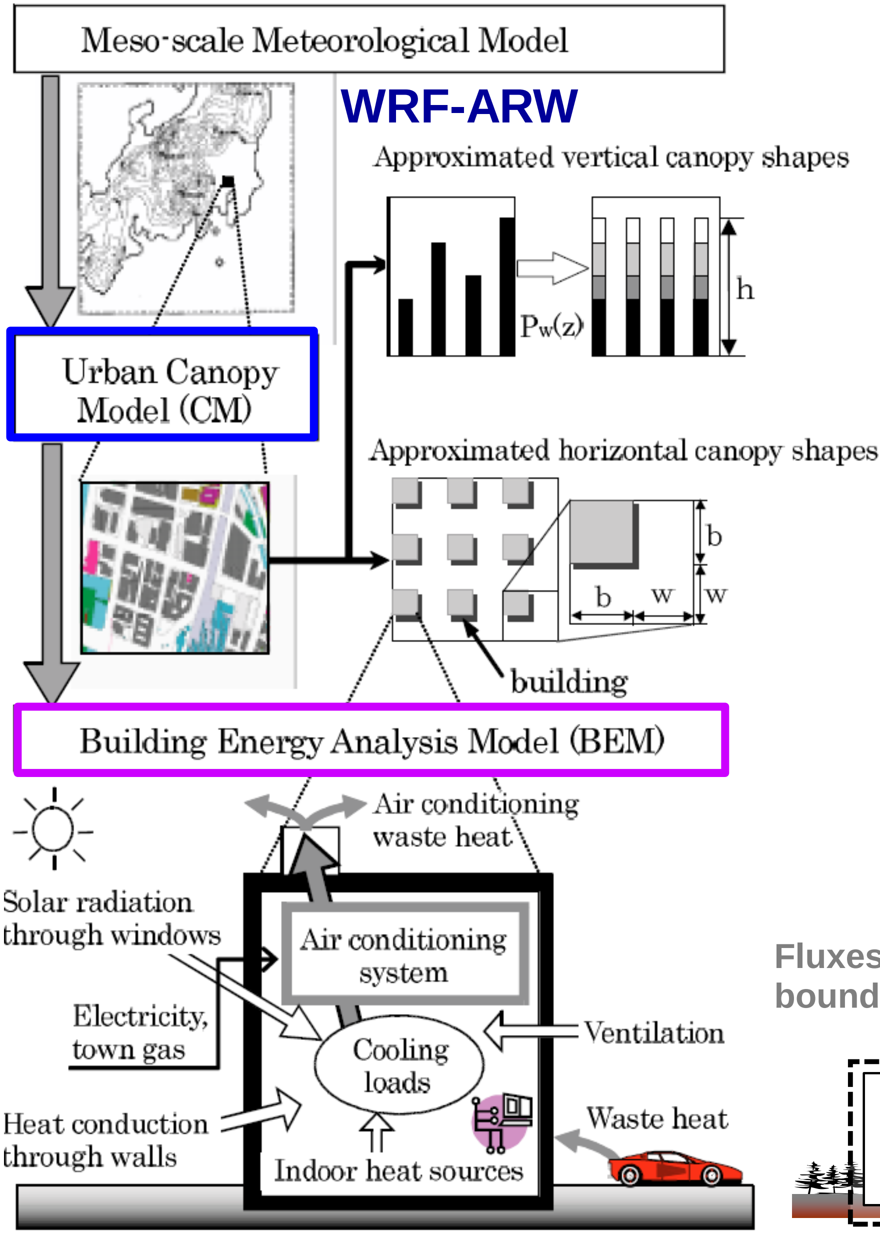
Mas... $CO_2$

## Goal of Study

To substantiate the performance of **WRF-CM-BEM** in coupling simulation of urban climate and building electricity demand, and to check its potential as an urban energy management tool especially in the prediction of photovoltaic power generation toward the contribution to "smart grid" technology.

Y. Ashie, Urban Climate News, No.41, 2011

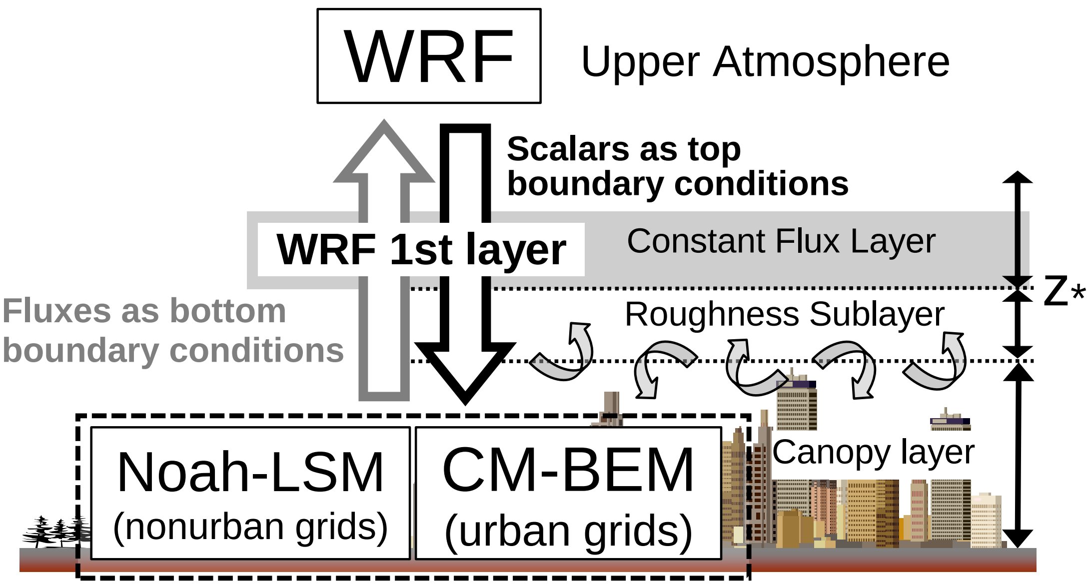
# Models (WRF-CM-BEM, Kikegawa et al., *TAAC*, 2014)




**CM (Kondo & Kikegawa, *PAGEOPH*, 2003, Kondo *et al.*, *BLMet*, 2005)**

**BEM (Kikegawa *et al.*, *Appl. Energy*, 2003 & 2006)**

**CM-BEM: the first model for coupled simulation of urban canopy climate and building energy demand**

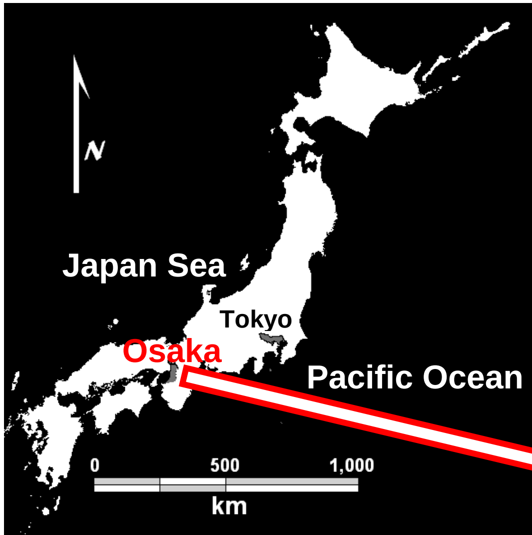


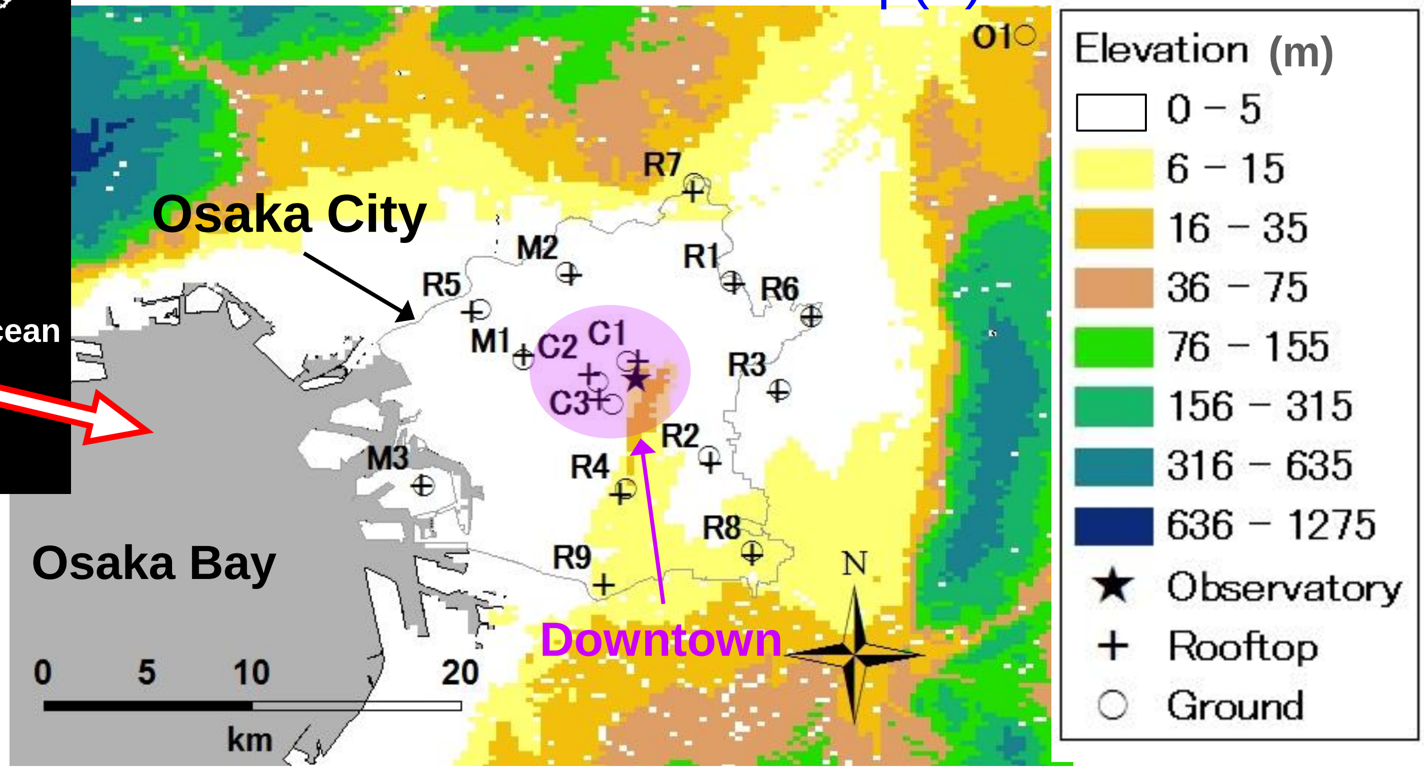

Two-way coupling of CM-BEM with WRF

# Yearlong field campaign in Osaka (FY 2013) 1/2

In 15 urban areas, at a couple of rooftop and ground sites in each area.

Mean distance between rooftop(+) sites = 3.8km




Commercial areas: C1～C3

Residential areas : R1～R9

Mixed-use areas : M1～M3

Rural: ground site O1


Commercial

Residential

# Yearlong field campaign in Osaka (FY 2013) 2/2

- **Period: March 2013 – March 2014**
- **Meteorological Measurements**

**- Rooftop level (3 to 5- storey school buildings)**
**temp., humid., atmos. pressure (every 10 min.)**
**S↓ global irradiance , L↓ (every 5 min.)**

**- Ground level ( at 2.5m, open space near rooftop sites)**
**temp., humid. (every 10 min.)**

- **Electricity demand monitoring**

Areal & hourly electricity demand monitored at 13 distribution substation each located in 13 observation areas with horizontal dimensions of 500 m to 2 km square each (except M2 & R3 areas).

**Meteorological elements** ➡ **CM validation** (ex. temp. in UCL)

**Electricity demand data** ➡ **BEM validation**

**S↓ global irradiance** ➡ **WRF validation** (S↓ & its spatial inhomogeneity)

**Potential in the prediction of PV power generation in urban area?**

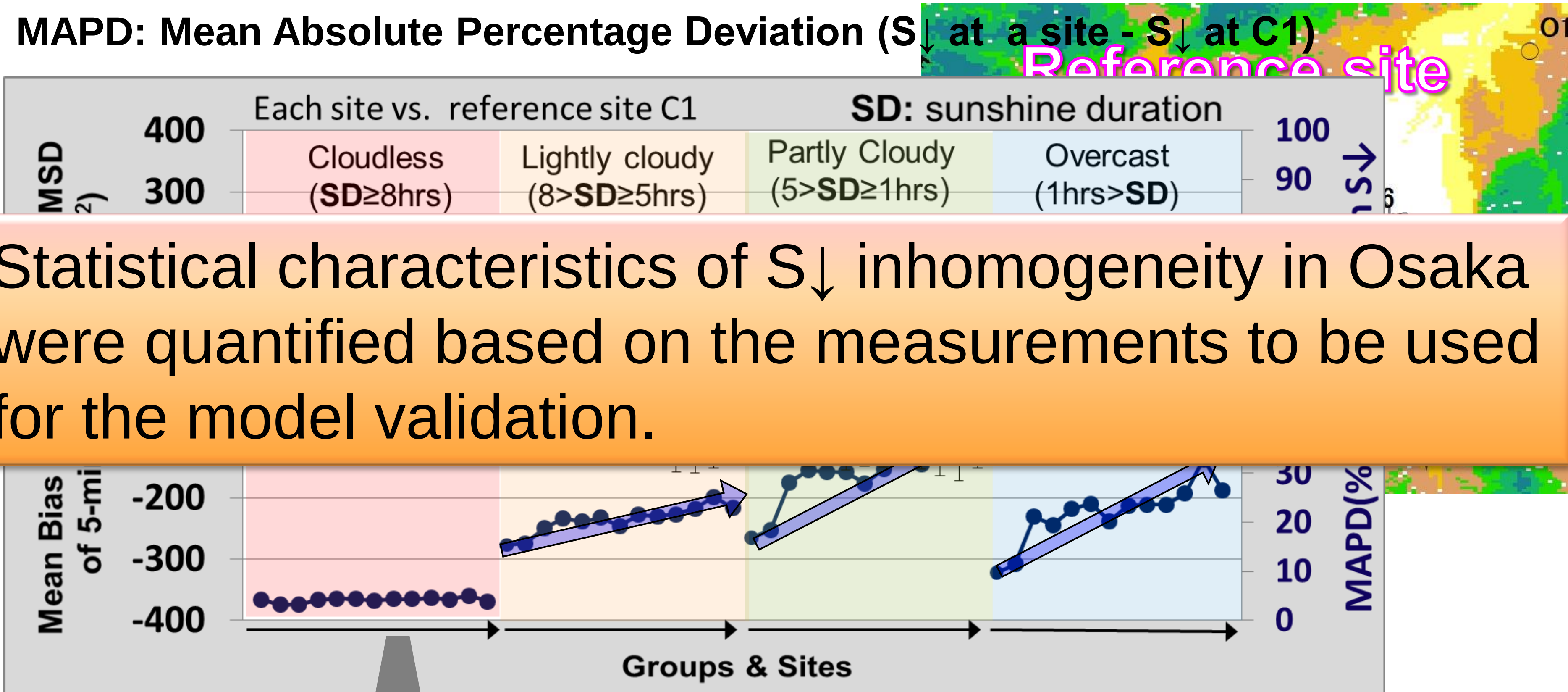
# Results 1/4 (Observed intraurban inhomogeneity in S↓)

- **Period: 14 March 2013 – 17 March 2014 (0800 – 1600 LST)**

**Unbiased Root Mean Square Deviation = ±1σ of (S↓ at a site - S↓ at C1)**

**MAPD: Mean Absolute Percentage Deviation (S↓ at a site - S↓ at C1)**

**16 observation sites for S↓**

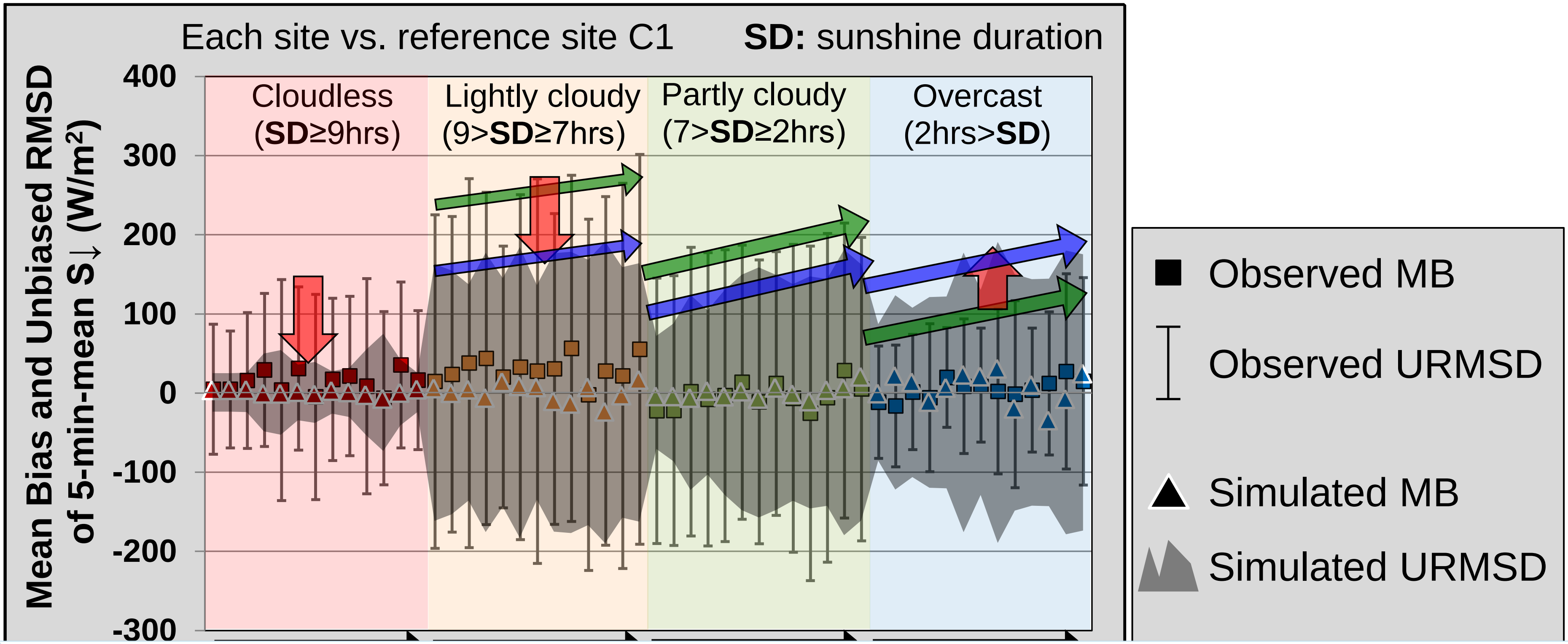



Statistical characteristics of S↓ inhomogeneity in Osaka were quantified based on the measurements to be used for the model validation.

Intraurban spatial inhomogeneity in S↓ becomes larger on lightly & partly cloudy days than that on sunny & overcast days maybe due to partly cloud cover in the sky, showing reasonable dependency on distances between each site and reference site (larger unbiased RMSD & MAPD at more distant sites).

# Preliminary Results 2/4 (Simulated intraurban inhomogeneity in S↓)

- **Period: Jul. 2013 – Aug. 2013 (0700 - 1700 LST) Summer**
- **Simulation: Δx,Δy = 1km, Cloud Microphysics = Thompson et al. scheme**

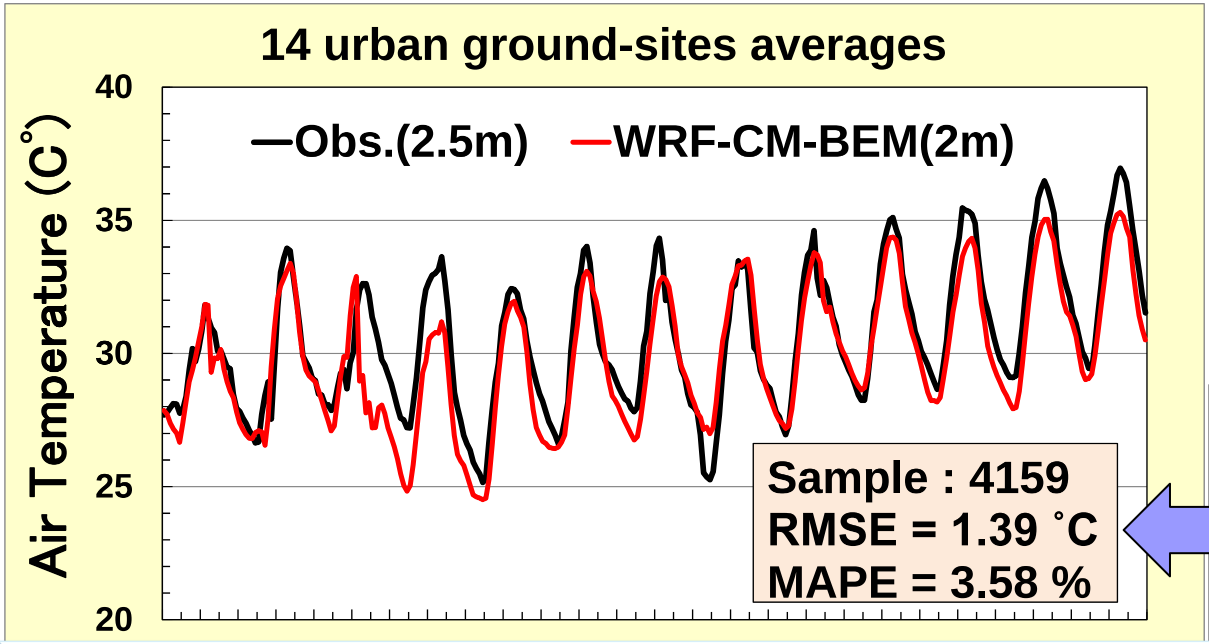



**However, overall statistical features of S↓ inhomogeneity seem to be roughly reproducible by WRF-CM-BEM so far, suggesting a potential of its application to detailed-evaluation of photovoltaic power generation in urban areas.**

# Preliminary Results 3/4 (Simulated air temperatures)

- **Period: 0000 LST 30 July - 0000 LST 12 August 2013 (13 days)**

**RMSE :Root-Mean-Square Error**
**MAPE: Mean Absolute Percentage Error**



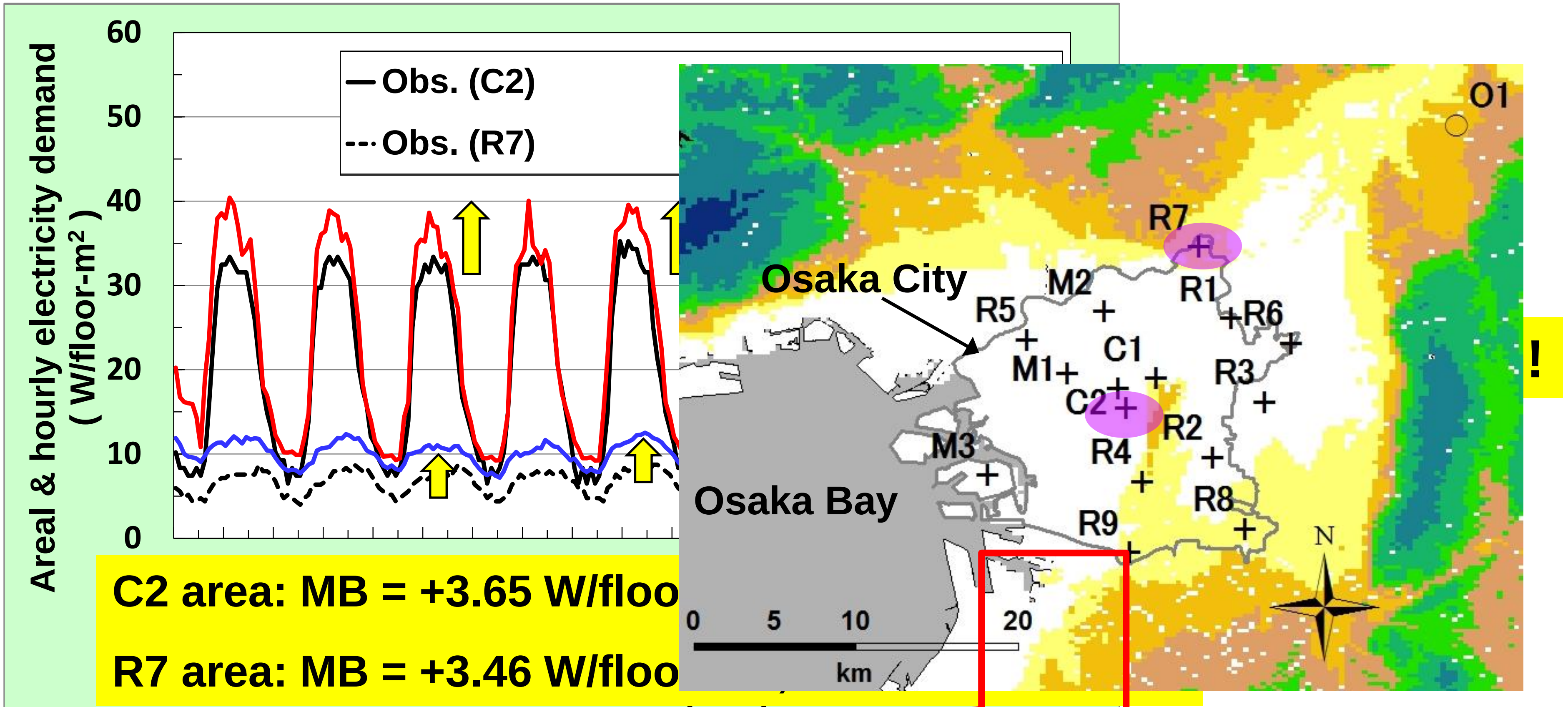

cf. Salamanca et al. [JGR,2014]

**Sample : 720**
**RMSE = 1.7 ˚C**
**MAPE = 3.9 %**

**WRF-CM-BEM shows good performance in terms of reproducibility of the near-surface urban climatology over Osaka in summer so far, compared with the result in recent investigation which used UCP-BEM model.**

# Preliminary Results 4/4 (Simulated electricity demand)

➢ **Period: 30 July - 12 August 2013** **(results on 9 weekdays in C2 & R7)**




**Possible causes**

1. Changes in human behavior after 2011 disaster (about 20% energy-saving, but not yet considered in the simulation)
2. Less realistic settings of BEM parameters? (building materials, HVAC, etc.)

# Conclusions & Ongoing works

- The original system for the simulation of the interaction between building energy demand and urban climate, named WRF-CM-BEM, is used.

- To substantiate the system performance, yearlong field campaign was conducted in Osaka city. Multi-site measurements on UCL climatology and areal electricity demand have been obtained for the model validation.

- Statistical characteristics of Intraurban spatial inhomogeneity in observed S↓ are being quantified with significant site-by-site fluctuations. WRF-CM-BEM seems to be able to roughly reproduce those observed S↓ inhomogeneities suggesting its potential application to evaluation of PV power generation.

- Preliminary analyses suggest promising performance of WRF-CM-BEM so far, in terms of reproducibility of the near-surface air temperature and areal building electricity demand but with a certain overestimation on the latter.

- Further validations are being carried out using yearlong measurements to clarify the ability of WRF-CM-BEM in coupling simulation of urban climate and building electricity demand.