Developing Fine-scale Urban Canopy Parameters in Guangzhou City and its Application in the WRF-Urban model

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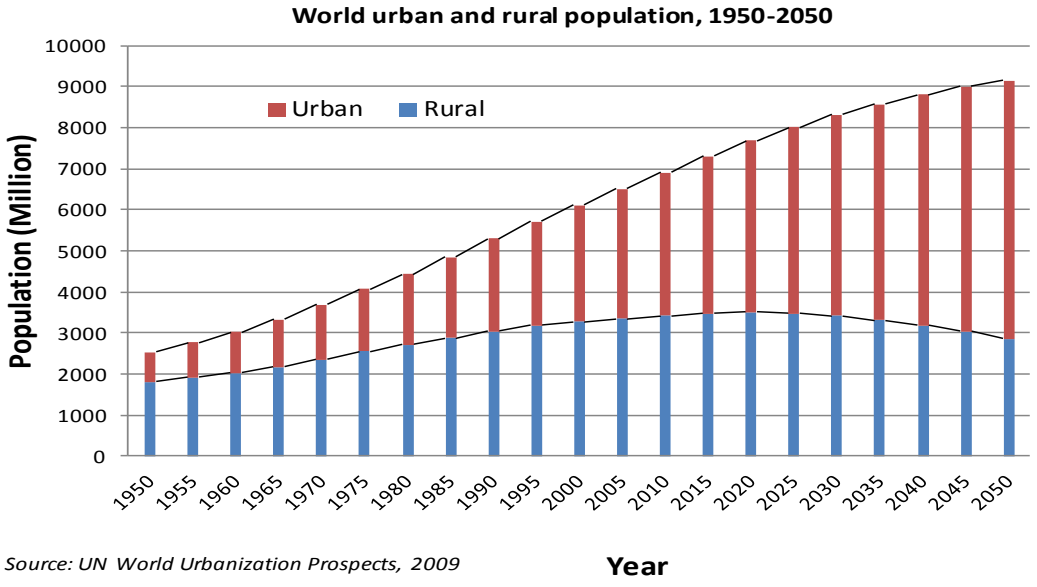
Guangzhou, China
25 May, 2017

Rapid urbanization

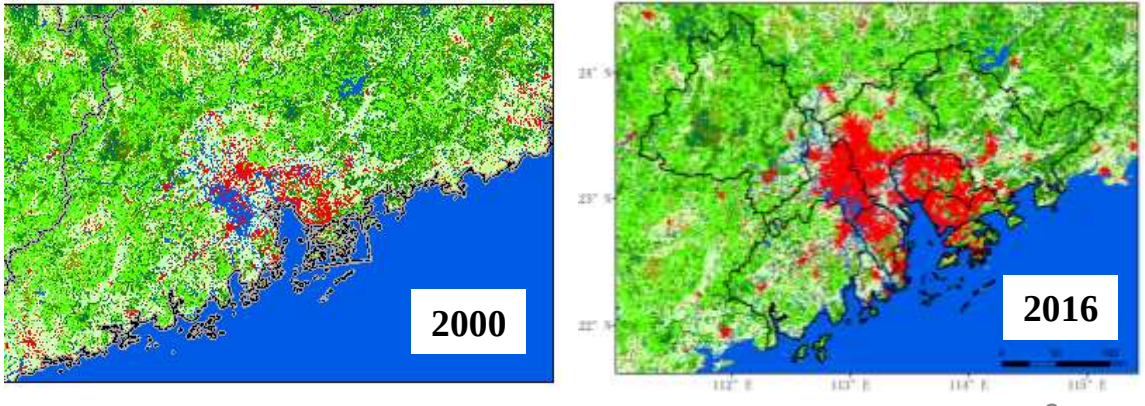
Wong et al. “Hong Kong, past, present and future”



Source: UN World Urbanization Prospects, 2009

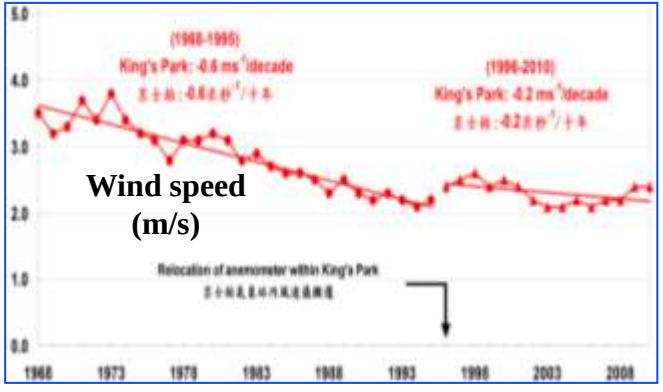
- 51% (i.e. 3.5 billion) of 6.9 billion by 2010; 60% (i.e. 5.0 billion) of 8.3 billion by 2030.
- Large cities worldwide (>1 million): 355, by 2000; 449 by 2010 , 668 by 2025.

Land use in Pear River Delta region(2000→2016)



Urban air pollution, urban heat island/urban warming
Coupling with global warming and regional air pollution

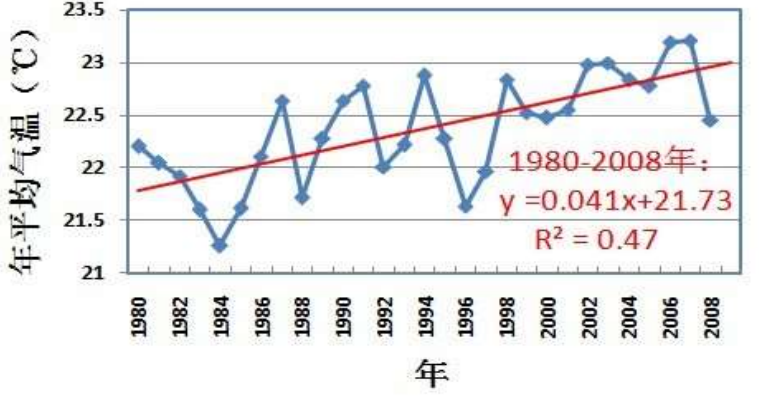
Urban wind speed is decreasing



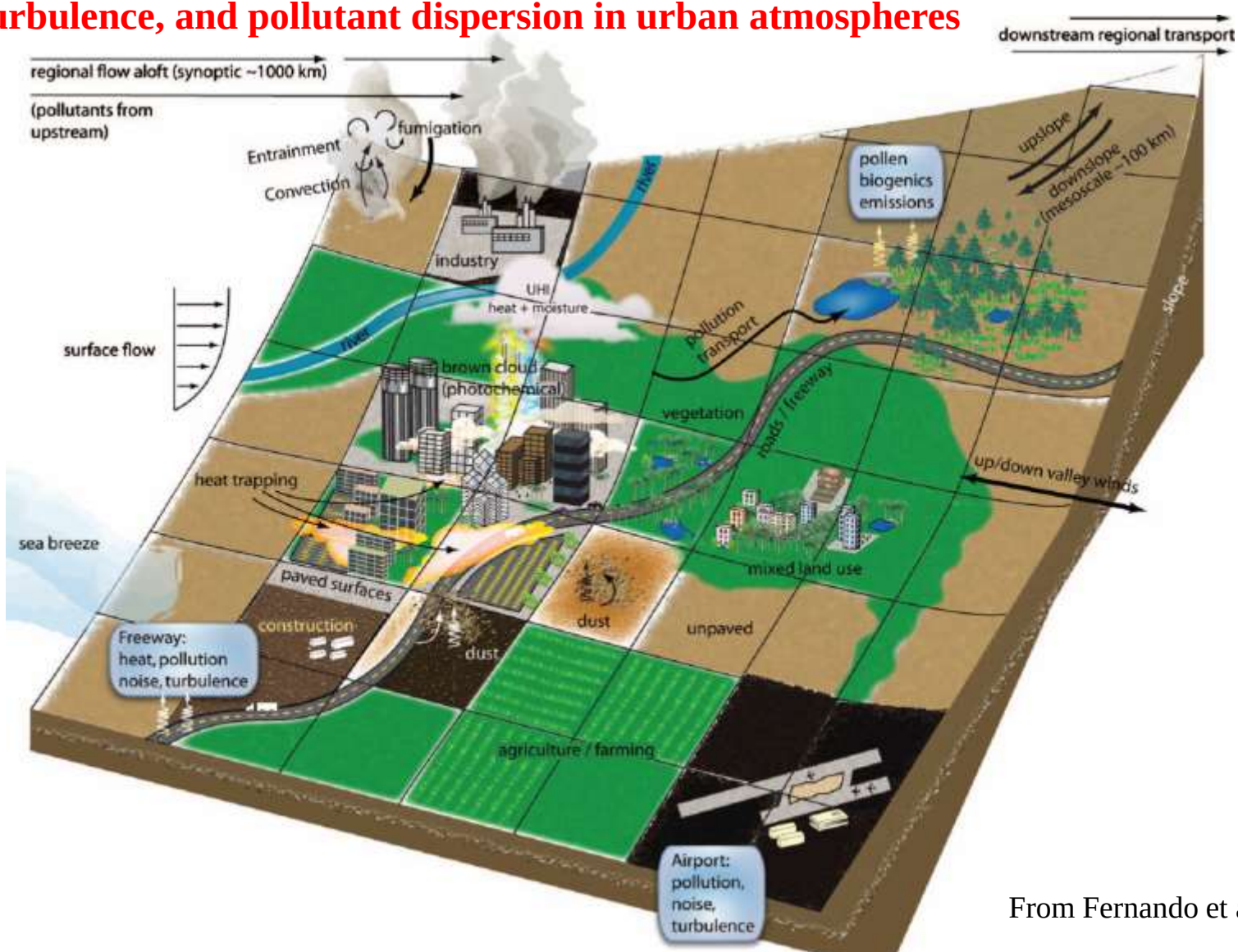
Urban air pollution and visibility

- In the last 30 years, Urban air temperature of Guangzhou increased 0.41°C/10yr, larger than the increase by global warming (0.19 °C/10yr)
- In hot regions, urban ventilation and solar sheltering are more significant.

Temperature increases in Guangzhou

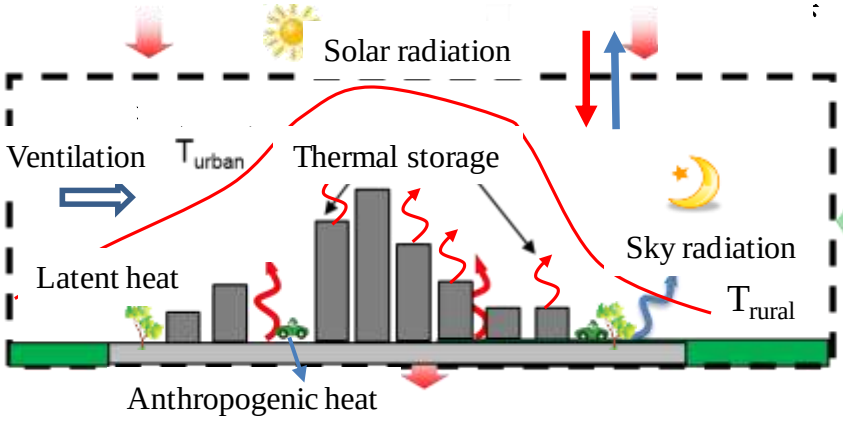


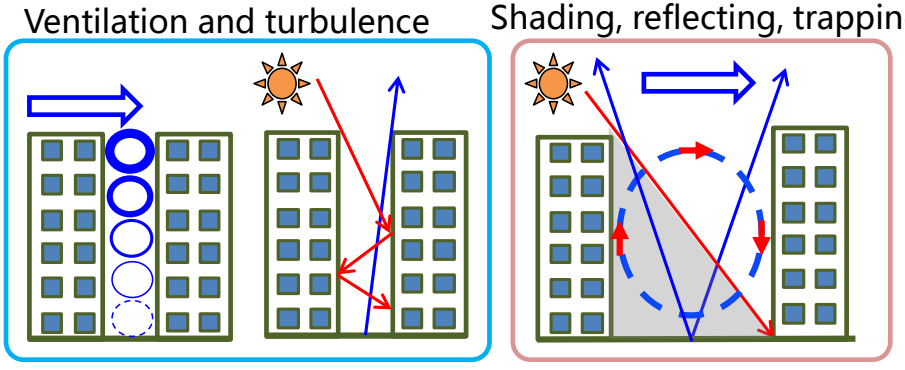
Flow, turbulence, and pollutant dispersion in urban atmospheres

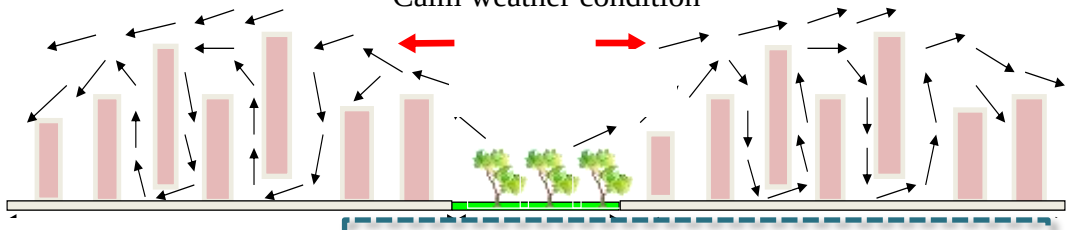


From Fernando et al. (2010)

The impacts of each factor have not been clearly known





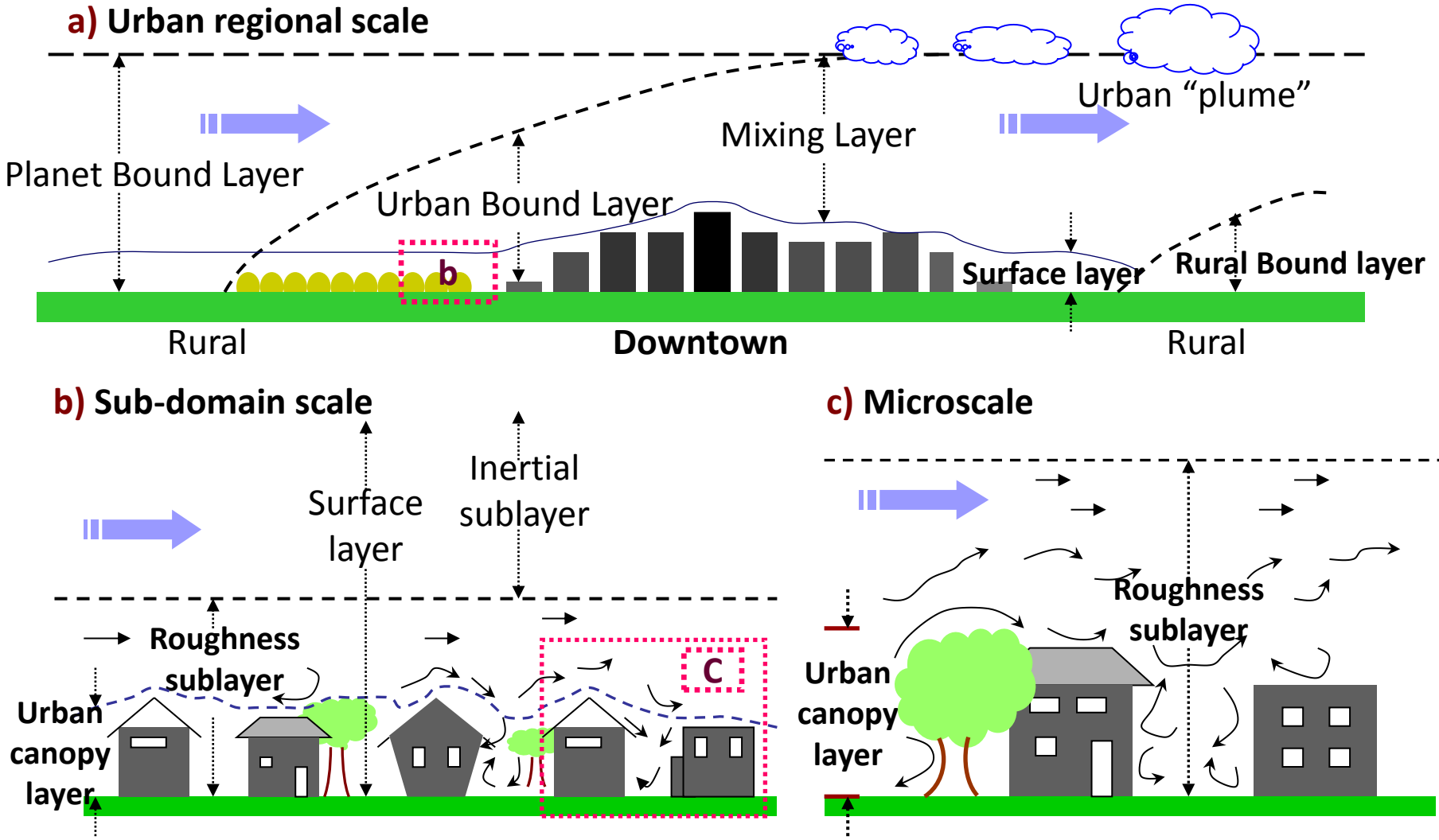


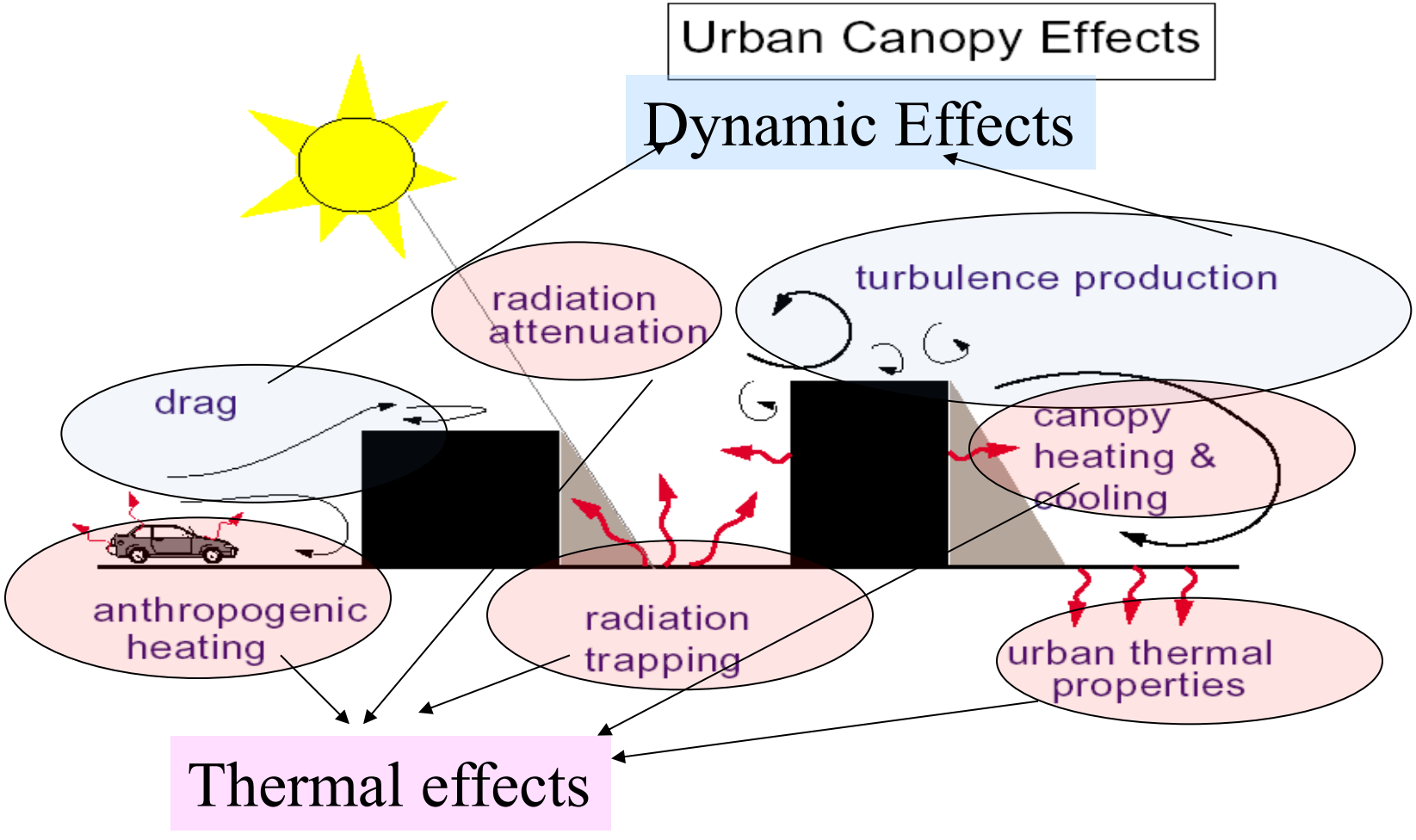
- Regional air pollution
- Meteorological condition
- Building morphologies
- Urban vegetation
- Anthropogenic heat
- Chemical reaction/green-house effect of pollutants

Non-linear coupling impact

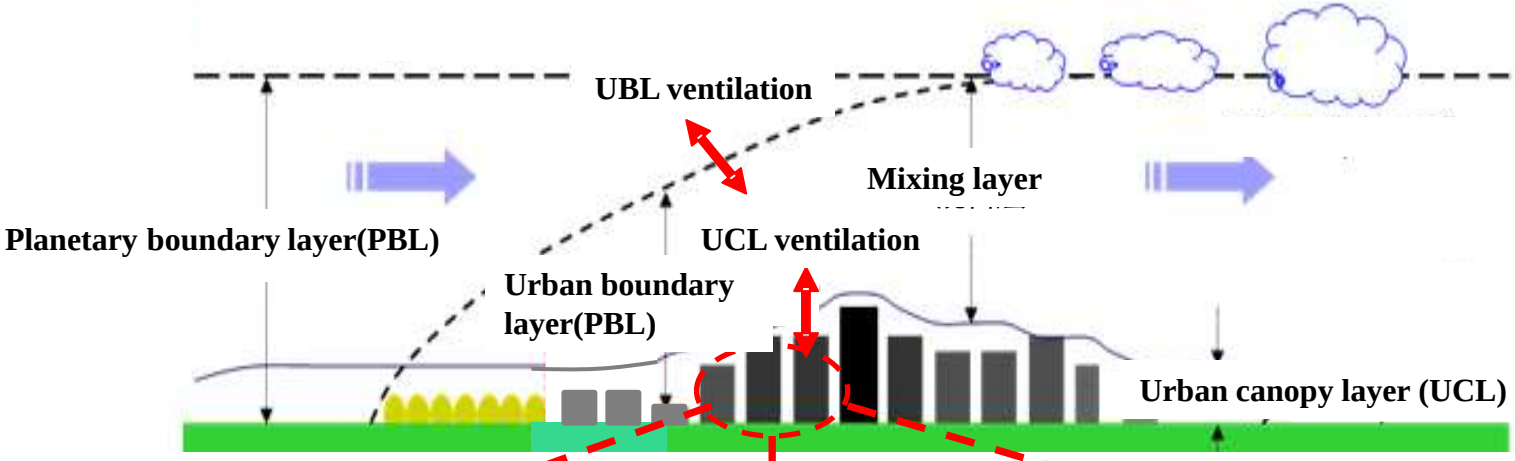
- Urban air pollution/visibility
- Urban thermal environment
- Urban air pollution/human health
- Urban energy consumption

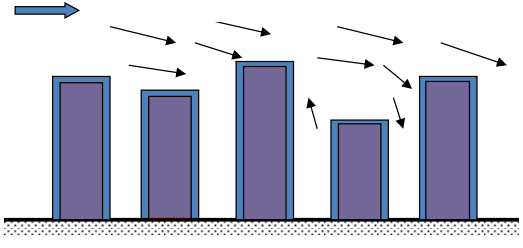
Multi-scale complex structure of atmospheric motions in UBL



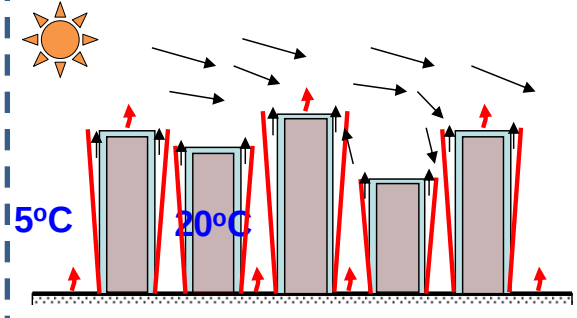

Urban Canopy Effects
Dynamic Effects
radiation attenuation
turbulence production
drag
canopy heating & cooling
anthropogenic heating
radiation trapping
urban thermal properties
Thermal effects

Urban Thermal and Dynamics effects

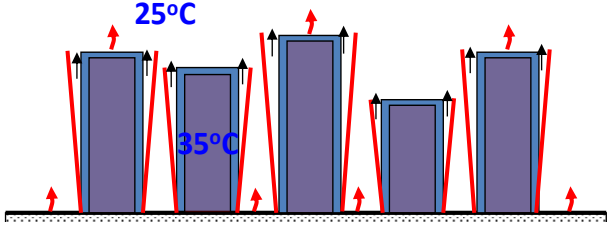




As wind is strong, thermal effect can be disregarded.



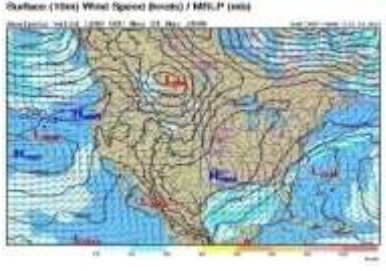
Both wind and thermal effects are key factors



Thermal effects dominate urban turbulence in calm weather conditions

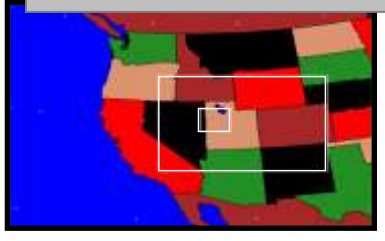
The physical modeling system:
----A spectrum of coupled scales

Global Scales

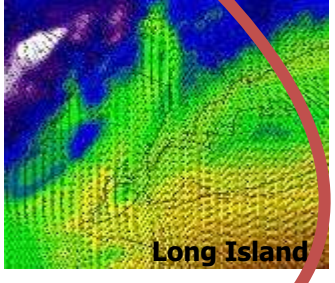


Continental Scales

Current technology for operational weather and climate prediction



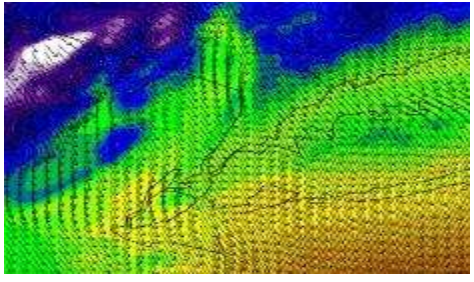
Regional Scales



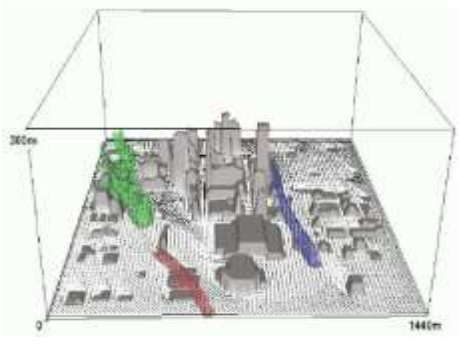
Local Scales

Urban Scales

Challenge in representing multi-scale urban microclimate

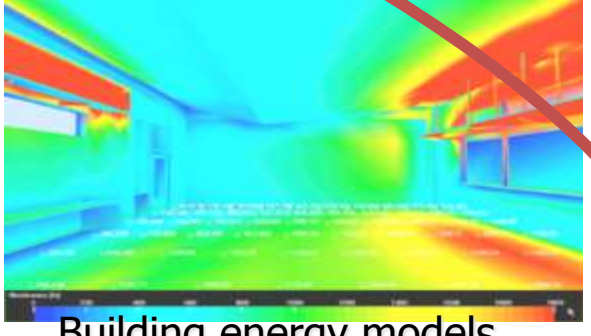


Mesoscale models



Urban Scale models (CFD, LES)

New technology for coupling fine-scale models



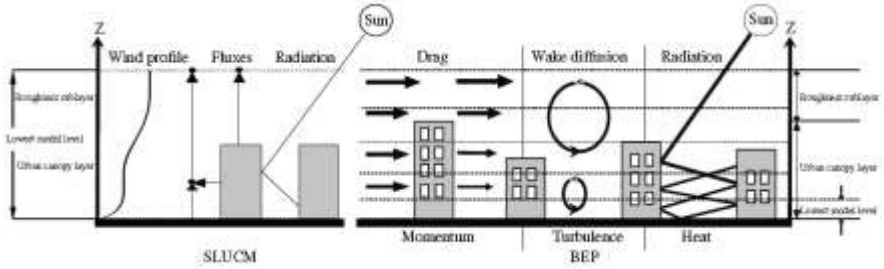
Building energy models
Indoor-outdoor exchange

$C = C_{regional} + C_{city} + C_{neighborhood} + C_{street}$

$C_{regional}$	C_{city}	$C_{neighborhood}$	C_{street}
(~1000km)	(~10km)	(~1km)	(~100m)
WRF/MM5	UCM	CFD	CFD

The numerical simulation for urban climate

Urban canopy models (UCM) in WRF-Urban



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(wileyonlinelibrary.com) DOI: 10.1002/joc.2158

RMetS
Royal Meteorological Society

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

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UCM requires Urban Canopy Parameters (UCP) !

UCPs are available for US

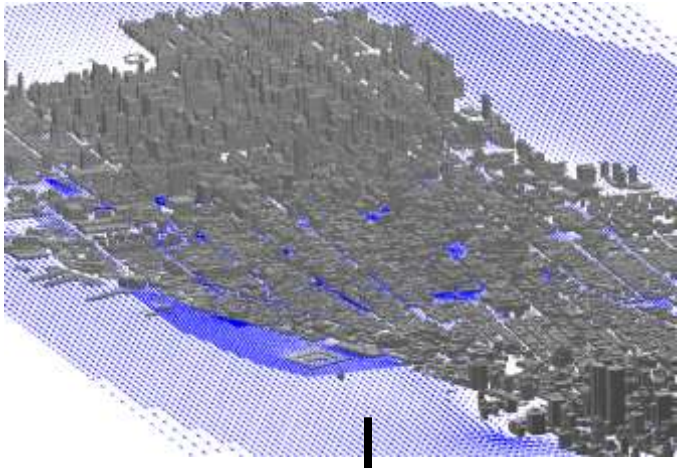
(NUDAPT, Ching et al. 2009).

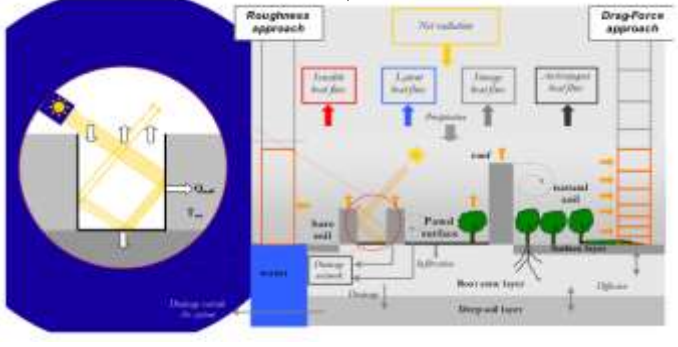
The NBSD was developed by NUDAPT including data for 44 cities in the USA and it is available to the WRF-Urban.

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

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

Challenge: from Real World to UCM





Urban canopy model (UCM) parameter space

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

α:19°, θ:68°

27th Oct 2010

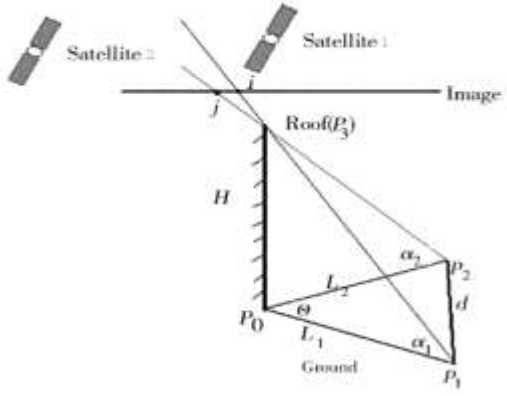
α:18°, θ:144°

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



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

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

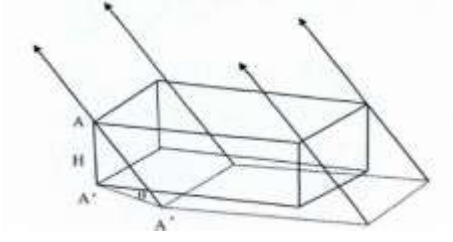
$$K = \sqrt{\cot(\alpha_1)^2 + \cot(\alpha_2)^2 - 2\cos(\theta)\cot(\alpha_1)\cot(\alpha_2)}$$

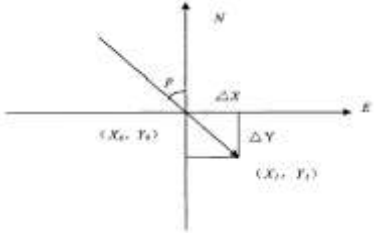
H: building height, GSD: cell size

θ: azimuth difference between two images

α_1: satellite1 elevation , α_2: satellite2 elevation

Adjustment of roof shift





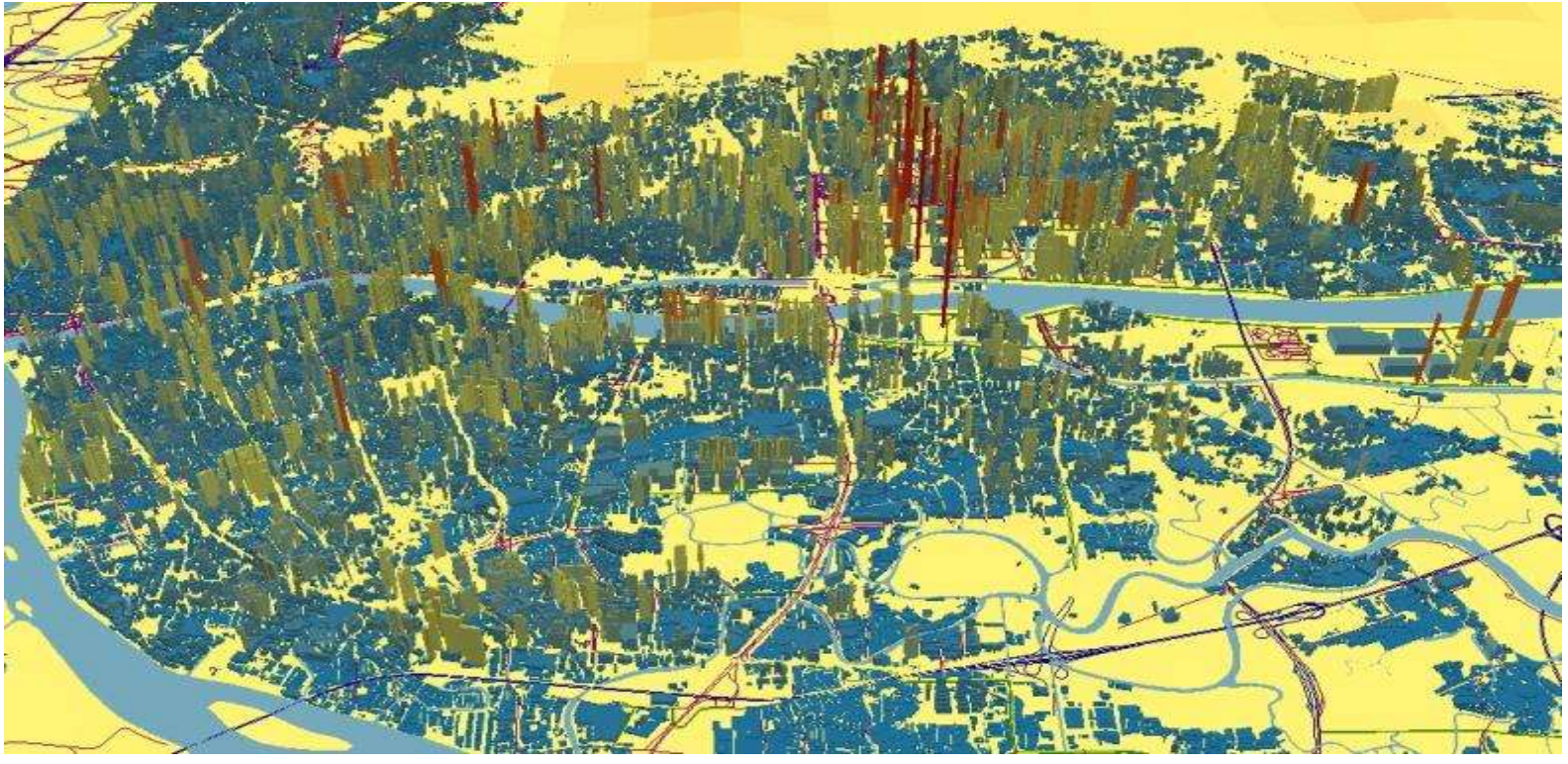
$$\begin{cases} \Delta X = H \sin p / \tan\theta \\ \Delta Y = H \cos p / \tan\theta \end{cases}$$

H: building height

P: satellite azimuth, θ : satellite elevation

Dai W. and Wang X.M., 2015

A 3D map of building models in Guangzhou city



Over 77 thousand 3D building models

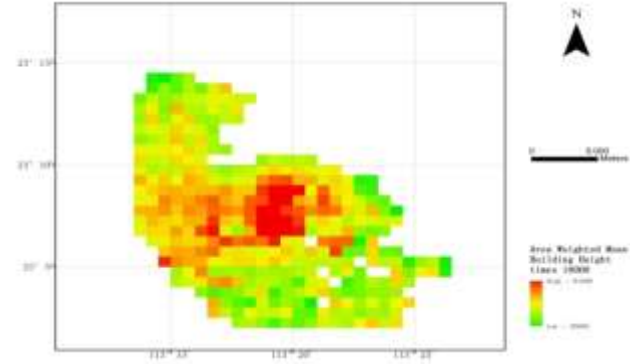
Dai W. and Wang X.M., 2015

Urban Morphology Parameters

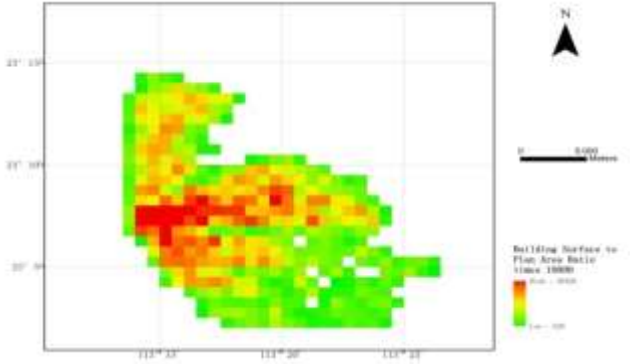
- mean building height: $\bar{h} = \frac{\sum_{i=1}^{N} h_i}{N}$
- mean building height weighted by building plan area: $\bar{h}_{AW} = \frac{\sum_{i=1}^{N} A_i h_i}{\sum_{i=1}^{N} A_i}$
- building plan area fraction: $\lambda_p = \frac{A_p}{A_T}$
- Building Plan Area Density: $a_p(z) \cong \frac{\lambda_p(z)}{\Delta z}$
- 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.

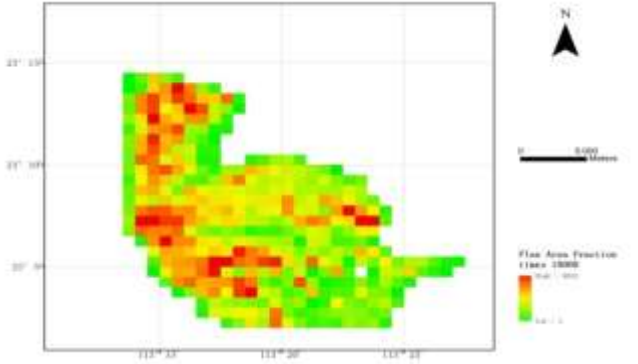
1-km UCPs in Guangzhou



Area weight mean build height

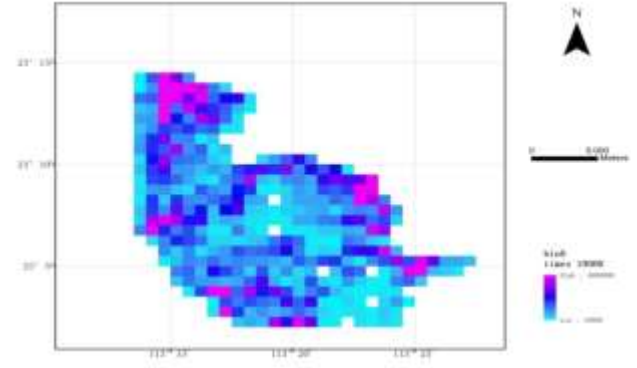


Building Surface to Plan Area Ratio

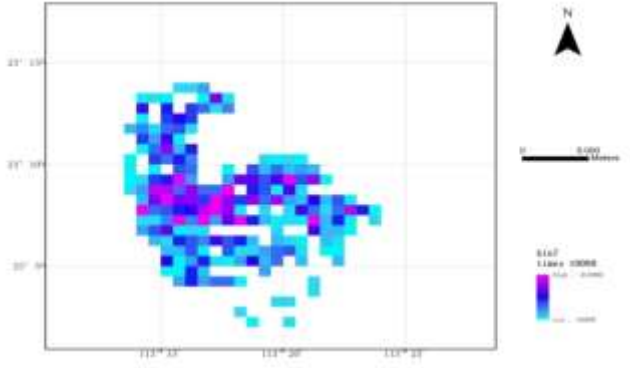


Plan Area Fraction

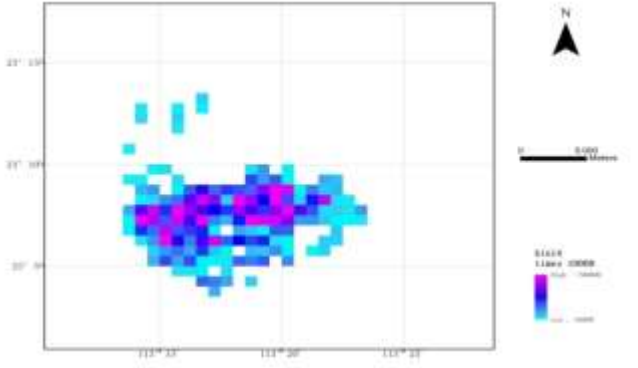
Distribution of building heights



5m



35m



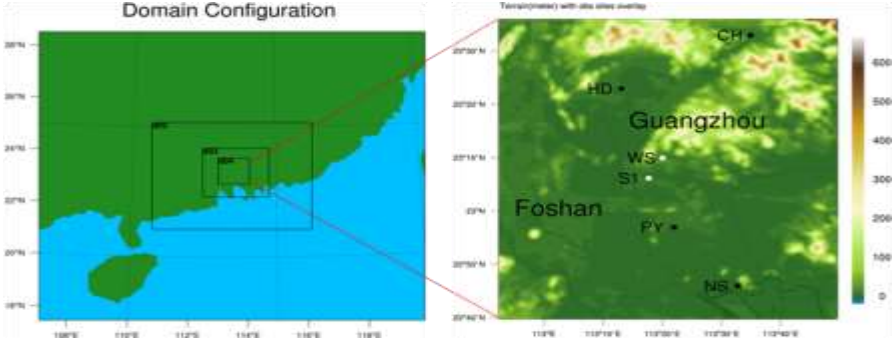
70m and more

Dai W. and Wang X.M., 2015

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



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

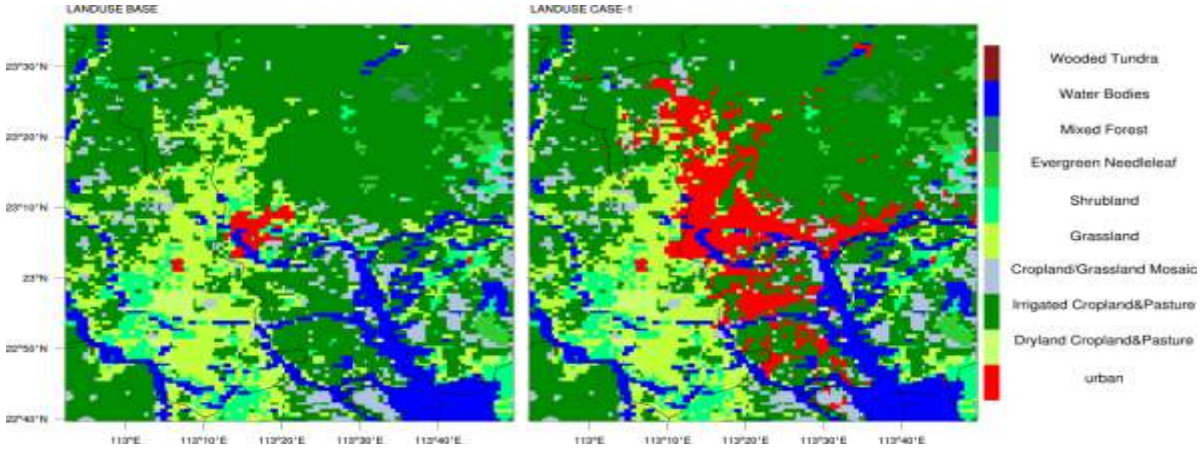
The d04 includes the core urban area of Guangzhou with six meteorological stations for model evaluation, and two stations drawn by white point located in the range of GZ-UCPs area.

- 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

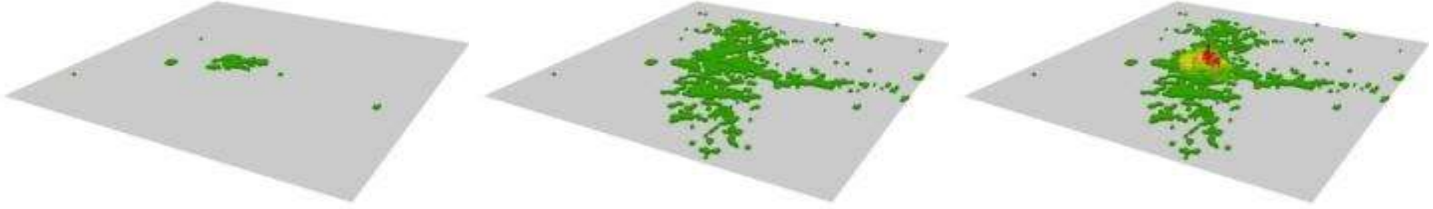
Model BEP variable	GZ-UCPs (new)		URBPARM.TBL (old)	
LF_URB2D	Plan area fraction	LamP		Function of Street width & Building width
HGT_URB2D	Area weighted mean building height	awaHT		Function of building Distribution
HI_URB2D	Distribution of building heights	Histogram	Building Distribution	5 m : 33 % 10 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

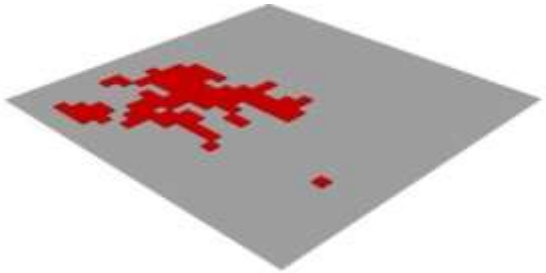


Base Case1 Case2

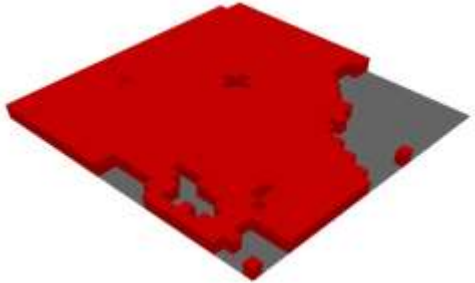
Dai W. and Wang X.M., 2015

WRF coupled with Urban canopy model (UCM)

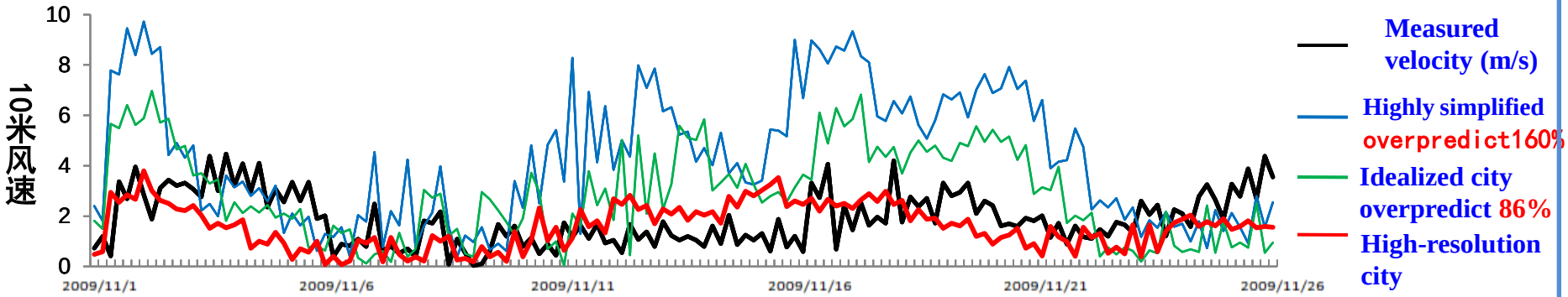
Highly simplified city



Idealized city



High-resolution city



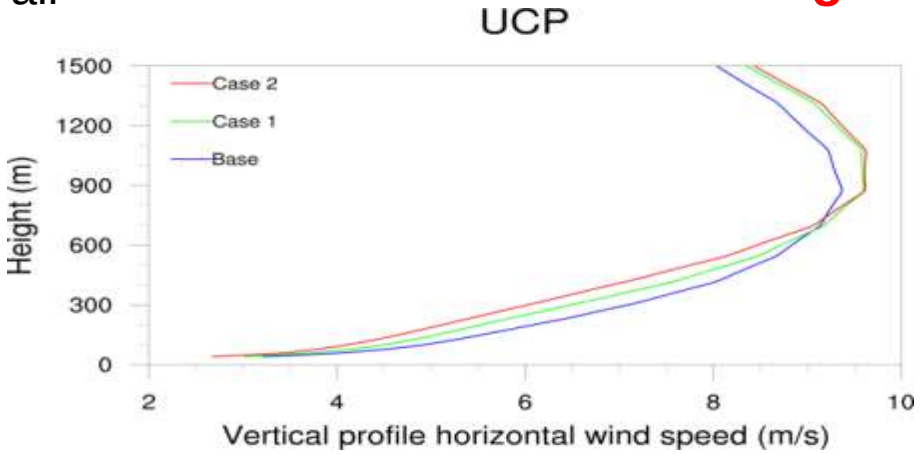
Work by my team： With the high-resolution urban canopy model coupled with WRF, the accuracy of wind prediction in cities are much improved.

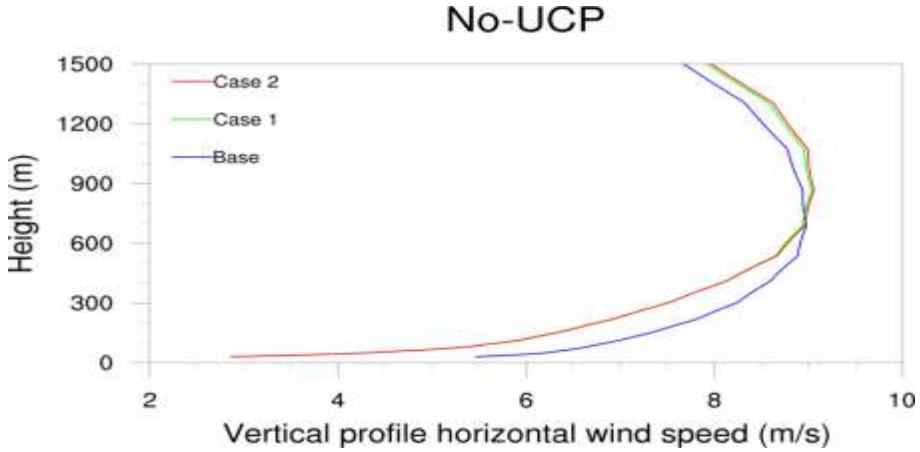
Wang X.M.*, Liao J.B., Zhang J., *et al*., 2014. ***J. Appl. Meteorol. Clim.***, 53, 346-362.

Vertical distribution of wind speed

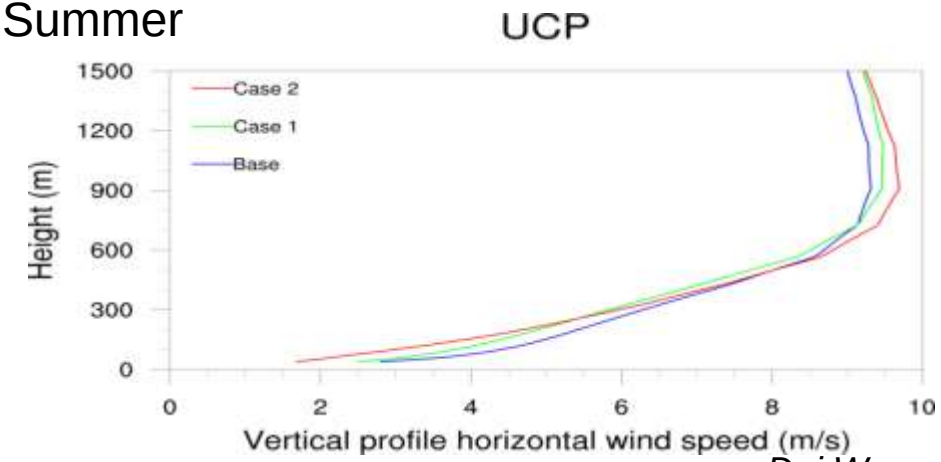
GZ-UCPs strengthen the vertical wind shear

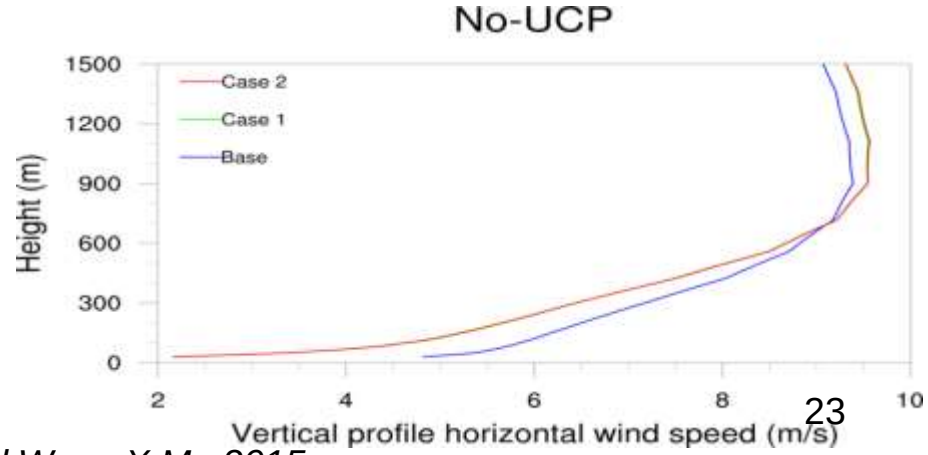
Fall





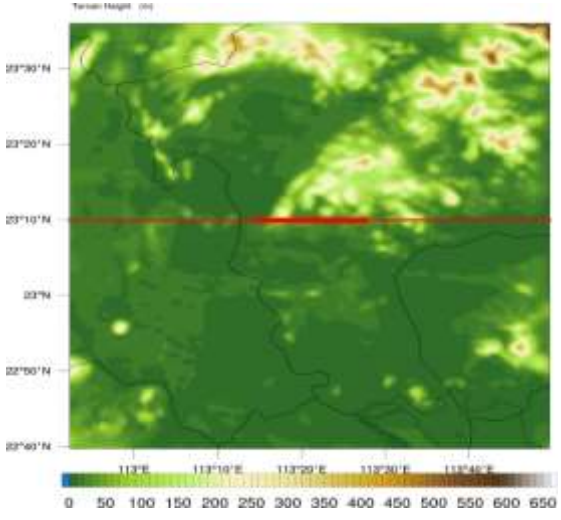
Summer

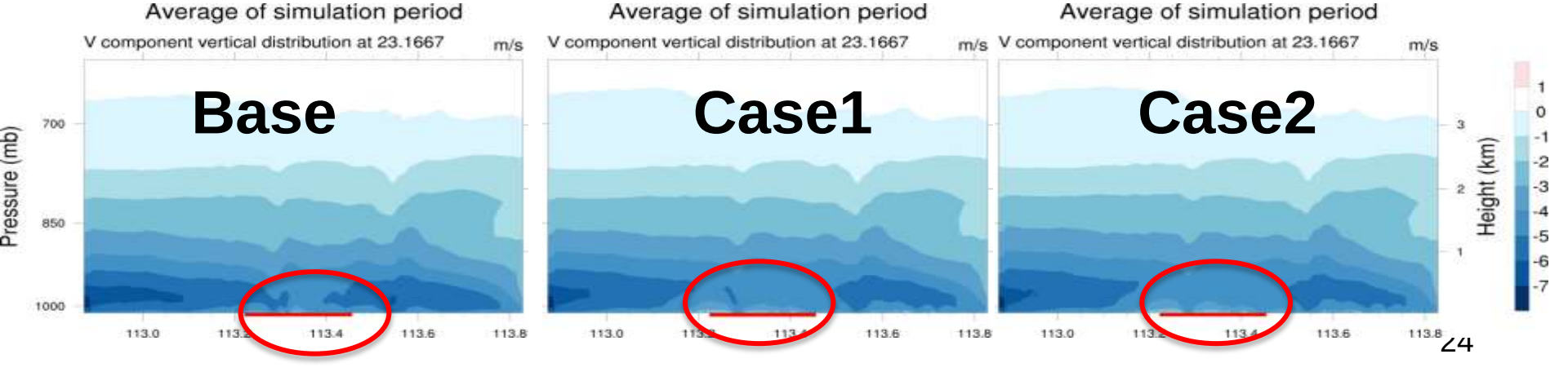




Dai W. and Wang X.M., 2015

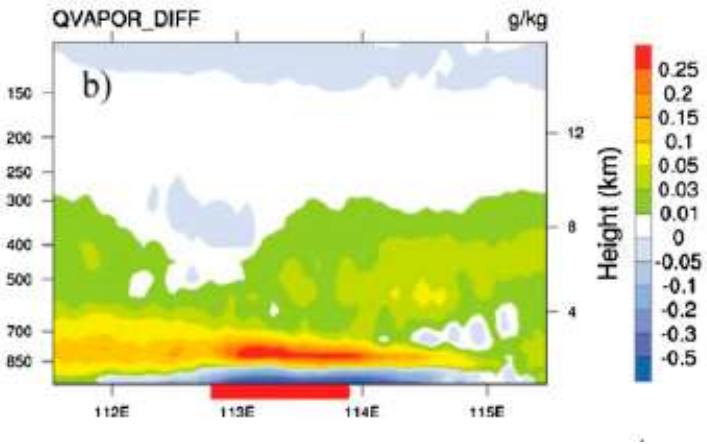
Vertical section of V wind distribution



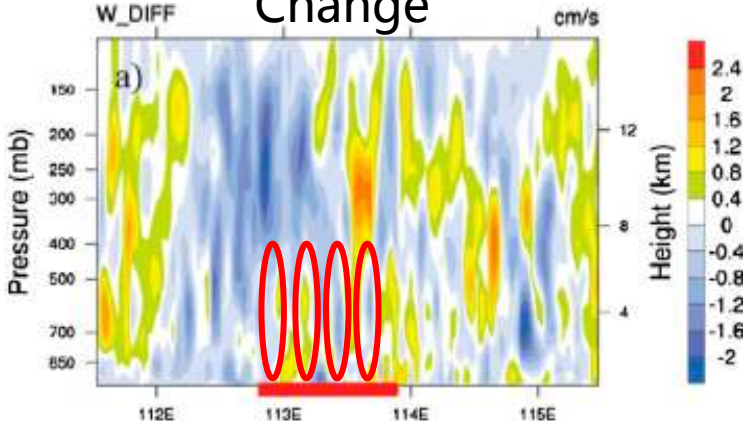


Vertical change of Vapor and W wind

Vapor Change



Vertical W Wind Change

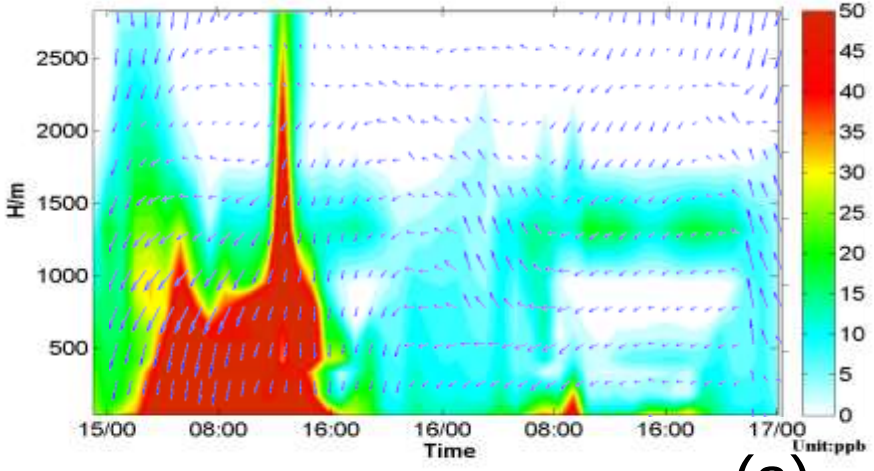


Increase of surface temperature enhance the water vapor transfer

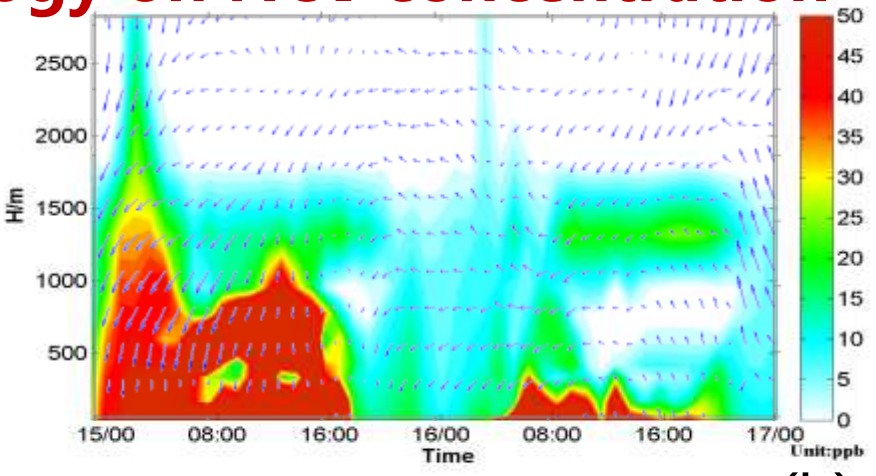
Increase of surface temperature enhance the convection activity, and provide a development of convective rolls over the city

Wang X. M. et al., 2010

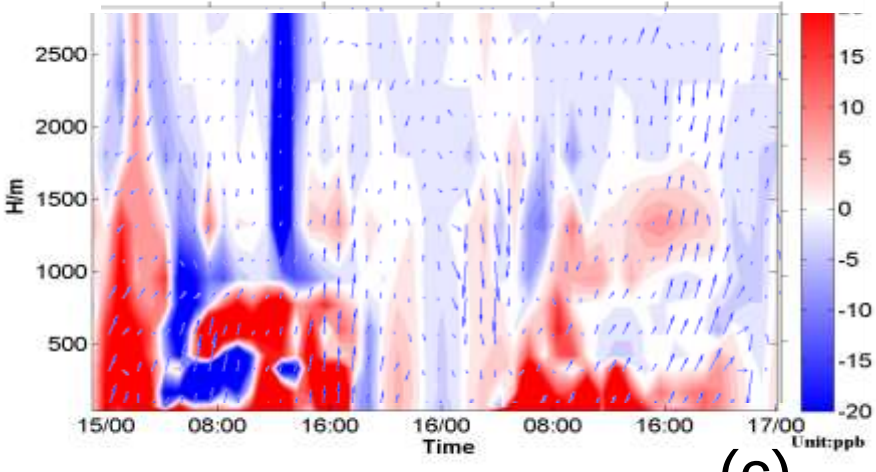
The impact of urban morphology on NO_2 concentration



(a)



(b)



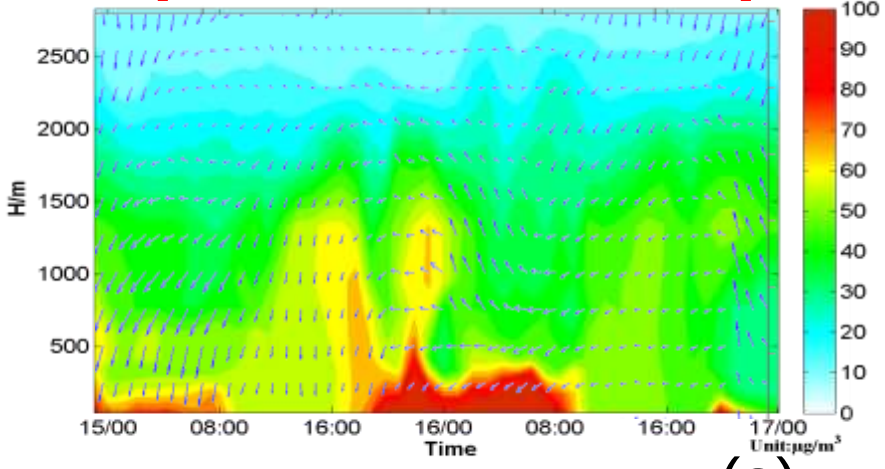
(c)

The variation of NO_2 concentration change with time and height

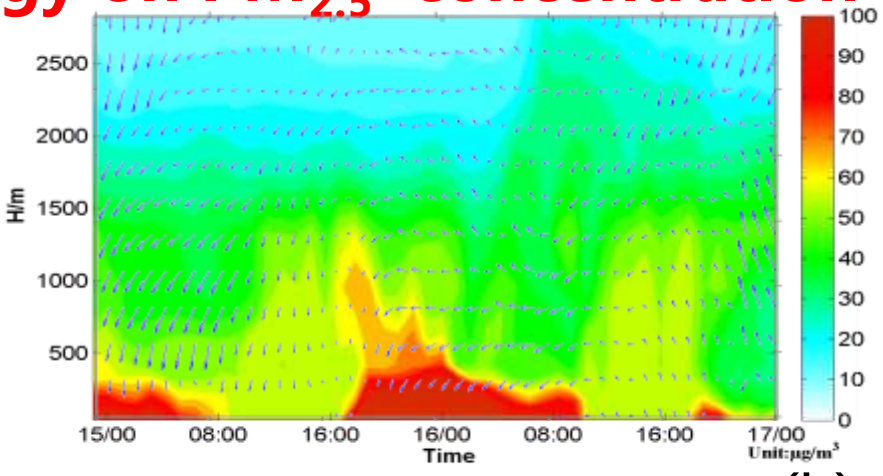
(a)base(b)case(c)case-base

NO_2 concentration increase below 1000m

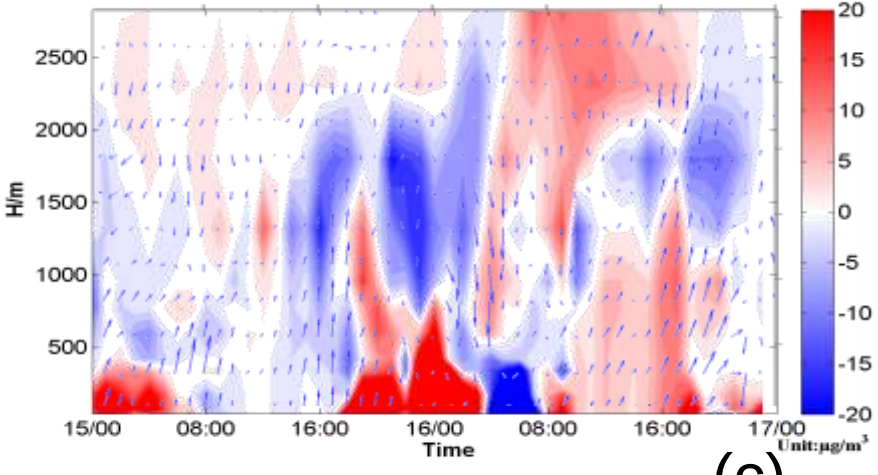
The impact of urban morphology on $PM_{2.5}$ concentration



(a)



(b)



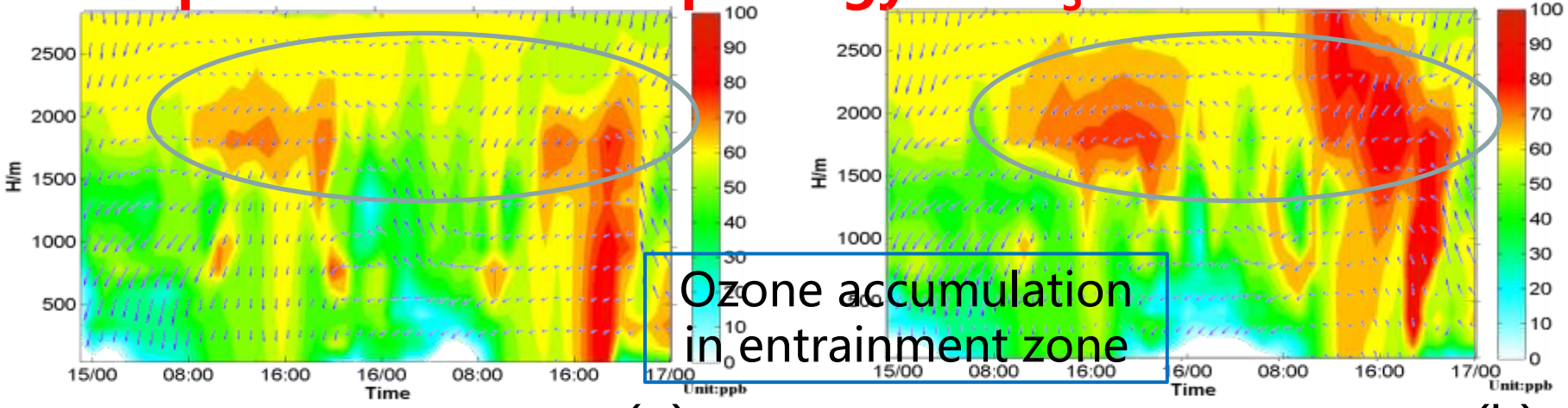
(c)

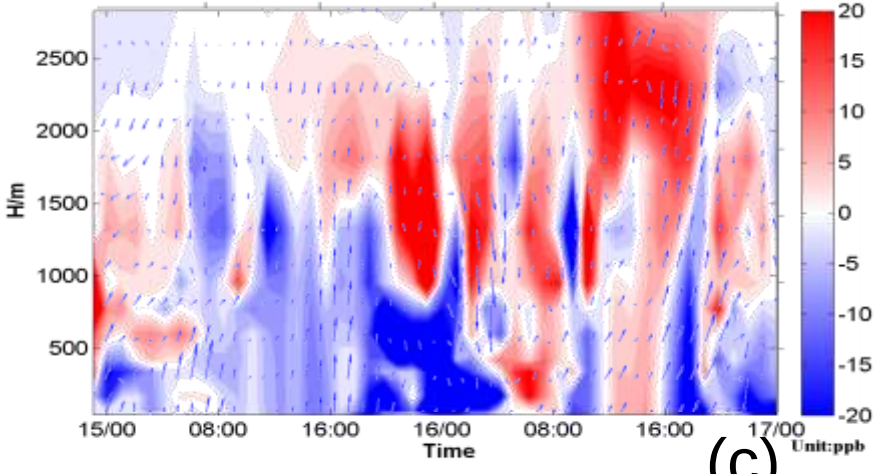
The variation of PM25 concentration change with time and height

(a)base(b)case(c)case-base

The surface $PM_{2.5}$ concentration increase, especially on the surface.

The impact of urban morphology on O_3 concentration





The variation of O_3 concentration change with time and height

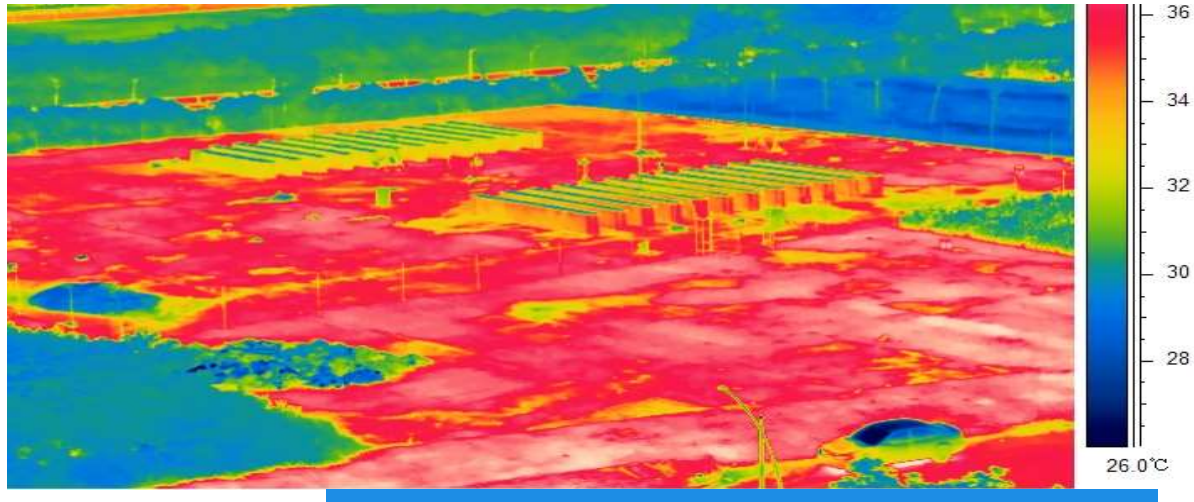
(a)base(b)case(c)case-base

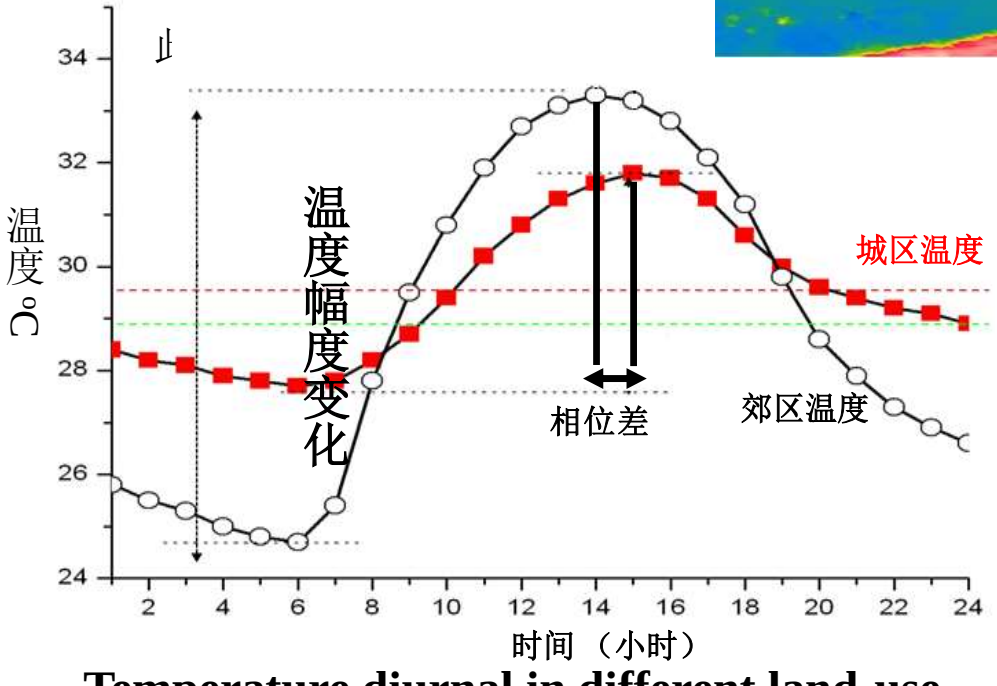
The change of urban morphology obviously decrease the surface ozone concentration

Outdoor field measurements setup in East Campus

Lead by Dr. Jian Hang

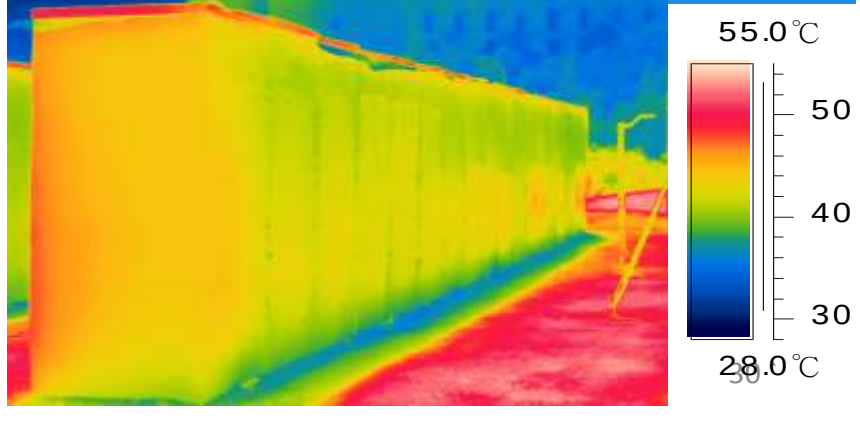
Experiments on building density, thermal storage, and color etc. to investigate the turbulence and and thermal environment.





Temperature diurnal in different land-use

More parameters can be obtained to improve model, such as how length/wide ratio influence the flow



Reflection on Urban Research

- The existence of cities may substantially affects local weather, climate, air pollution, and hydrology.

- Understand the complex interactions between urban physical system and urban-growth drivers (social-economical, policy, etc) is critical to design better adaptation and mitigation strategies.

- Integrated Atmosphere-Land-Urban-Aerosol Modeling System is required for addressing urban environmental problems.

Thank you!




Acknowledgement:

- NSFC
- MOST