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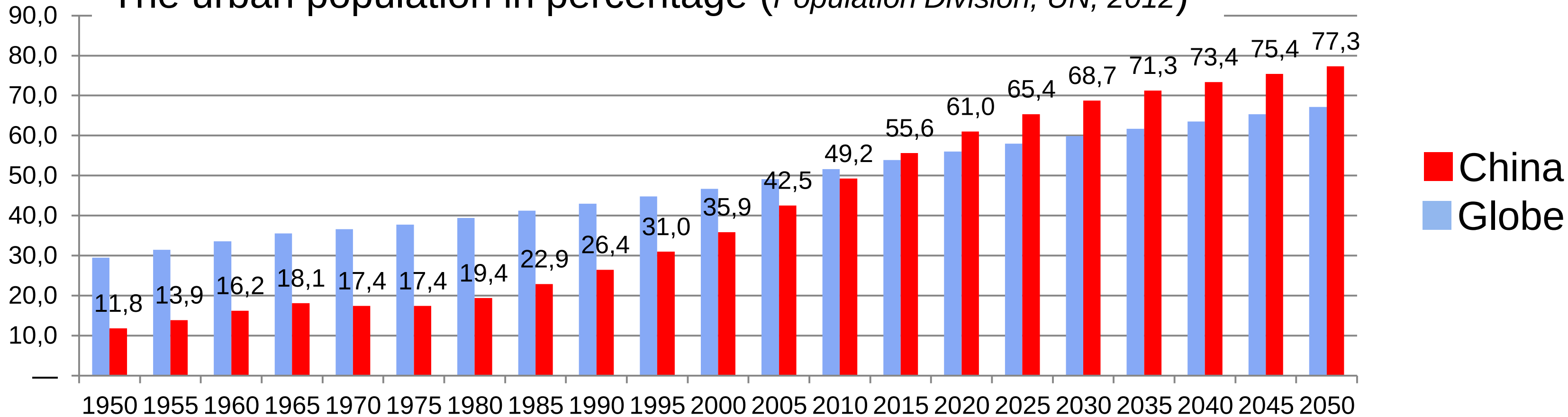
Developing fine-scale urban canopy parameters in Guangzhou city and its application in the WRF-Urban model

Xuemei Wang, Wei Dai
Sun Yat-Sen University
Guangzhou, China

Introduction

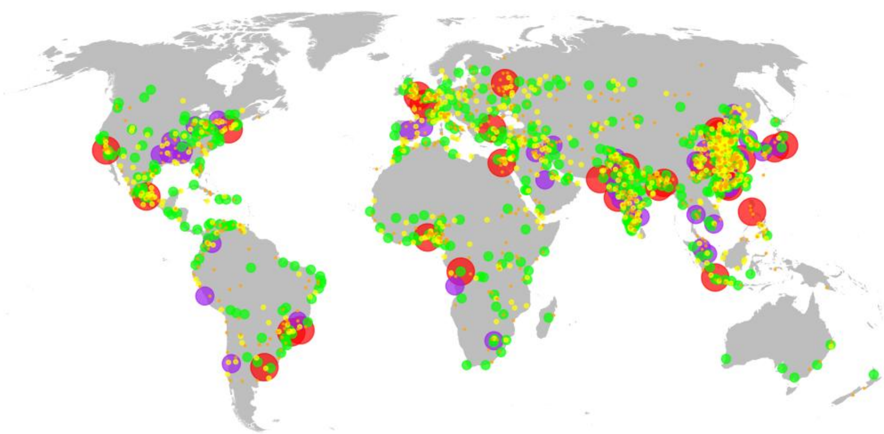
Development of city clusters in China pose a great scientific challenge

The urban population in percentage (*Population Division, UN, 2012*)



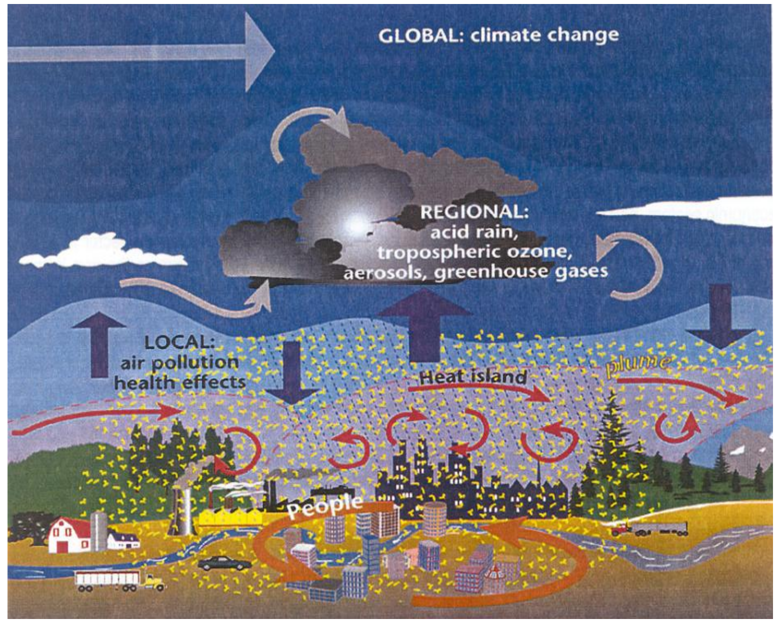
Data source: United Nations, Department of Economic and Social Affairs, Population Division (2012).

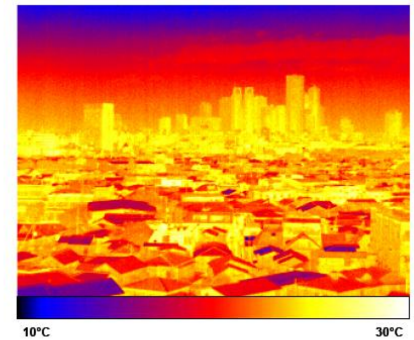
The world's cities by size class of urban settlement, in 2014 (*world urbanization prospects, UN, 2014*)



The challenge with Urbanization

- Urban Heat Island (UHI）
- Extreme weather and climate events
- Heavy air pollution
- Changing of LULC
- Balance of surface radiation、 water vapor and energy
- Anthropologic heat
- Harm human health

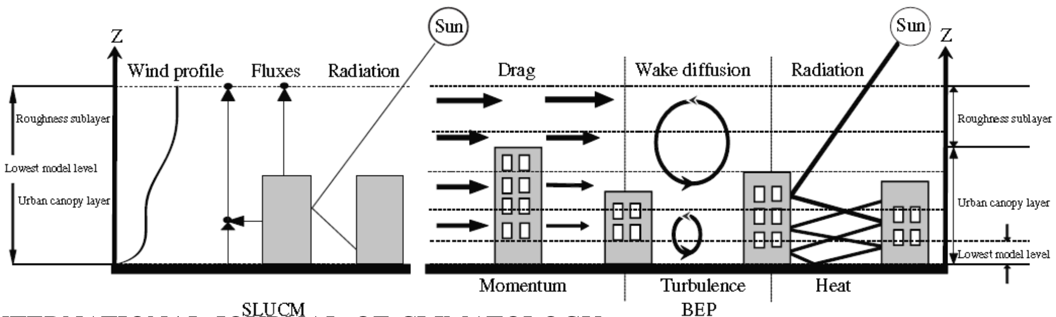




Zhang, Q.; He, K.; Huo, H. Nature 2012

The numerical simulation for Urban climate

Urban canopy models (UCM) in WRF-Urban



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RMetS
Royal Meteorological Society

The integrated WRF/urban modelling system: development, evaluation, and applications to urban environmental problems

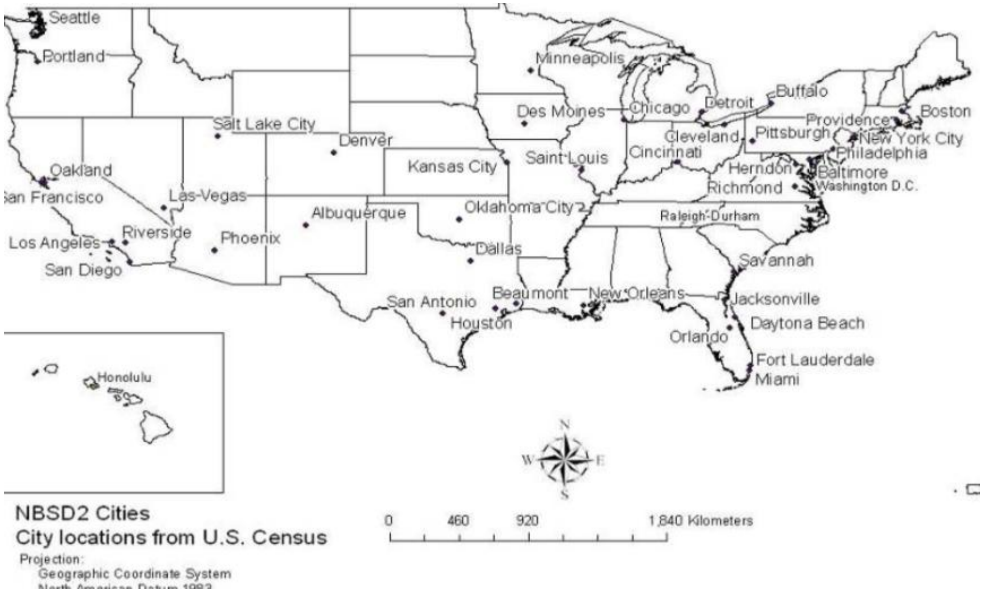
Fei Chen,[a]* Hiroyuki Kusaka,[b] Robert Bornstein,[c] Jason Ching,[d†] C. S. B. Grimmond,[e] Susanne Grossman-Clarke,[f] Thomas Loridan,[e] Kevin W. Manning,[a] Alberto Martilli,[g] Shiguang Miao,[h] David Sailor,[i] Francisco P. Salamanca,[g] Haider Taha,[j] Mukul Tewari,[a] Xuemei Wang,[k] Andrzej A. Wyszogrodzki[a] and Chaolin Zhang[h,l]

UCM requires Urban Canopy Parameters (UCP) !

UCPs are available for US (NUDAPT, Ching et al. 2009).

The NBSD was developed by NUDAPT including data for 44 cities in the USA and it is available to the WRF-Urban.

(Burian et al., 2007, Ching et al., 2009, Burian and Ching, 2010)



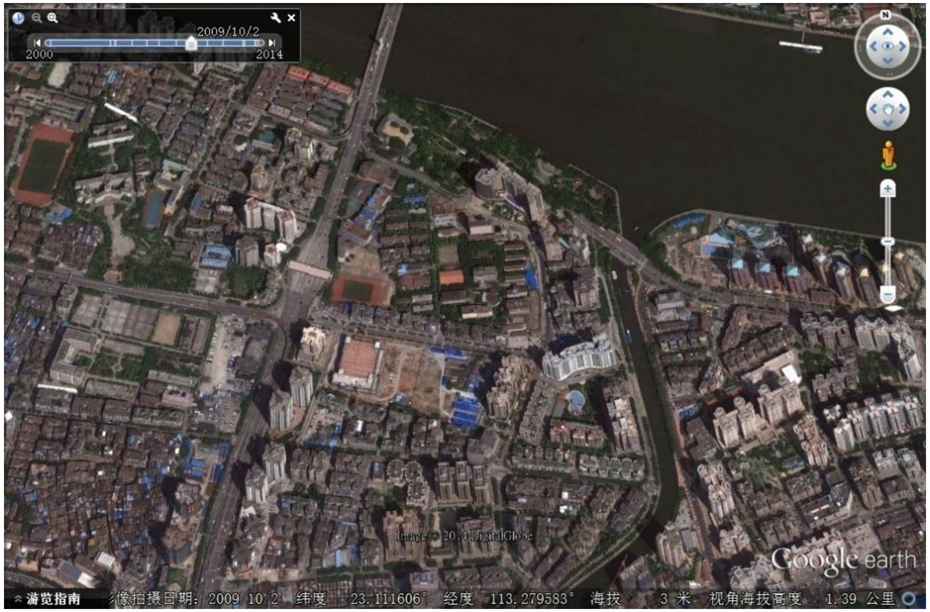
However, obtaining UCPs remains problematic in the developing countries, especially in China.

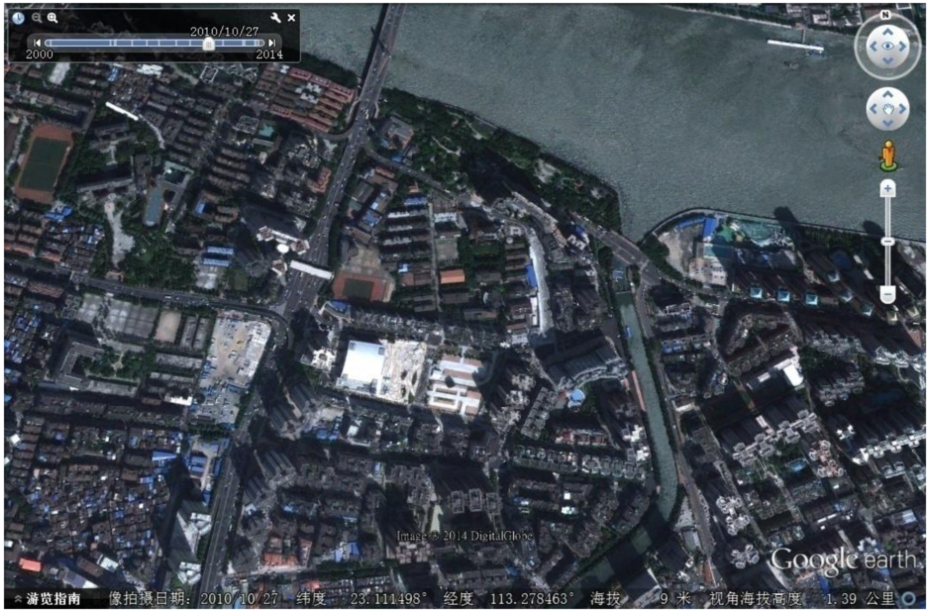
Objectives

- To **establish a methodology** to obtain specific urban morphology for UCM from **Google-Earth images**;
- To develop a **dataset** of fine-scale UCPs in Guangzhou city (GZ-UCPs);
- To **assess impact** of using the **new GZ-UCP**s in WRF-UCM on **local weather**.

Extract building span and height

Time series Google-Earth images for the same location show the building pictures with different solar angle





2th Oct 2009 | 27th Oct 2010

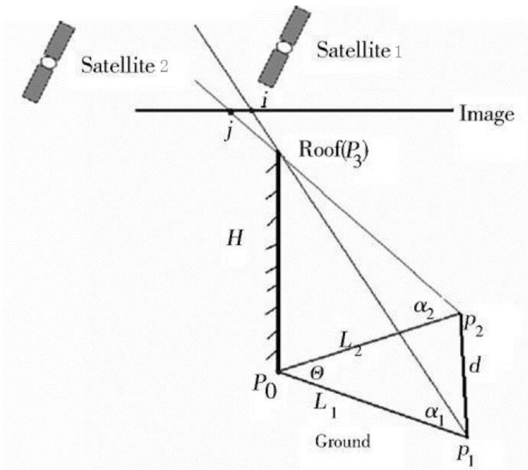
α:19°, θ:68° | α:18°, θ:144°

α:satellite elevation/off nadir angle; θ:satellite azimuth

Similar to the steropair (*Kazuhiko AKENO, 1996*), we could obtain building span and height with GIS and RS technologies, and make a 3D map with building models.

Principle of steropair

Calculation of building height



$$H = \frac{d}{K}$$

$$d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \times GSD$$

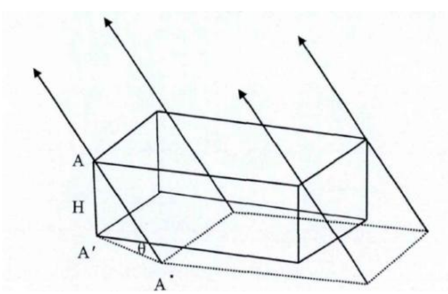
$$K = \sqrt{\cot(\alpha_1)^2 + \cot(\alpha_2)^2 - 2\cos(\theta)\cot(\alpha_1)\cot(\alpha_2)}$$

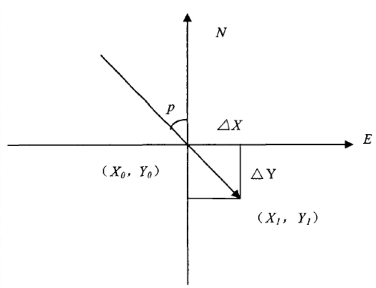
H: building height, GSD: cell size

θ: azimuth difference between two images

α_1: satellite1 elevation , α_2: satellite2 elevation

Adjustment of roof shift





$$\begin{cases} \Delta X = H \sin p / \tan\theta \\ \Delta Y = H \cos p / \tan\theta \end{cases}$$

H: building height

P: satellite azimuth, θ : satellite elevation

There is a little shift between roof and floor of building, and this shift can be fix by building height and satellite parameters.

Workflow

Example for Downloading Google earth image from http://khm1.google.com/kh/v=122&x=213575&y=113771&z=18

The details of tile encoding algorithm for web map imagery can be found in http://msdn.microsoft.com/en-us/library/bb259689.aspx & http://www.codeproject.com/Articles/14793/How-Google-Map-Works

Checking satellite parameters from https://browse.digitalglobe.com/imagefinder/main.jsp?

Roof from image A

Roof from image B

To download map tiles
↓
To mosaic the tiles
↓
Geometric correction
↓
Vectorization of the roof
↓
To calculate the distance between two related roofs of satellites
↓
Calculation of building height ← Satellite Parameters
↓
Adjustment of roof shift

Urban morphology parameters

- mean building height: $\bar{h} = \frac{\sum_{i=1}^{N} h_i}{N}$
- mean building height weighted by building plan area: $\bar{h}_{AW} = \frac{\sum_{i=1}^{N} A_i h_i}{\sum_{i=1}^{N} A_i}$
- building plan area fraction: $\lambda_p = \frac{A_p}{A_T}$
- Building Plan Area Density: $a_p(z) \cong \frac{\lambda_p(z)}{\Delta z}$
- Roof Area Density: $L(z) = \int_{z}^{h_c} a_r(z')\, dz'$
- Building Frontal Area Index: $\lambda_f(\theta) = \frac{A_{proj}}{A_T}$
- Frontal Area Density: $a_f(z,\theta) = \frac{A(\theta)_{proj\ (\Delta z)}}{A_T \Delta z}$
- Complete Aspect Ratio: $\lambda_c = \frac{A_c}{A_T} = \frac{A_W + A_R + A_G}{A_T}$
- Building Surface Area to Plan Area Ratio: $\lambda_B = \frac{A_W + A_R}{A_T}$
- Height-to-Width Ratio: $\lambda_S = \frac{(H_1 + H_2)/2}{S_{12}}$

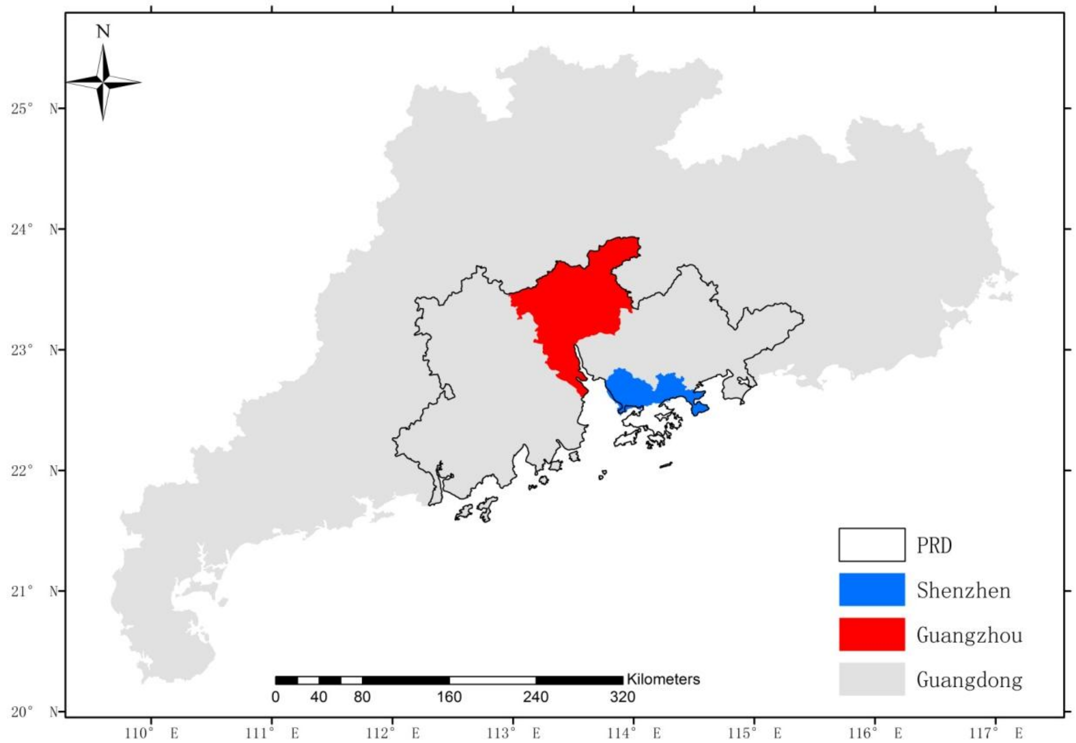
Burian et al., 2007, Development and assessment of the second generation national building statistics database.

City cluster of PRD

Pearl River Delta(PRD) is one of the largest city clusters in China, and it includes 9 cities.

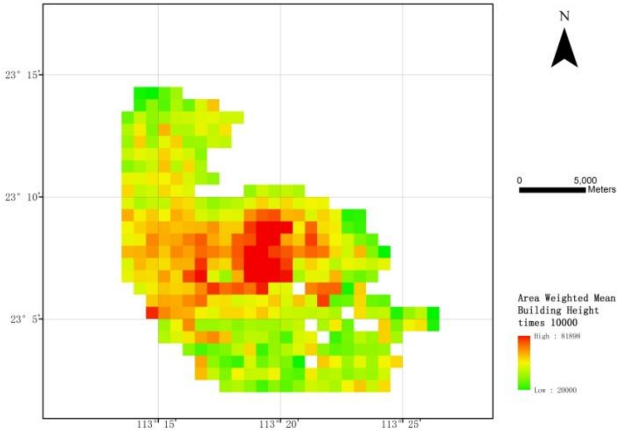
Population of built up area was 40 million with an area of about 20,000 km^2.

City	Area/Core (km^2)	Population (2010 census) >5 million
Guangzhou	7,434.4/ 279.63	12,700,800
Shenzhen	2,050/ 412	10,357,938
Dongguan	115.98/ 24.8	8,220,237
Foshan	3,840/ 154	7,194,311

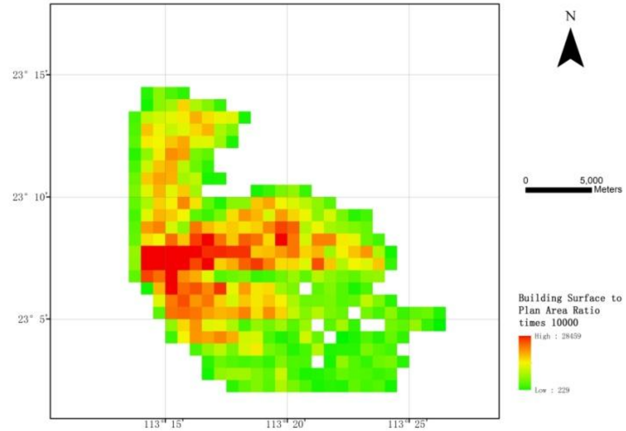


Because of the big populations and wide built-up areas, We chose Guangzhou for testing.

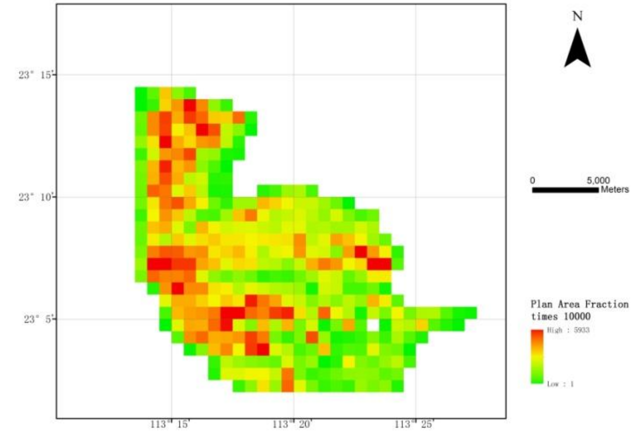
1-km UCPs in Guangzhou



Area weight mean build height

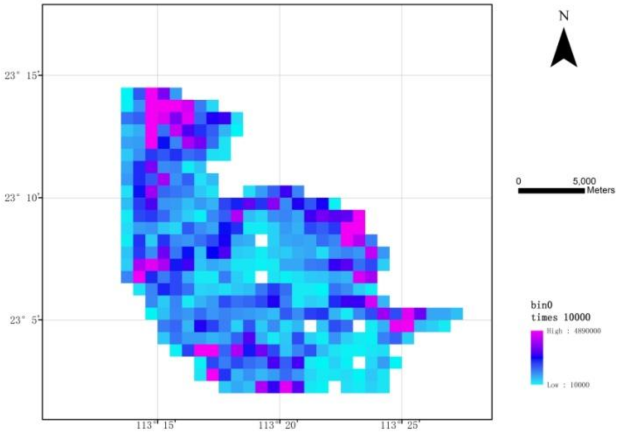


Building Surface to Plan Area Ratio

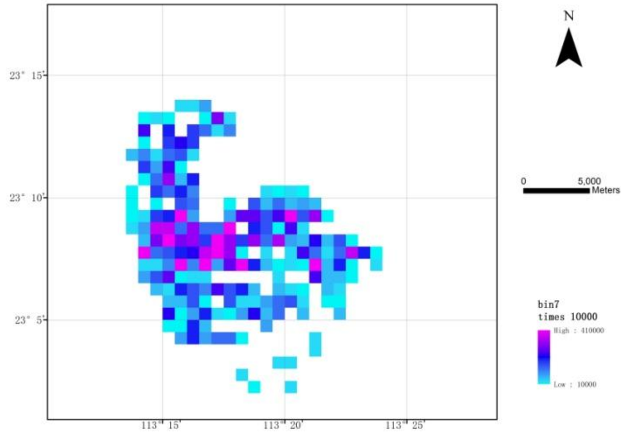


Plan Area Fraction

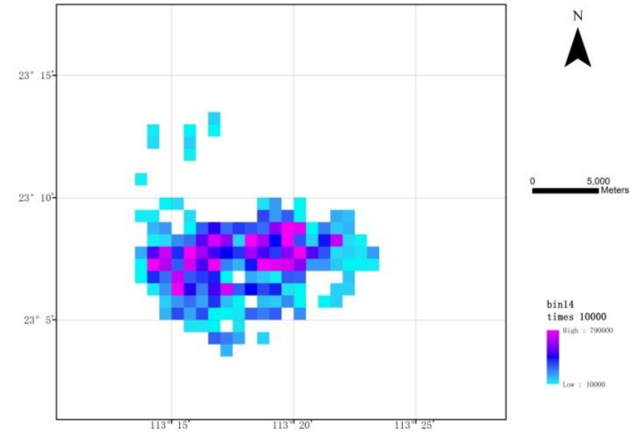
Distribution of building heights



5m

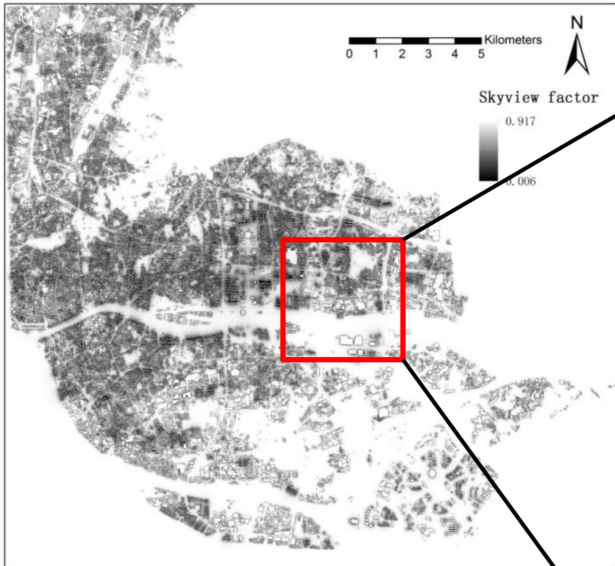


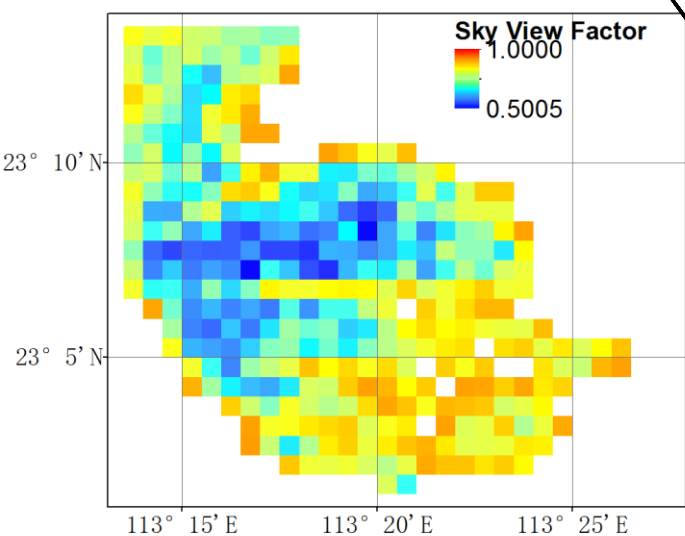
35m



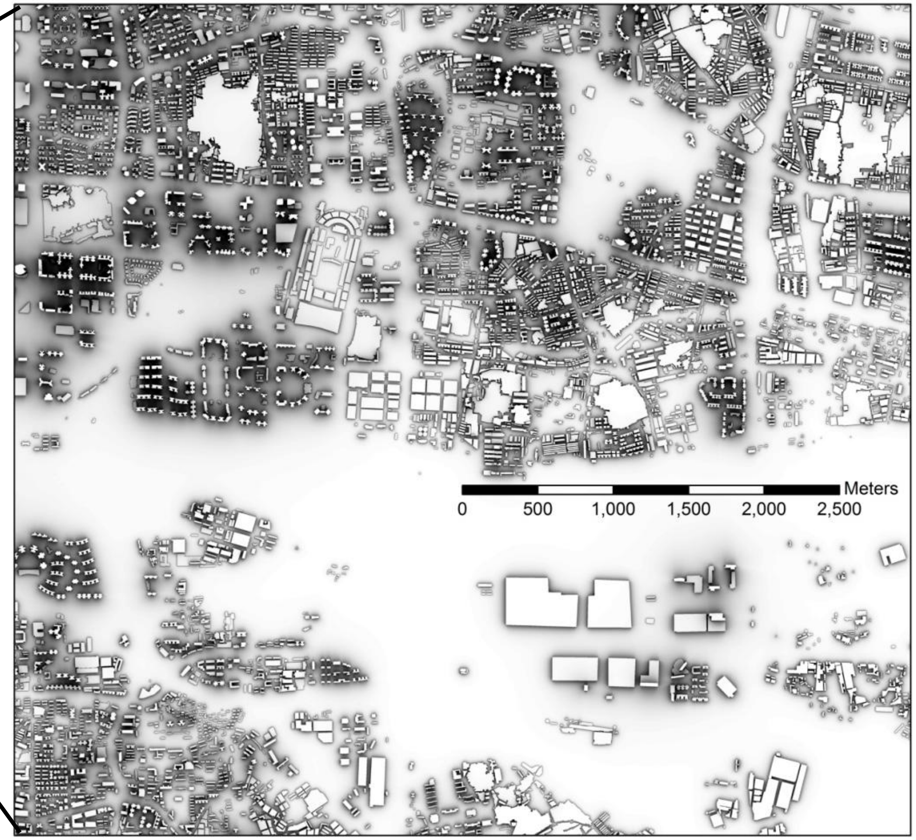
70m and more

Skyview factors



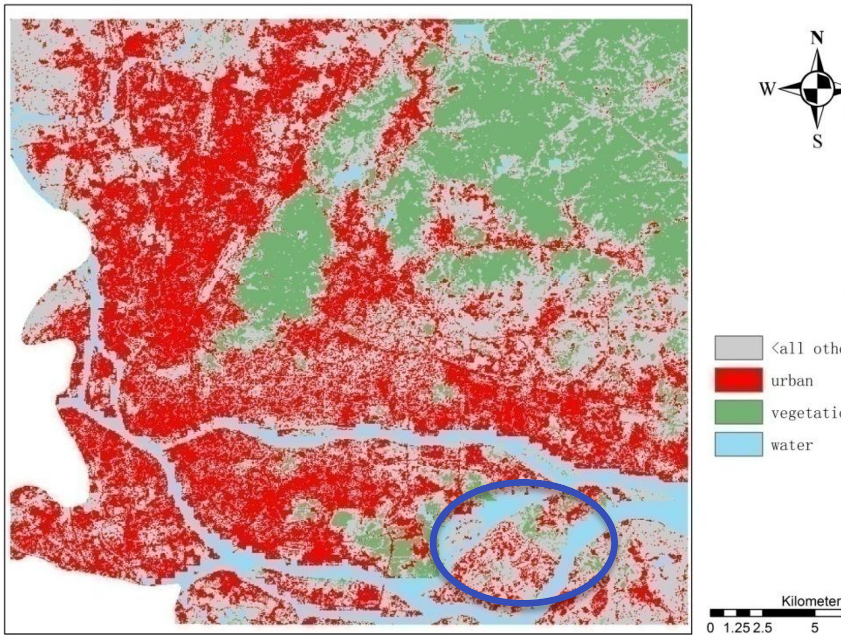


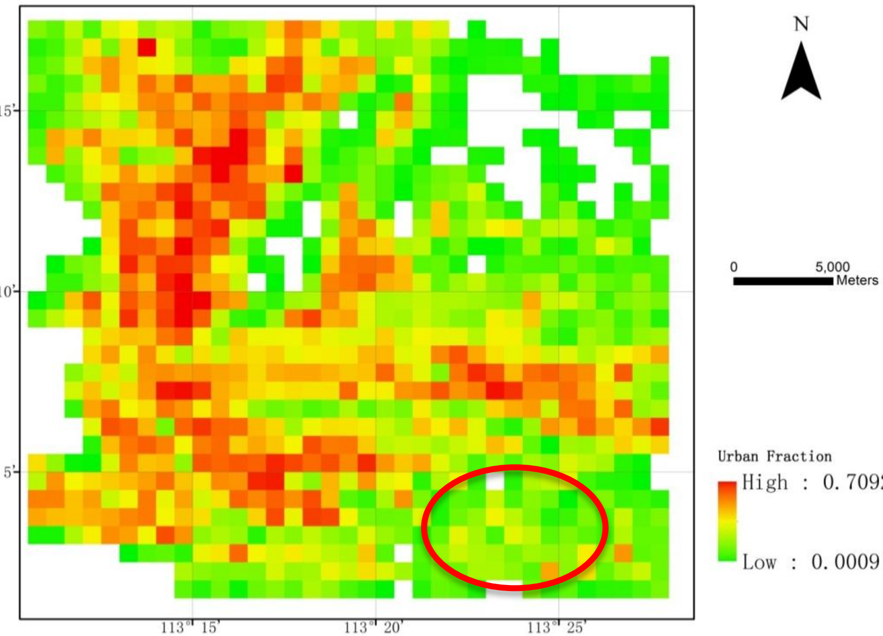
1km Grid size



Raw data with 1m grid size

Ensure consistency





The global land cover data 2010- 30 m resolution

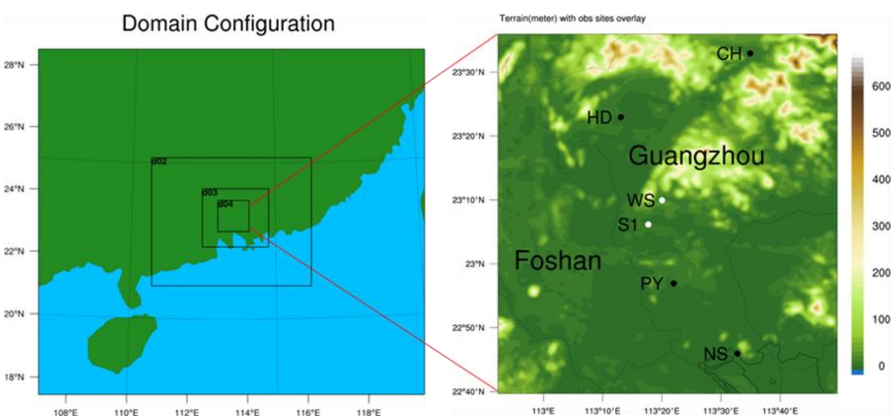
Urban fraction 1km resolution

The urban fraction calculated from ESS2013 (the global land cover database)
http://data.ess.tsinghua.edu.cn/index.html

Configuration of simulation

WRF-ARW V3.5.1 coupled with Noah3.1 LSM and UCM schemes (SLUCM and BEP)

11-day simulations are performed from 0000LST 31 Oct 2010 to 0000LST 11 Nov 2010



The d04 includes the core urban area of Guangzhou with six meteorological stations for model evaluation, and two stations drawn by white point located in the range of GZ-UCPs area.

Scheme	**d01(13.5km)**	**d03(4.5km)**	**d03(1.5km)**	**d04(500m)**
Microphysics	WSM5			
Long/short radiation schemes	RRTM/Dudhia			
Surface-layer physics option	Monin-Obukhov Eta scheme			
Land-surface option	Unified Noah LSM			
Cumulus parameterization option	KF	G3	disable	
Urban Surface option	Disable			BEP
Boundary Layer option	MYJ			BouLac

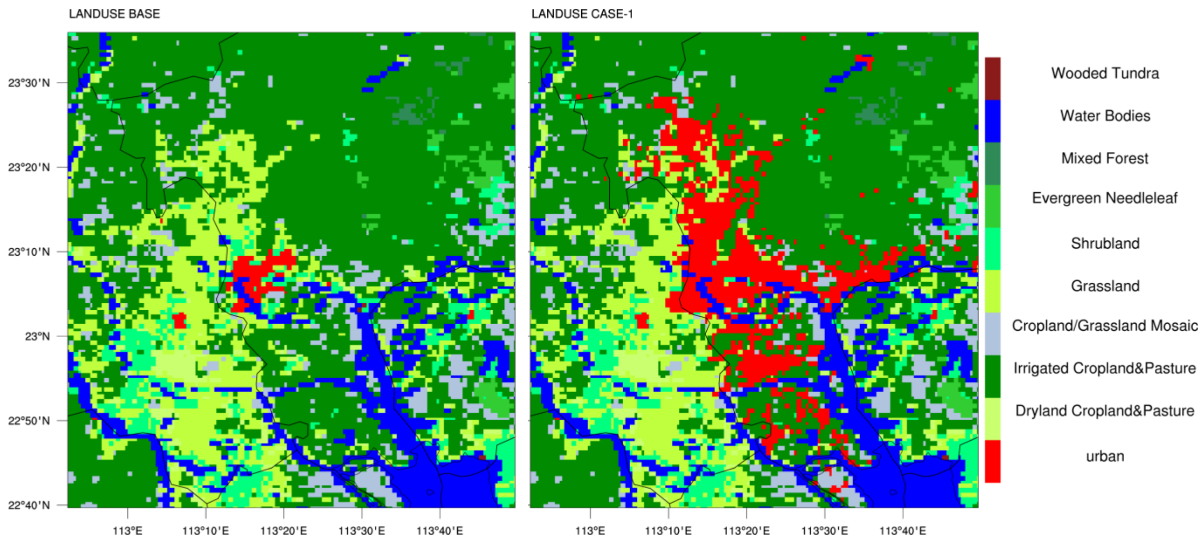
The setting of WRF parameterizations schemes

- The Initial and boundary conditions were provided by NCEP/FNL
- 4 nested domains with 500m grid size of inner domain. 48 vertical level

UCPs in WRF-urban replaced by GZ-UCPs

Model BEP variable	GZ-UCPs (new)		URBPARM.TBL (old)	
LF_URB2D	Plan area fraction	LamP		Function of Street width & Building width
HGT_URB2D	Area weighted mean building height	awaHT		Function of building Distribution
HI_URB2D	Distribution of building heights	Histogram	Building Distribution	5 m : 33 % 10 m : 34 % 15 m : 33 %
LB_URB2D	Building surface to plan area ratio	LamB		Function of Street width、Building width and Building Distribution
			Street width (m)	15
			Building width (m)	15
FRC_URB	Urban fraction	LamU	Urban fraction	0.95 %

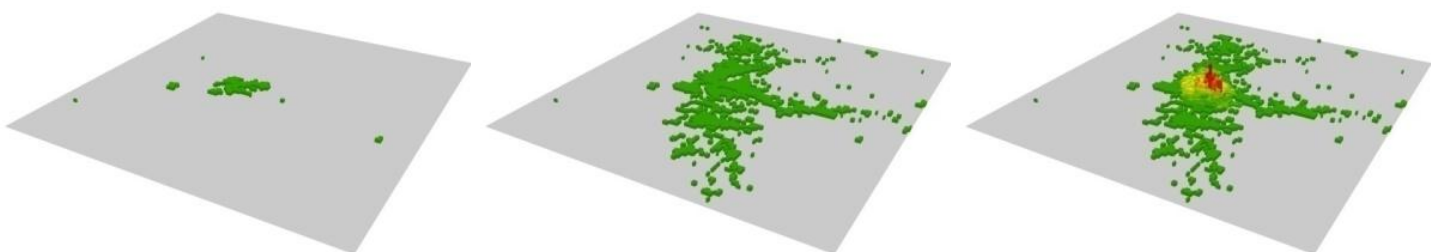
WRF-Urban Experiment setup



Base

Case1 & Case2

- Base: Before rapid urbanization (USGS 1993)
- Case1: Urbanized Guangzhou city (MODIS 2001)
- Case2: Urbanized Guangzhou city with GZ-UCPs



Base

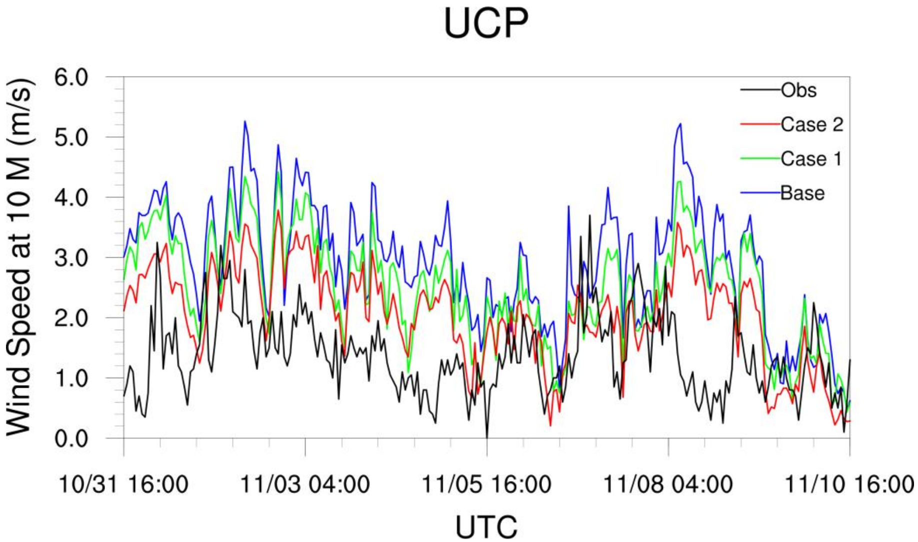
Case1

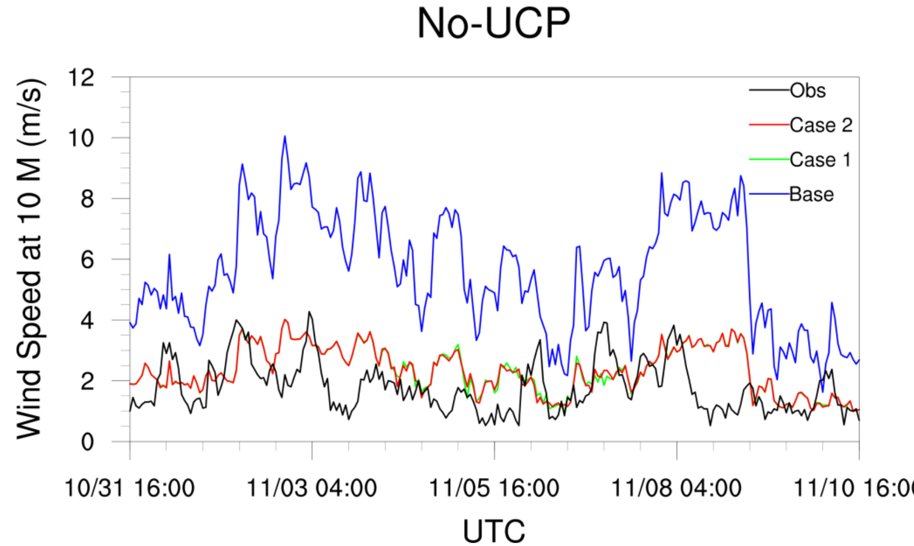
Case2

Time series of wind speed Simulation Vs. Observation

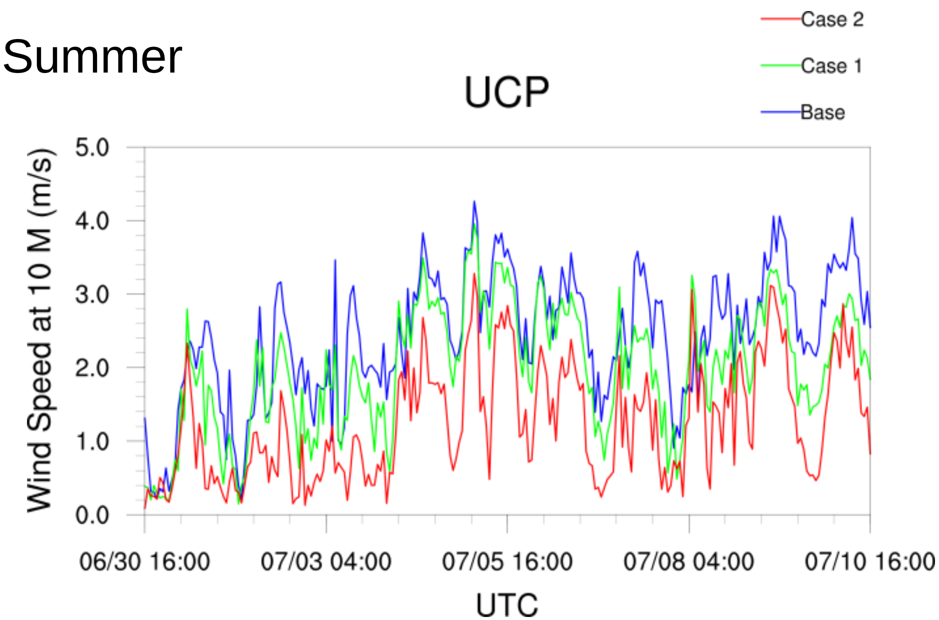
Fall

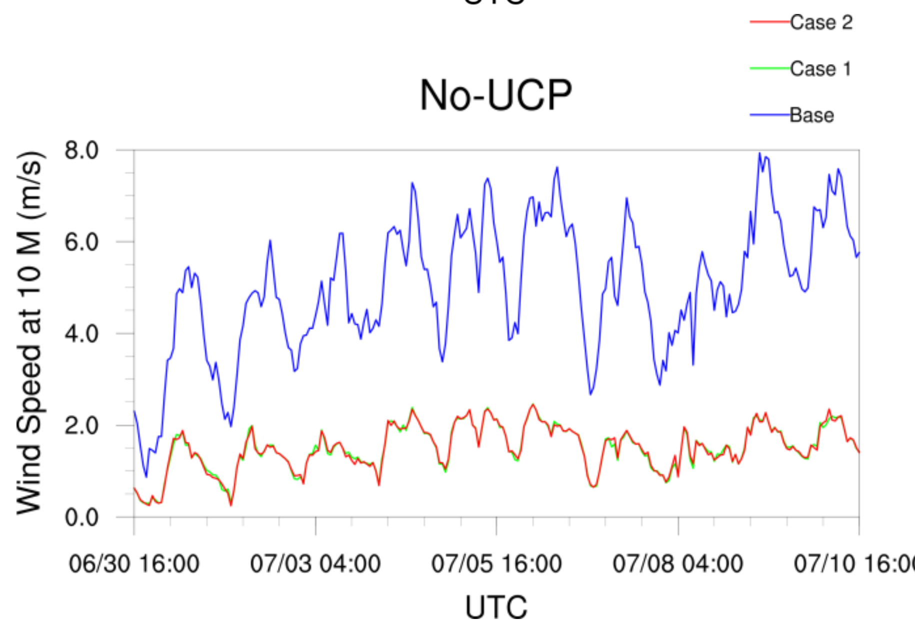
GZ-UCPs is more close to observation





Summer



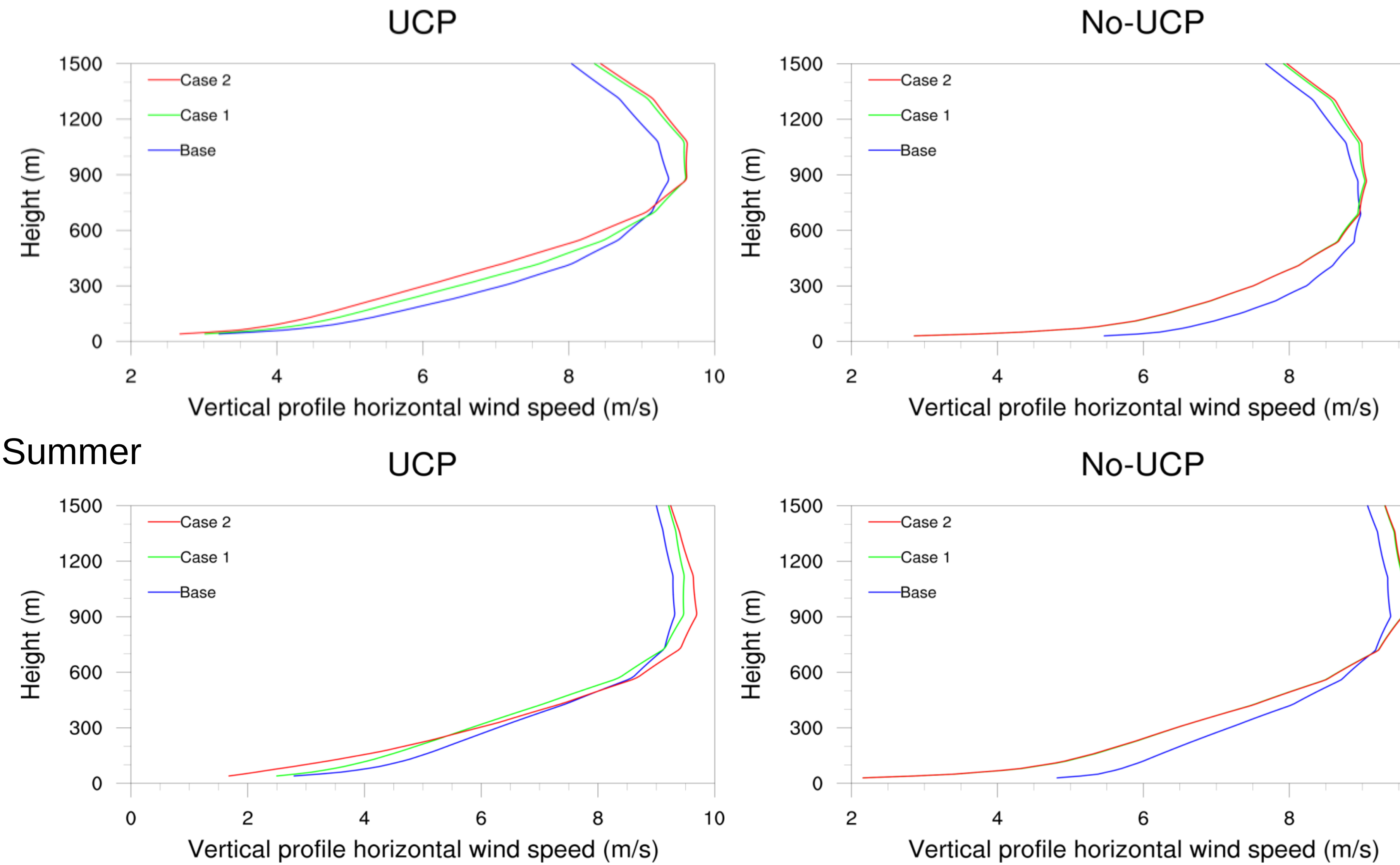


Vertical distribution of wind speed

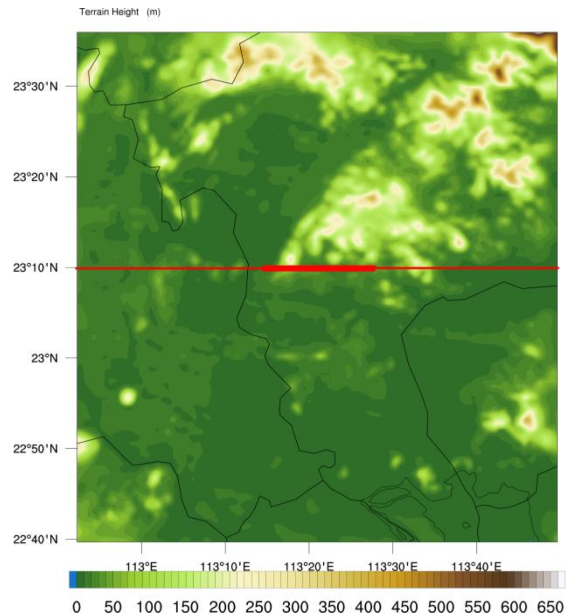
GZ-UCPs strengthen the vertical wind shear

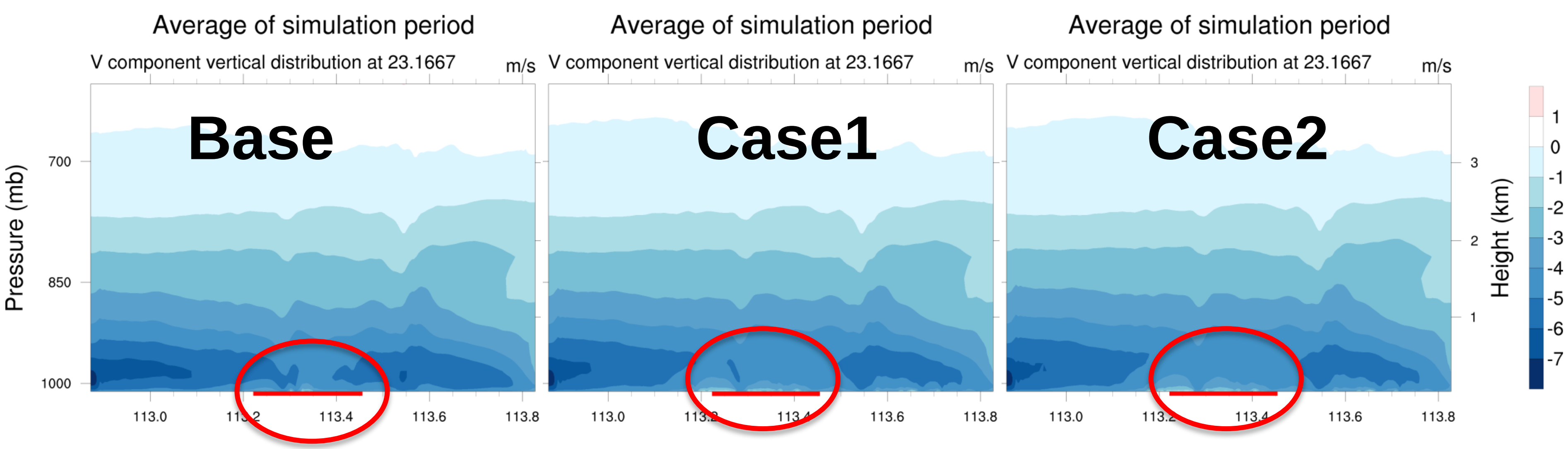
Fall

Summer



Vertical section of V wind distribution





Conclusion

1. We developed a new framework, based on Google-earth images, to derive comprehensive UCPs for its applications in WRF-Urban in Guangzhou.
2. New UCPs significantly impact WRF-Urban:
   - Improve high biases in surface wind speed
   - Increase vertical wind shear, hence affect atmospheric transport and diffusion
   - Impact of cities on downwind has increased

Future work:

- To enhance efficiency of extracting building span,
- To create the urban structure database for the entire PRD city clusters

Thank you !

Diurnal variation of vertical temperature