Air Quality Modelling and Downscaling Activities and Methods in China

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Outline

- Introduction
- Current Status of Air Quality Modelling
- Urban Simulation
- Jinan University’s role in AIRQUIP










Air pollution now kills more people than high cholesterol

By Brad Plumer, Published: December 20, 2012 at 12:31 pm E-mail the writer

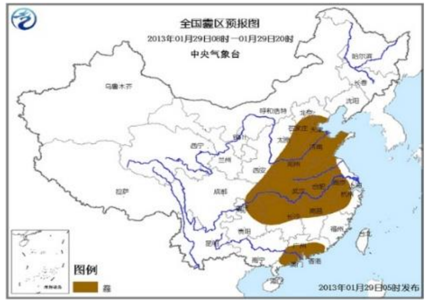
The Lancet recently unveiled a major overview of global health risks — and one of the most eye-catching papers highlighted just how deadly air pollution has become over the past two decades.

In 2010, 3.2 million people died prematurely from outdoor air pollution, mainly in Asia, and mainly from soot and other pollutants from diesel cars and trucks. That means outdoor air pollution is now a bigger health risk than high cholesterol — and, along with obesity, one of the fastest-growing health risks in the world. (Air pollution only killed about 800,000 people worldwide in 1990, although measurements were much cruder back then.)

A Chinese motorist wears a mask as she makes her way along a smog filled road in Hefei, east China's Anhui province on Nov. 29, 2011. (STR – AFP/Getty Images)

Haze and $PM_{2.5}$ Pollution in China

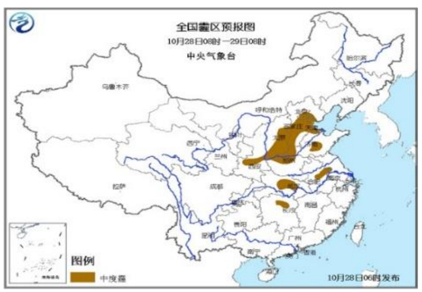
Jan 14-15, 2013



Jan 29, 2013

Feb 24-25, 2013

Oct 06-07, 2013



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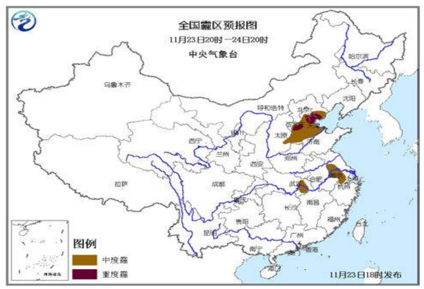
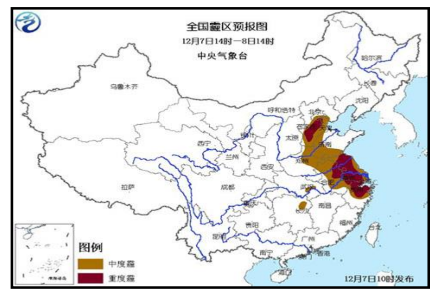
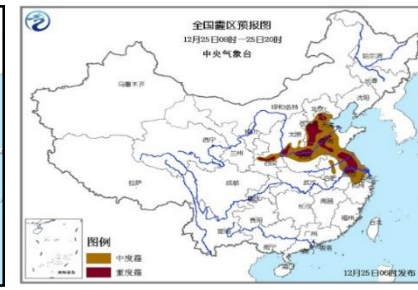


Nov 23-24, 2013



Dec 07-08, 2013



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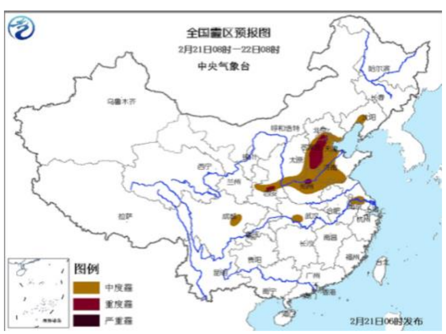
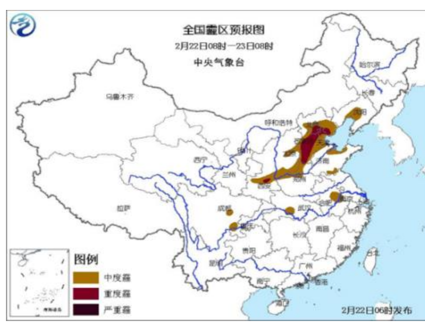
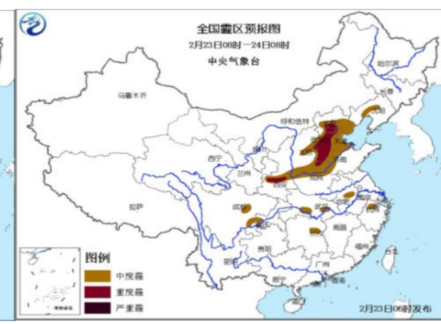


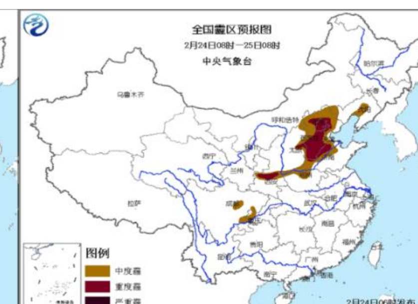
Feb 21-22, 2014



Feb 22-23, 2014

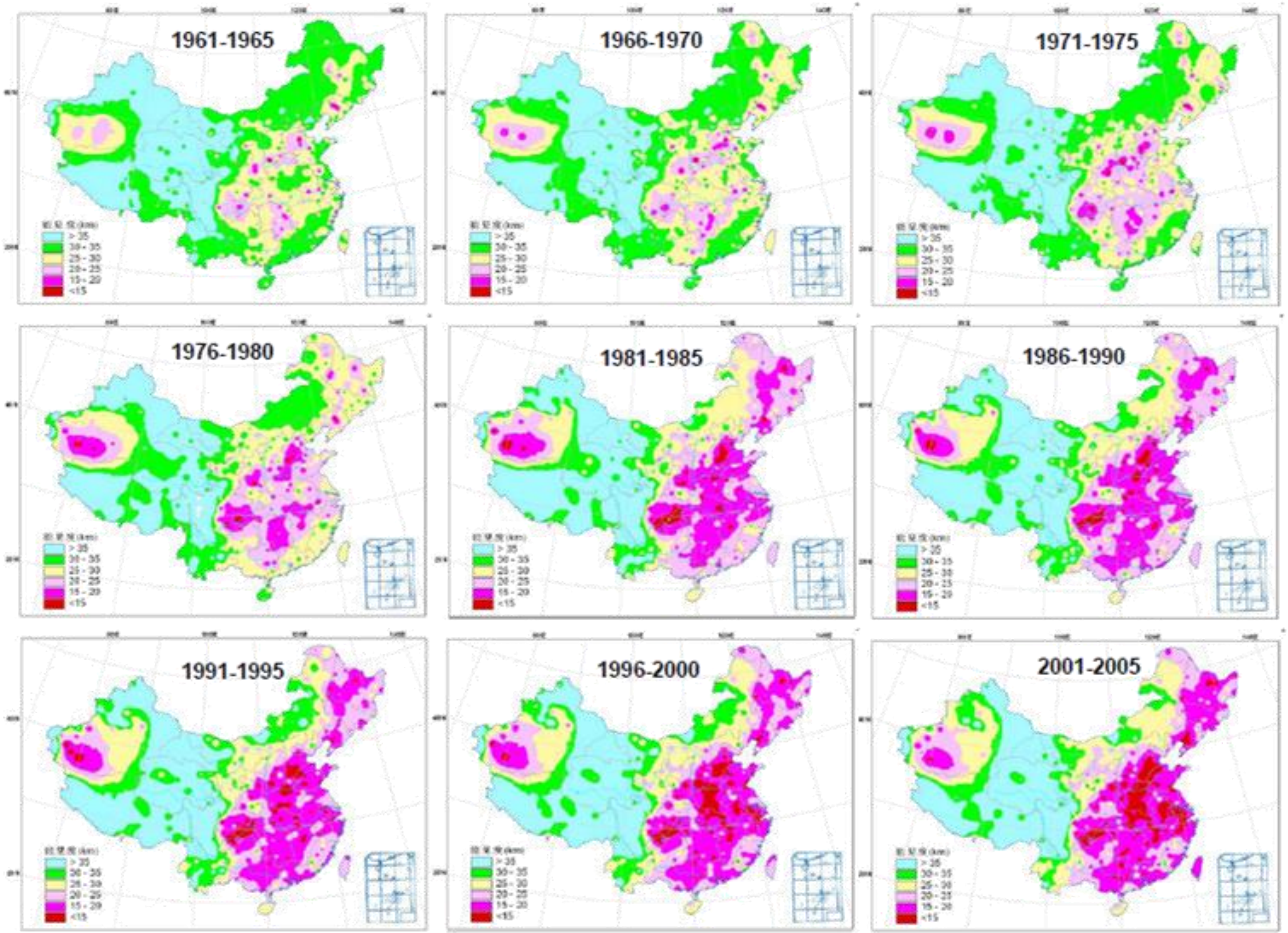


Feb 23-24, 2014



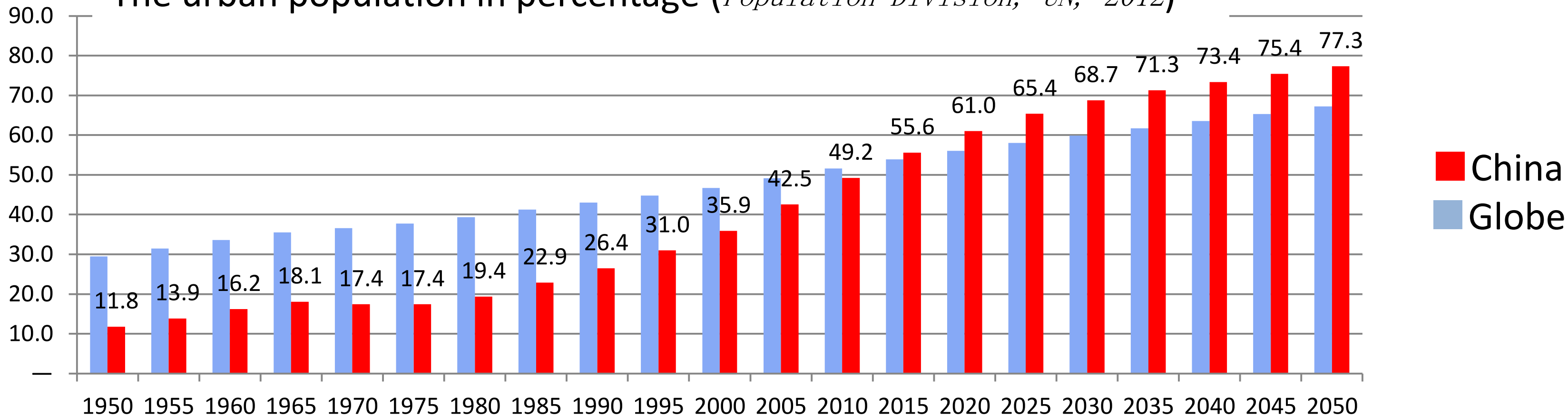
Feb 24-25, 2014

Trends of the visibility in the past 50 years



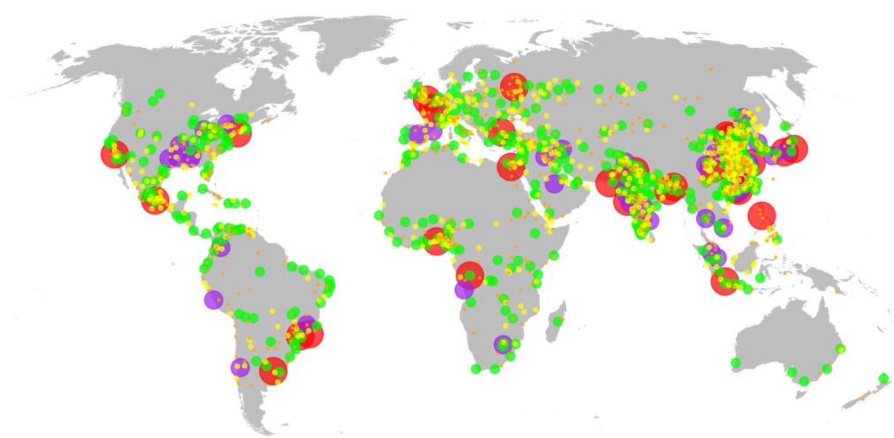
Development of city clusters in China pose a great scientific challenge

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

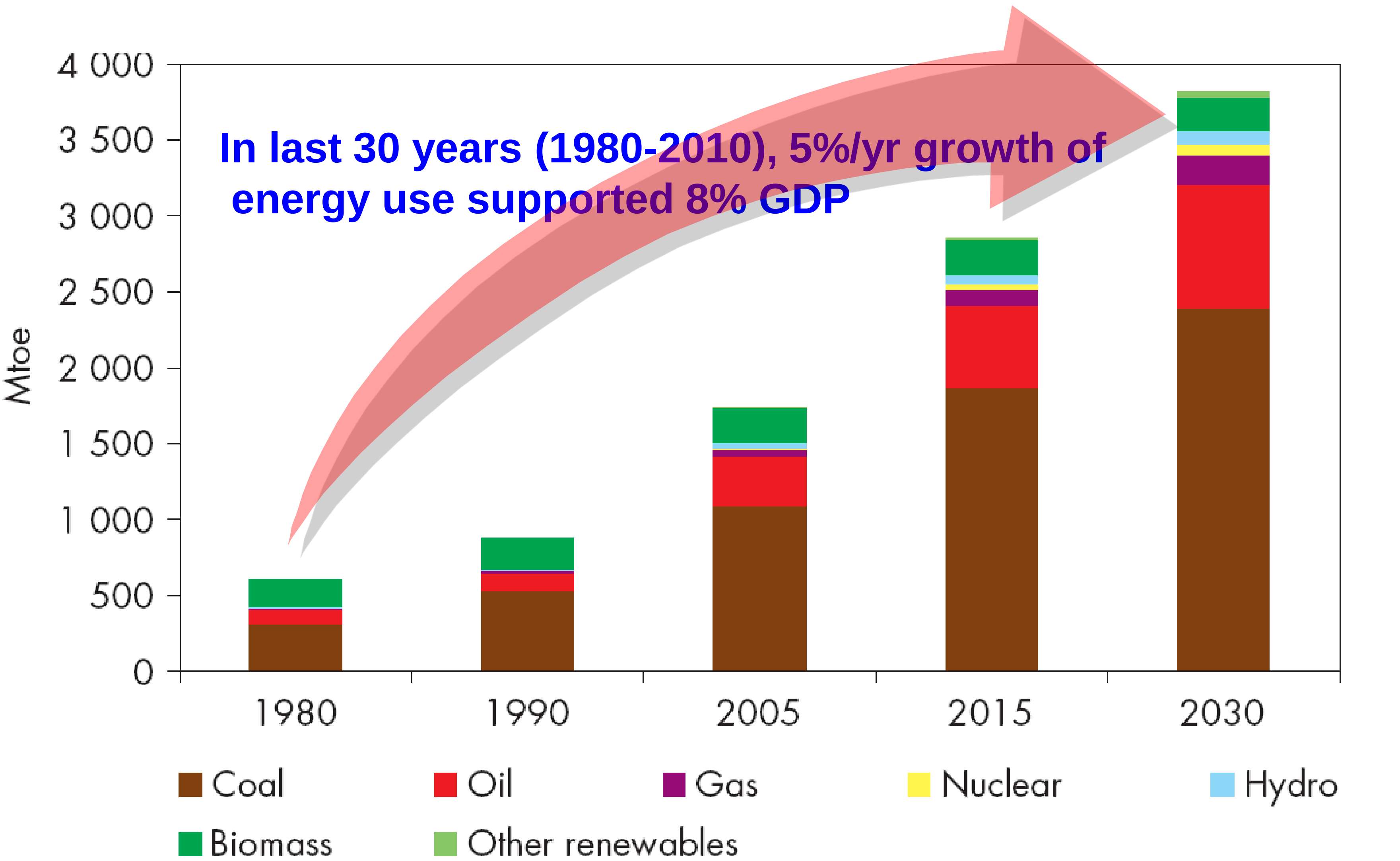


Data source: United Nations, Department of Economic and Social Affairs, Population Division (2012).

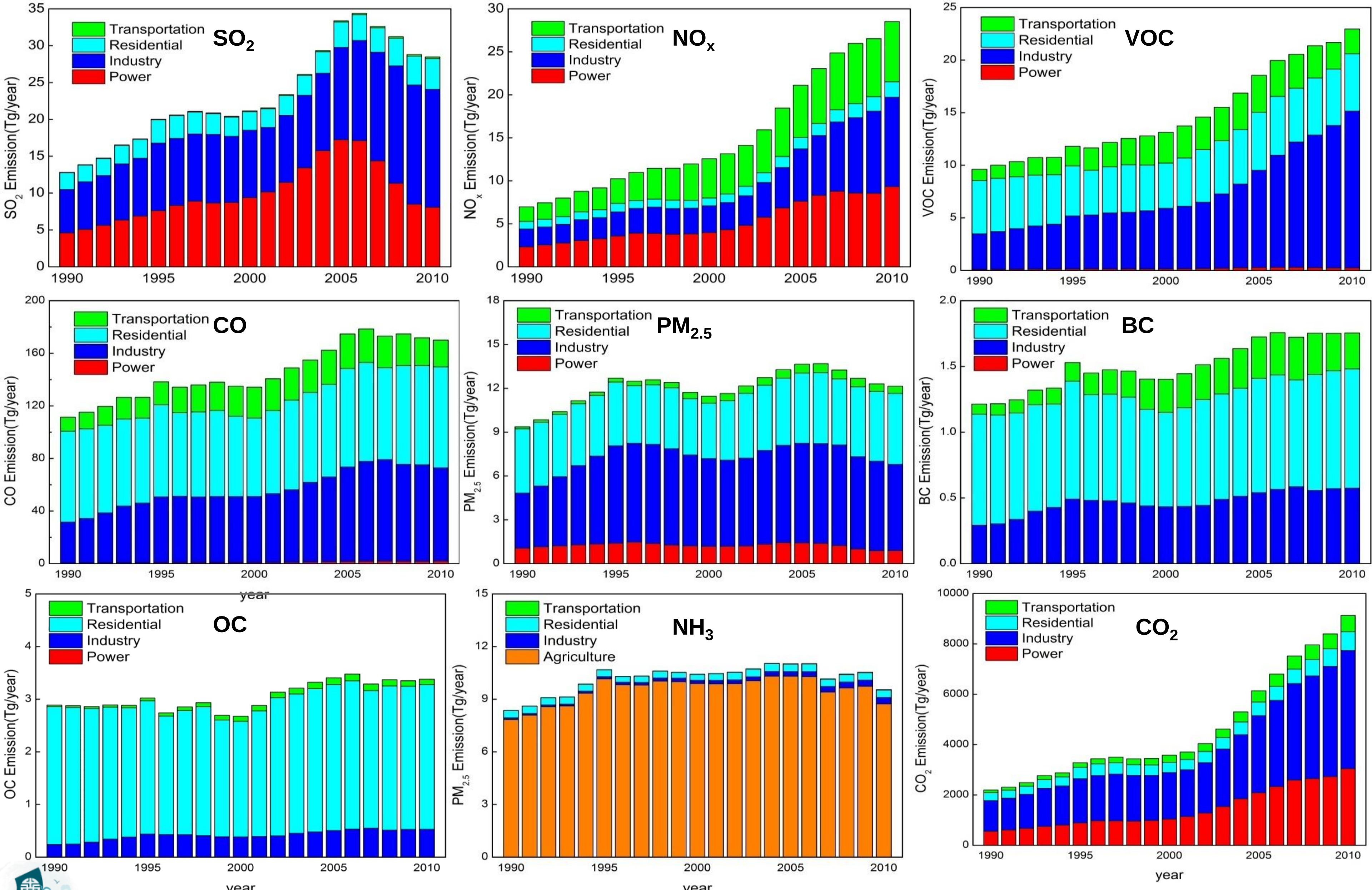
The world's cities by size class of urban settlement, in 2014 (*world urbanization prospects, UN, 2014*)



Future trends of energy structure in China

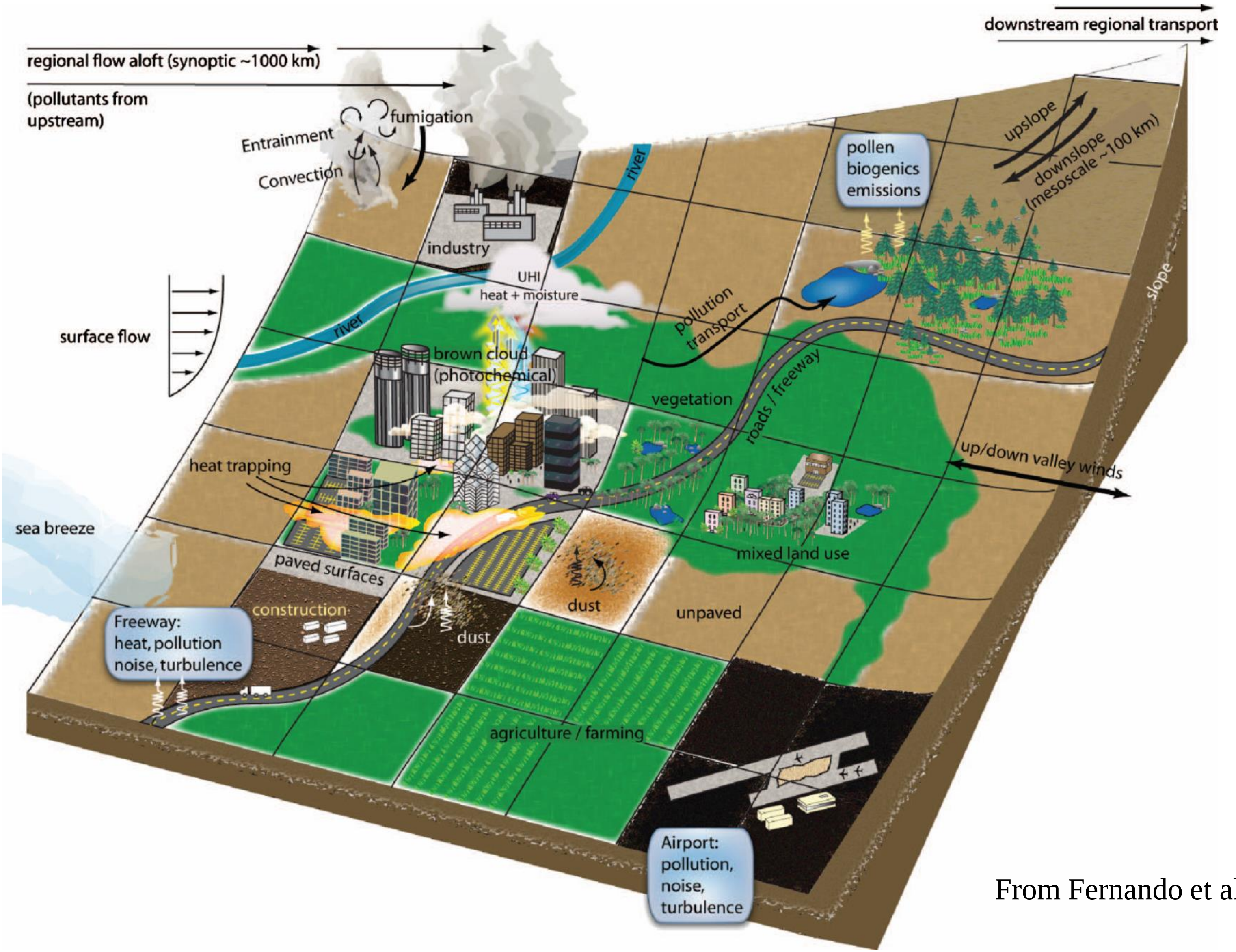


Trends of emissions in China: 1990-2010



Courtesy: Kebin He, Tusinghua U.

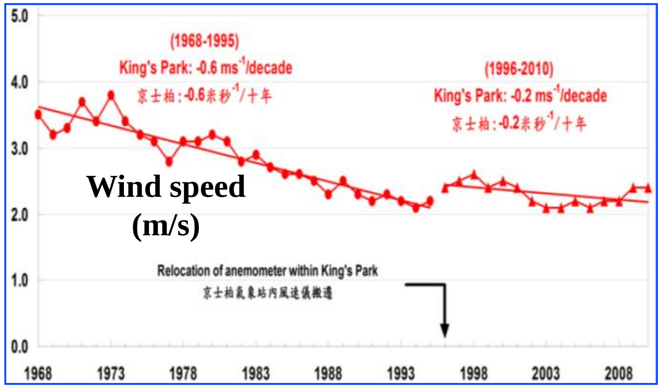
Flow, turbulence, and pollutant dispersion in urban atmospheres

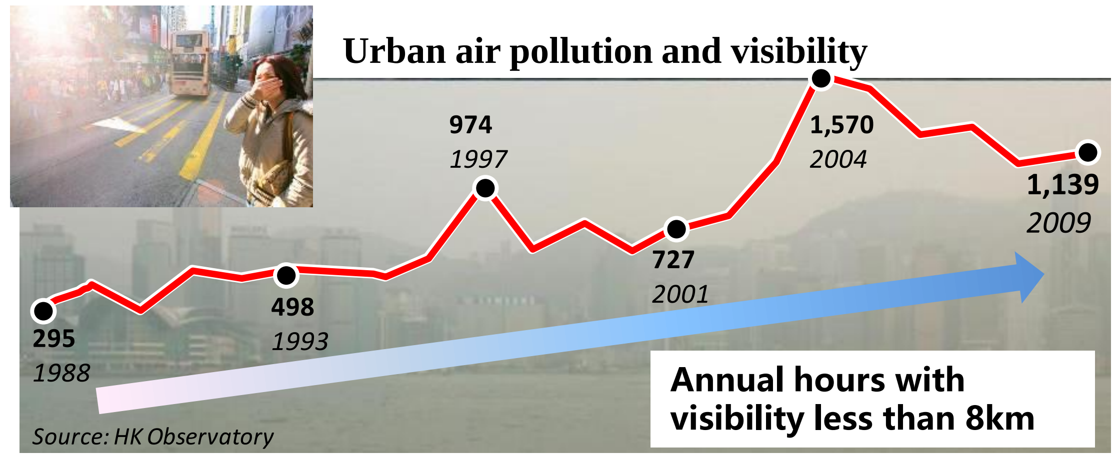


From Fernando et al. (2010)

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

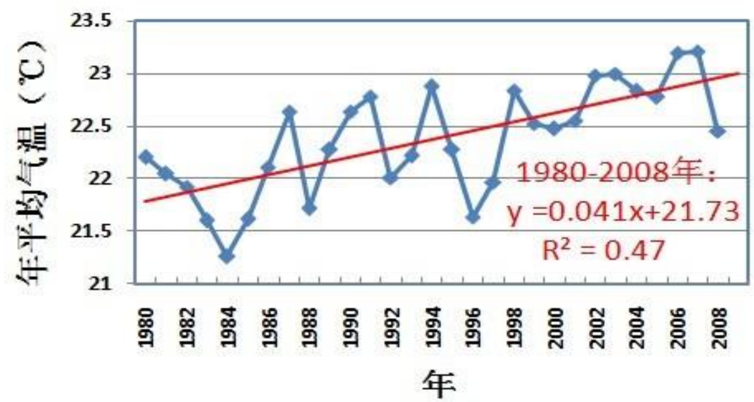
Urban wind speed is decreasing



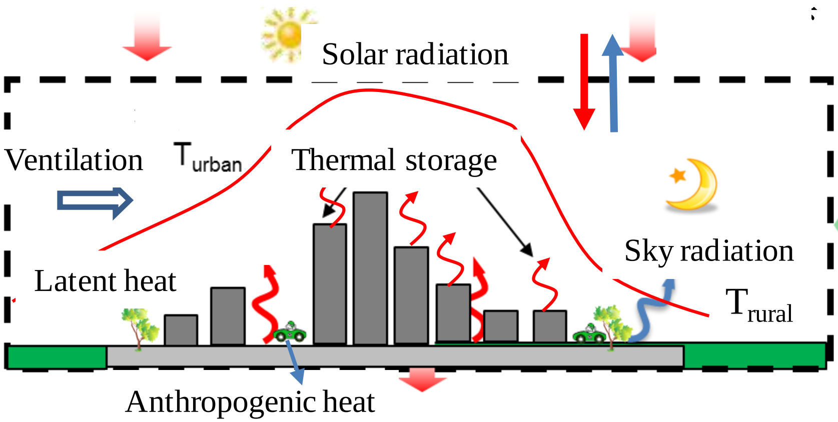


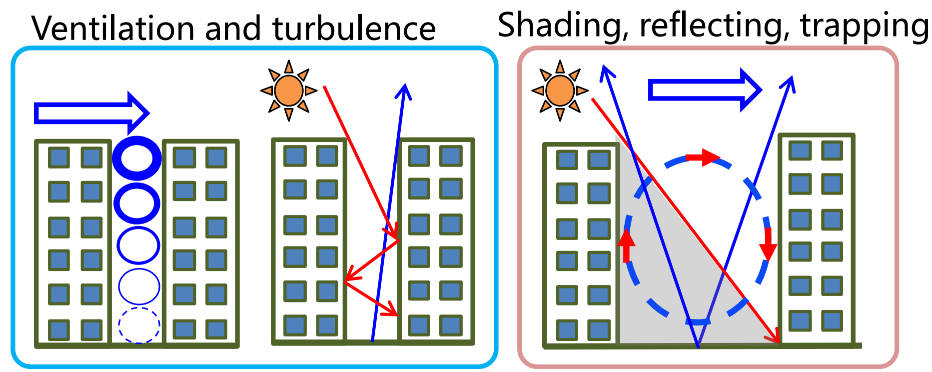
- In the last 30 years, Urban air temperature of Guangzhou increased 0.41°C/10yr, larger than the increase by global warming (0.19 °C/10yr)
- In hot regions, urban ventilation and solar sheltering are more significant.

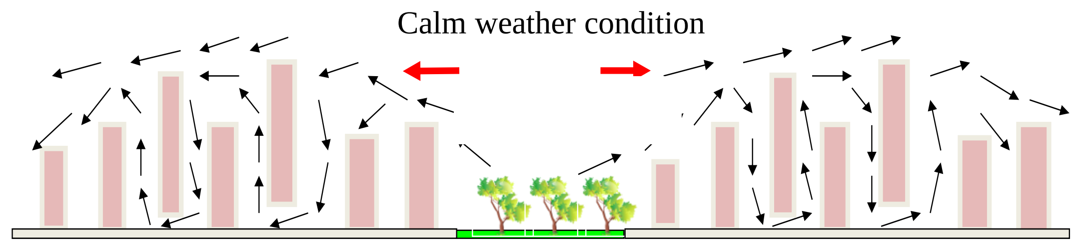
Temperature increases in Guangzhou



The impacts of each factor have not been clearly known





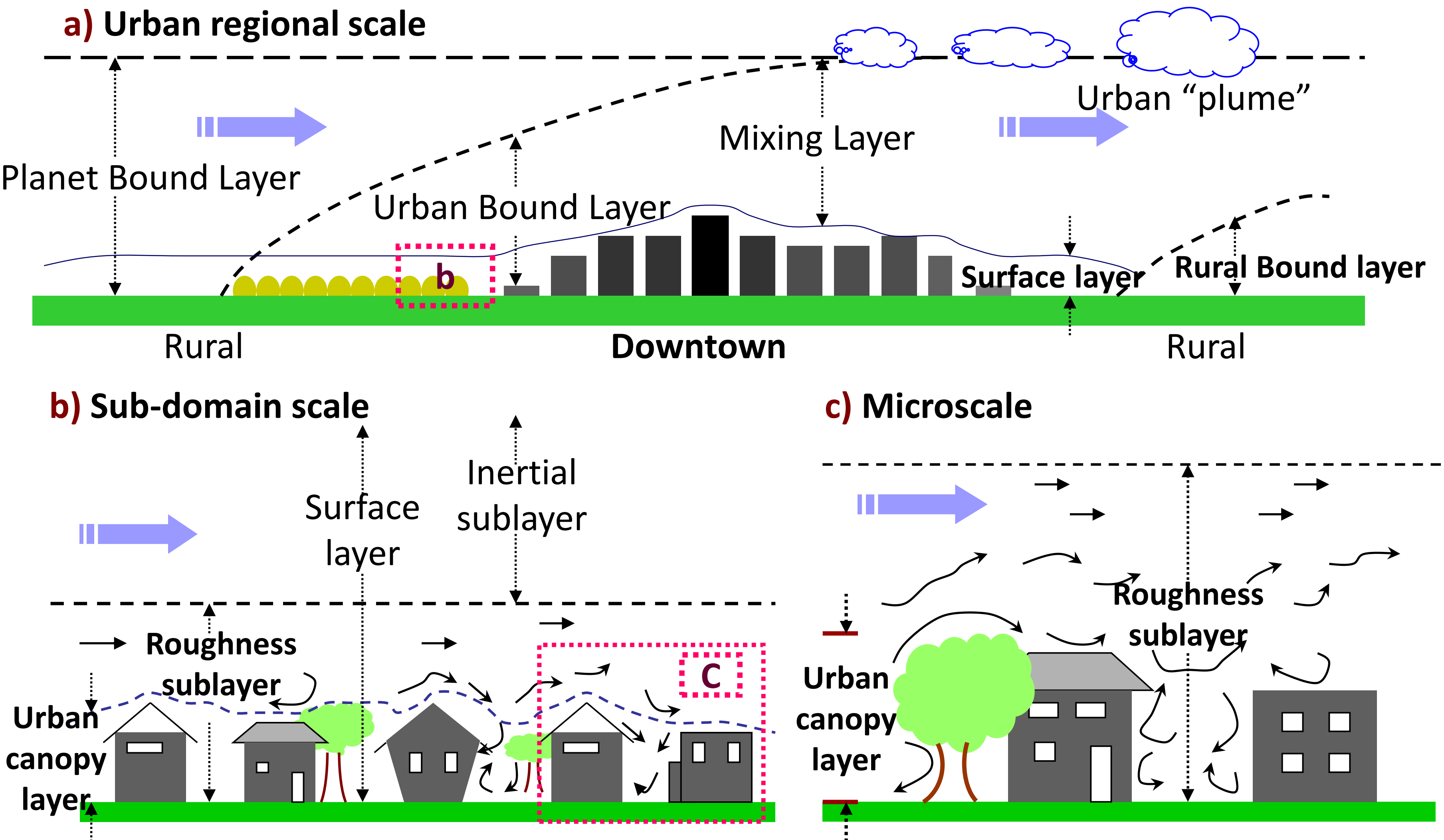


- Regional air pollution
- Meteorological condition
- Building morphologies
- Urban vegetation
- Anthropogenic heat
- Chemical reaction/green-house effect of pollutants

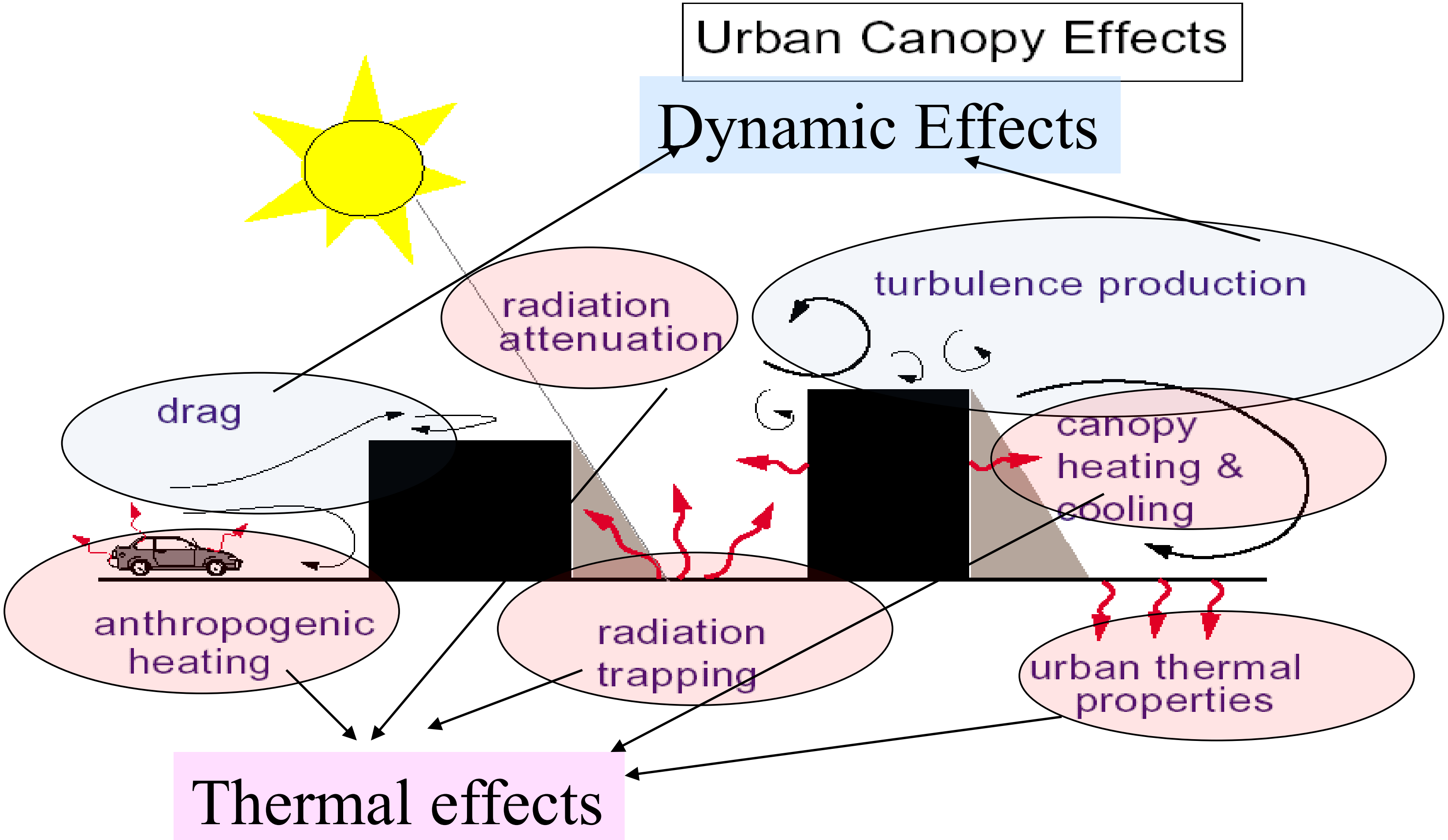
Non-linear coupling impact

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

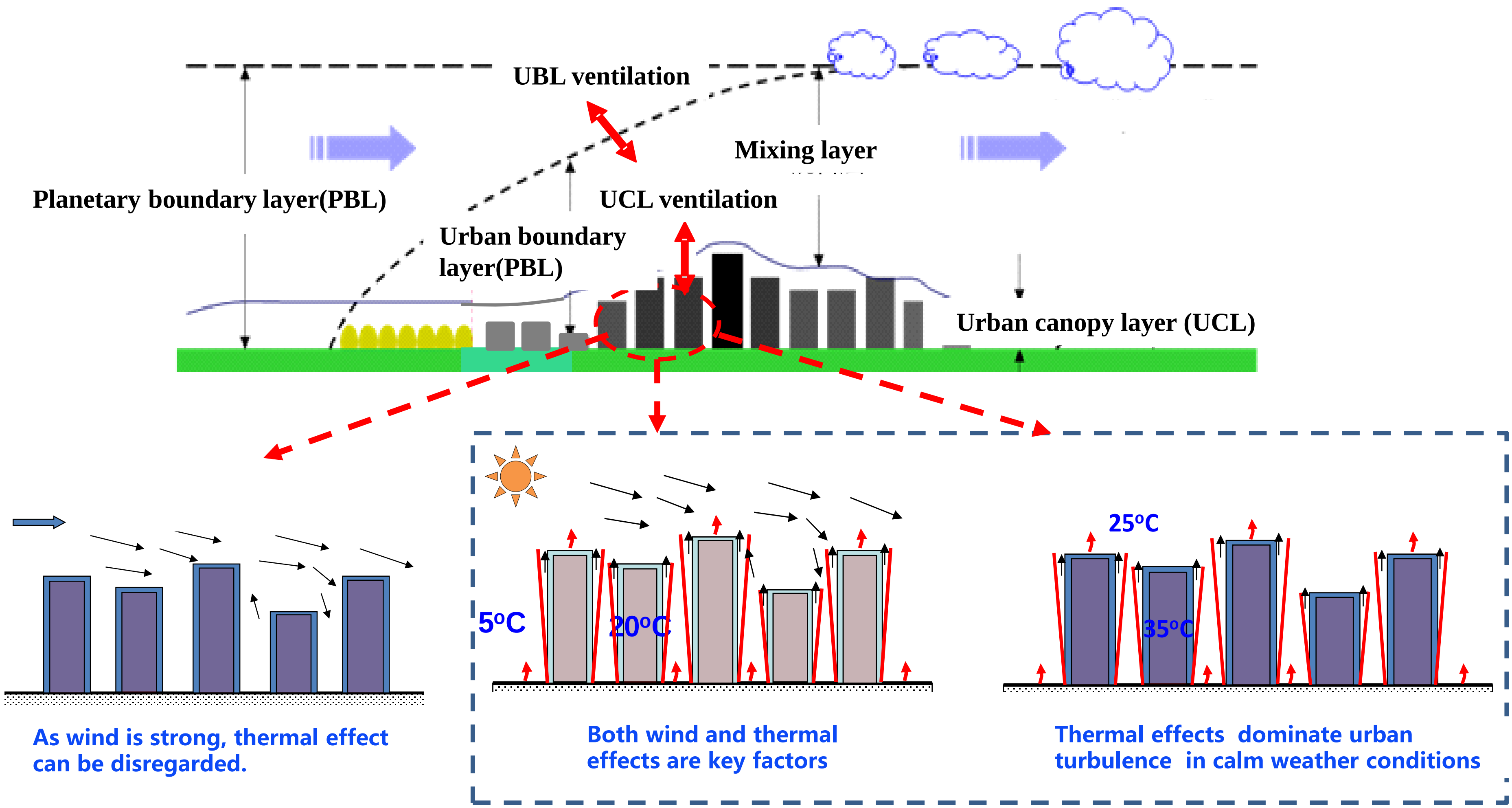
Multi-scale complex structure of atmospheric motions in UBL



C.S.B.Grimmond，2005

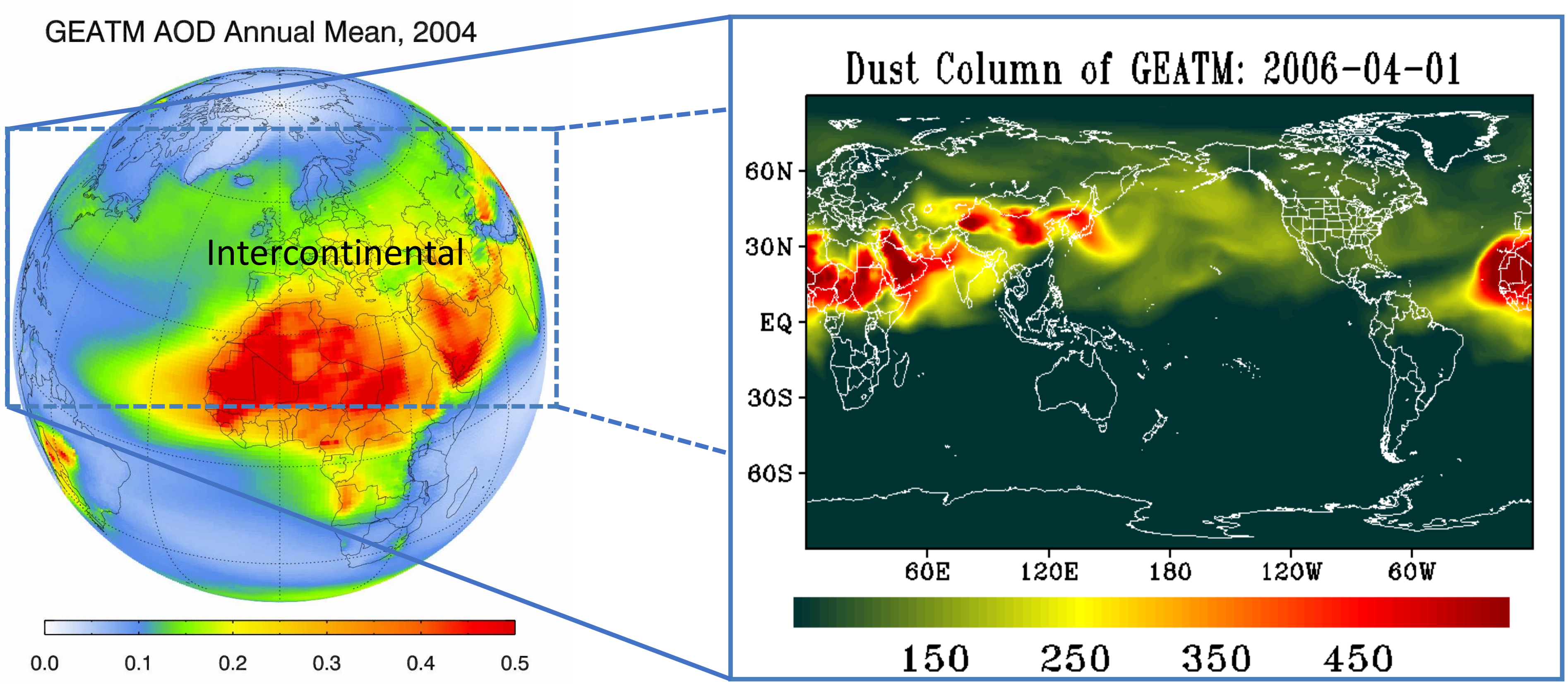

Urban Canopy Effects
Dynamic Effects
turbulence production
radiation attenuation
drag
canopy heating & cooling
anthropogenic heating
radiation trapping
urban thermal properties
Thermal effects

Urban Thermal and Dynamics effects



Current Status of Air Quality Modelling in China

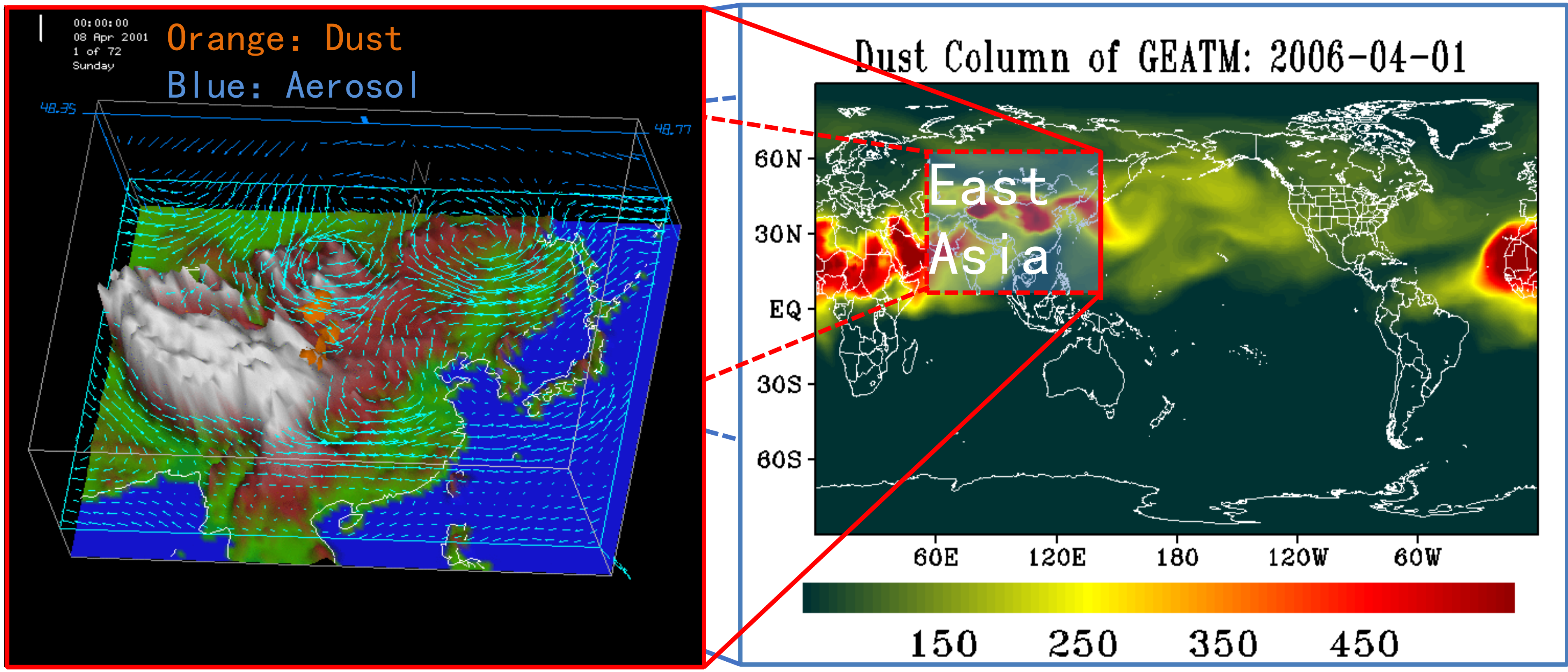
Global<- ->Intercontinental



Chen et al.,2015

Current Status of Air Quality Modelling in China

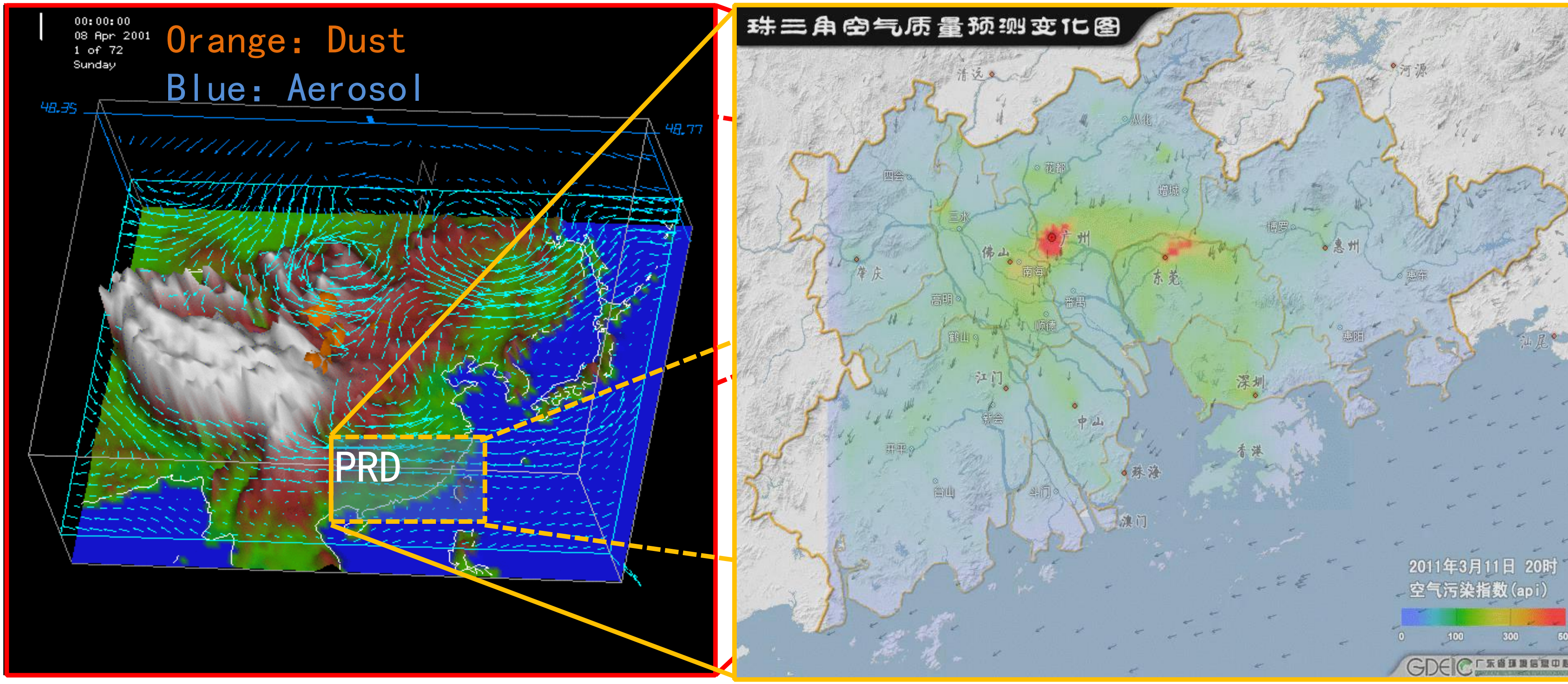
Global<- ->Intercontinental<- ->Regional



Chen et al.,2015

Current Status of Air Quality Modelling in China

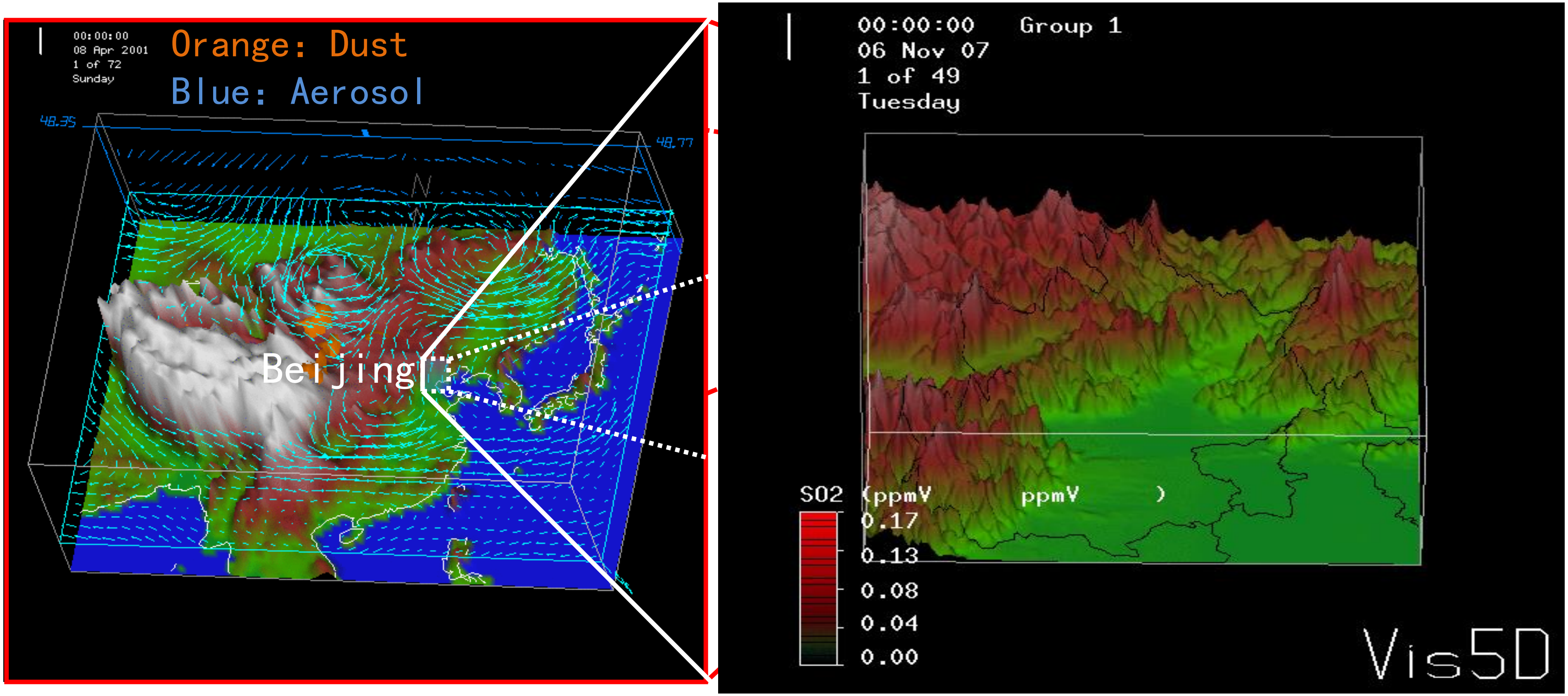
Global<- ->Intercontinental<- ->Regional<- ->Metropolitan



Chen et al.,2015

Current Status of Air Quality Modelling in China

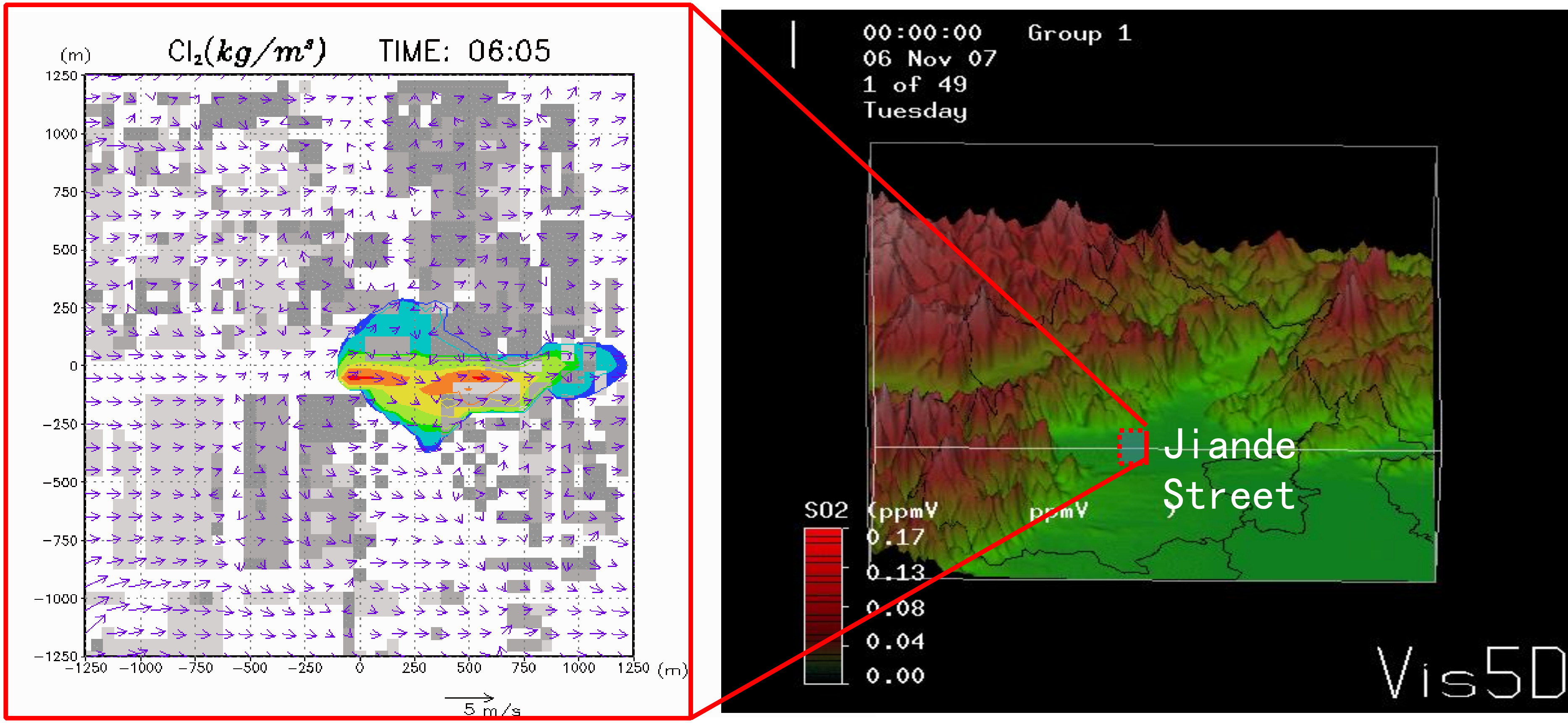
Global<- ->Intercontinental<- ->Regional<- ->Metropolitan<- ->City



Chen et al.,2015

Current Status of Air Quality Modelling in China

Global<- ->Intercontinental<- ->Regional<- ->Metropolitan<- ->City<- ->Street



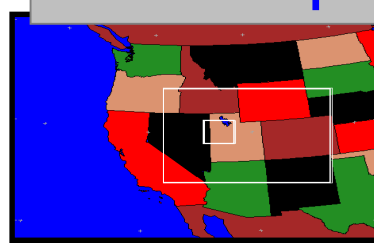
Chen et al.,2015

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

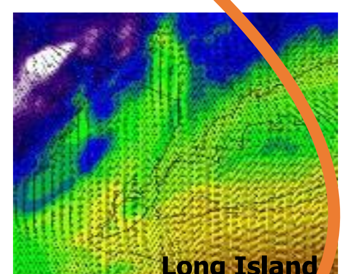
Current technology for operational weather and climate prediction

Global Scales

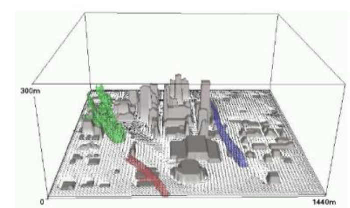
Continental Scales



Regional Scales



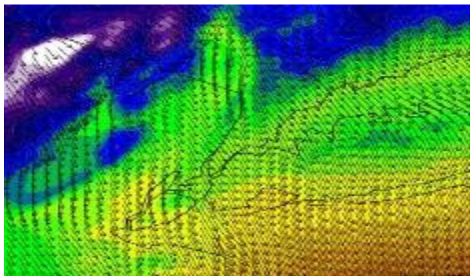
Local Scales



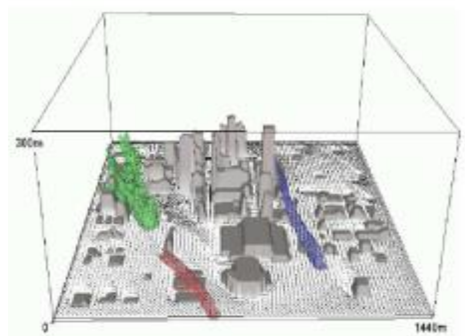
Urban Scales

Challenge in representing multi-scale urban microclimate

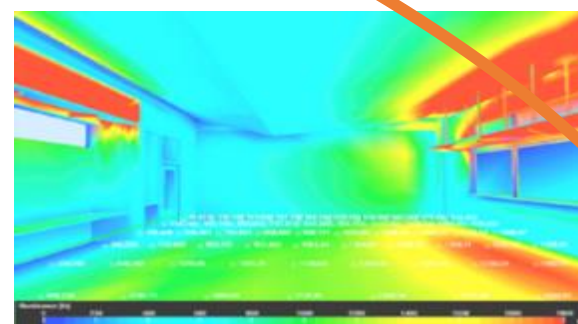
New technology for coupling fine-scale models



Mesoscale models



Urban Scale models (CFD, LES)



Building energy models
Indoor-outdoor exchange

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

(~1000km)	(~10km)	(~1km)	(~100m)
WRF/MM5	UCM	CFD	CFD

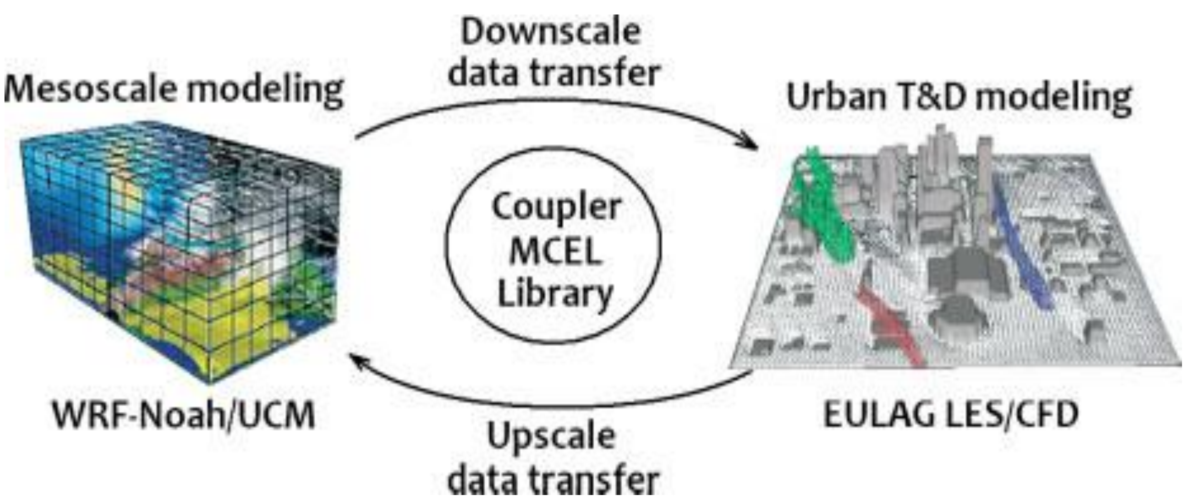
Developing WRF-Urban modeling capability

INTERNATIONAL JOURNAL OF CLIMATOLOG
Int. J. Climatol. **31**: 273–288 (2011)
Published online 7 June 2010 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/joc.2158

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]

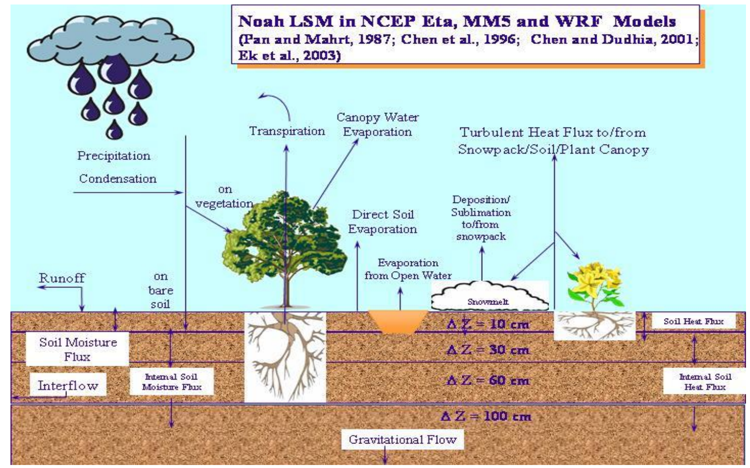


WRF-urban modeling system

- Coupling the Noah land surface model (LSM)
- Two urban canopy models (UCM)
  - Single layer urban-canopy model (SLUCM, based on Kusaka 2001). Released in WRF V2.2 (Dec. 2006).
  - Multi-layer UCM (Building Effect Parameterization, BEP) by Martilli et al. (2002). Released in WRF V3.1

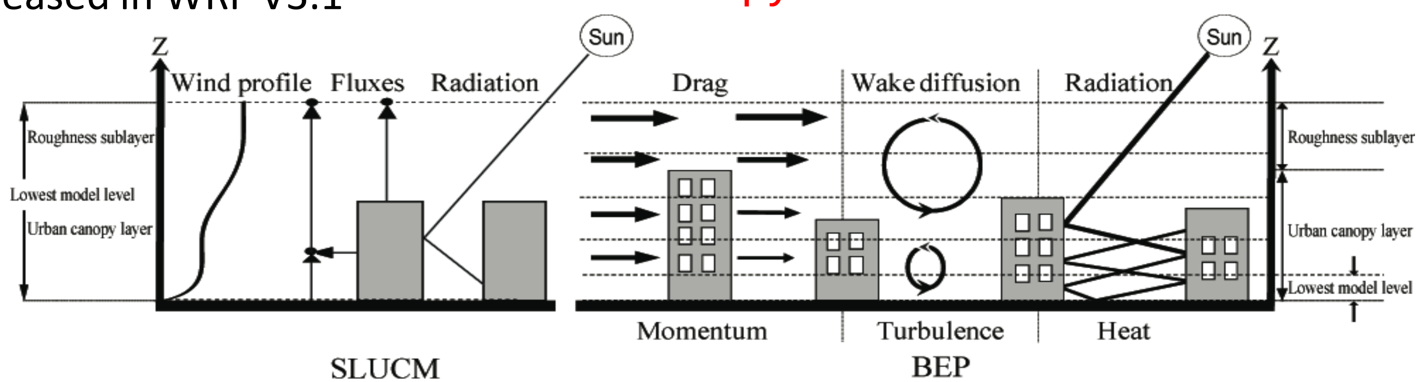
The Noah Land Model

Natural surface



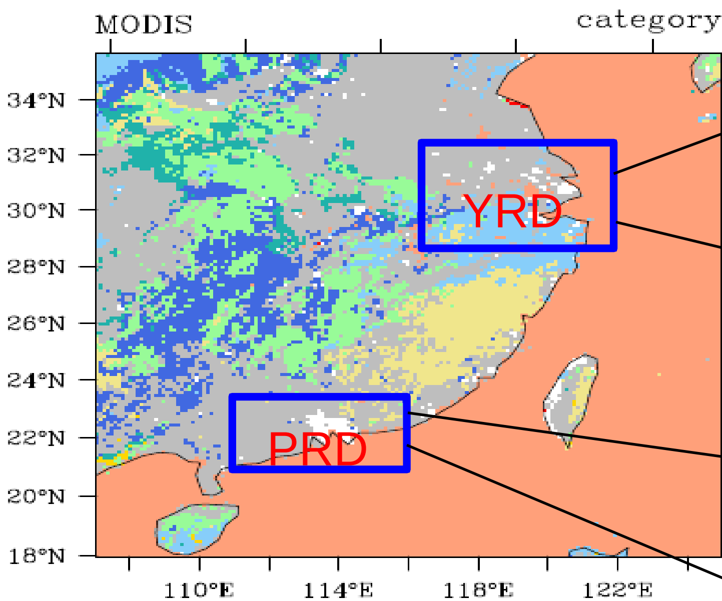
Coupled through ‘urban fraction’

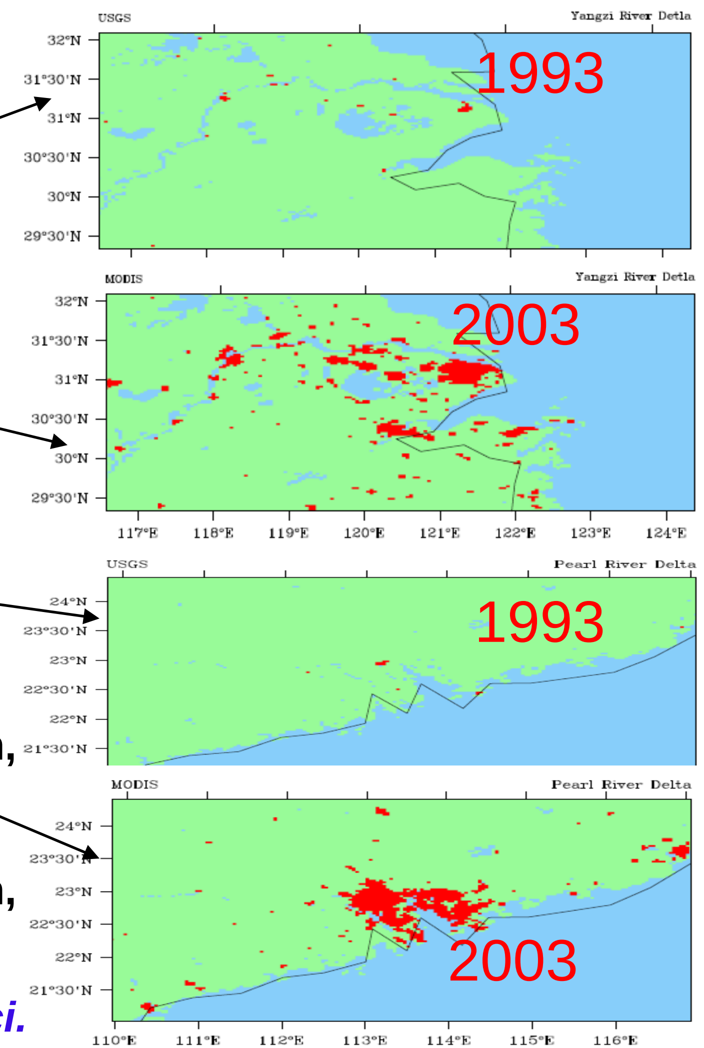
Urban canopy models: Man-made surface



Chen et al., 2011, *Intl. J. Climatology*

Rapid Urban Expansion in PRD and YRD





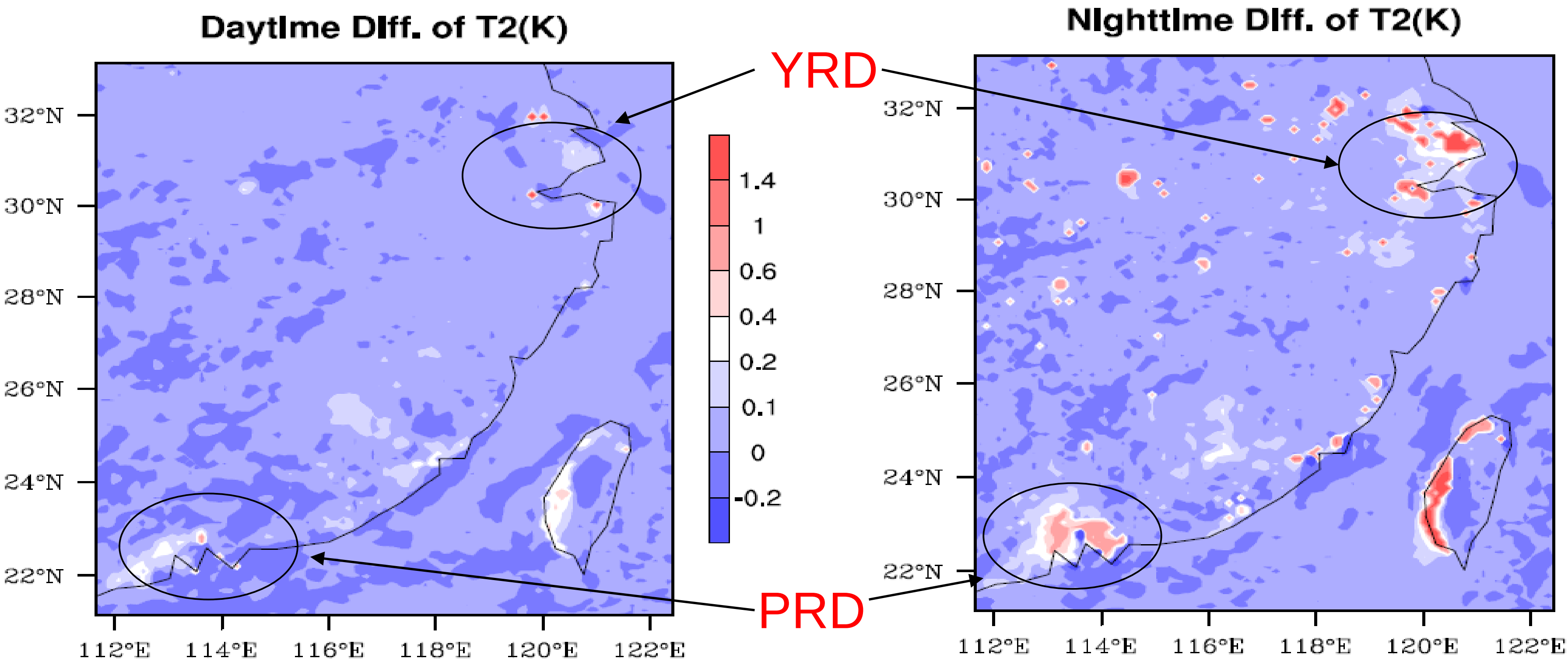
PRD **Area = 41700 km², Population: 1986~20million, 2005 > 50 million**

YRD **Area= 95225 km², Population: 1986~30million, 2005 > 60 million**

Wang X.M., et al., 2009, *Adv. Atmos. Sci.*

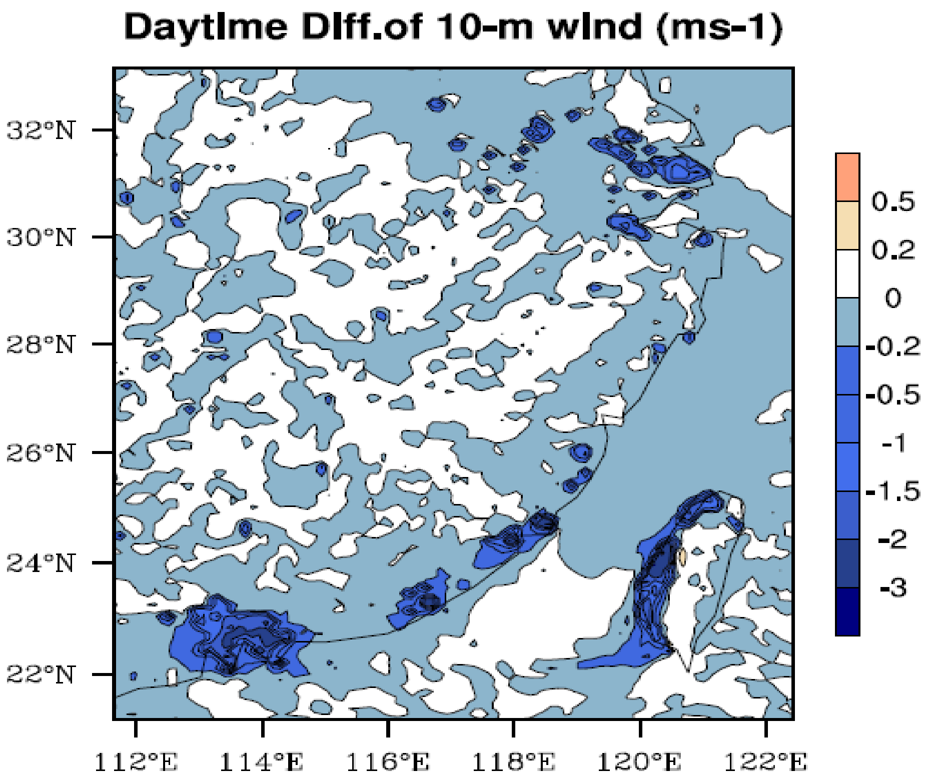
Urbanization Increases both Day- and Night-time 2-m Temperature

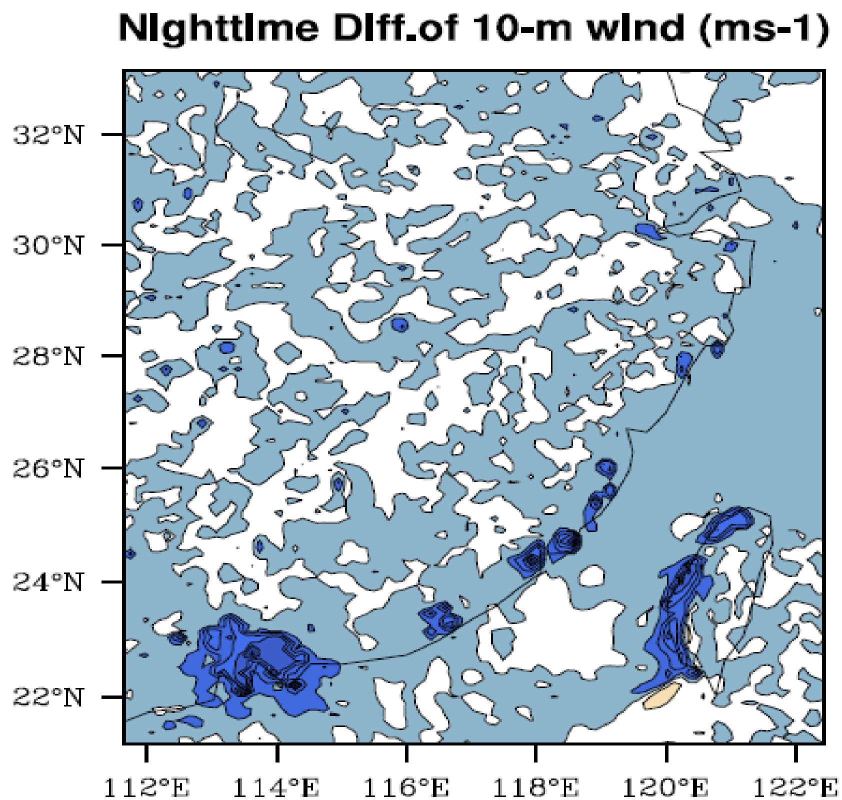
Simulation Urban - Simulation PRE-Urban averaged for March 2001



PRD has smaller increase of 2-m temperature than YRD

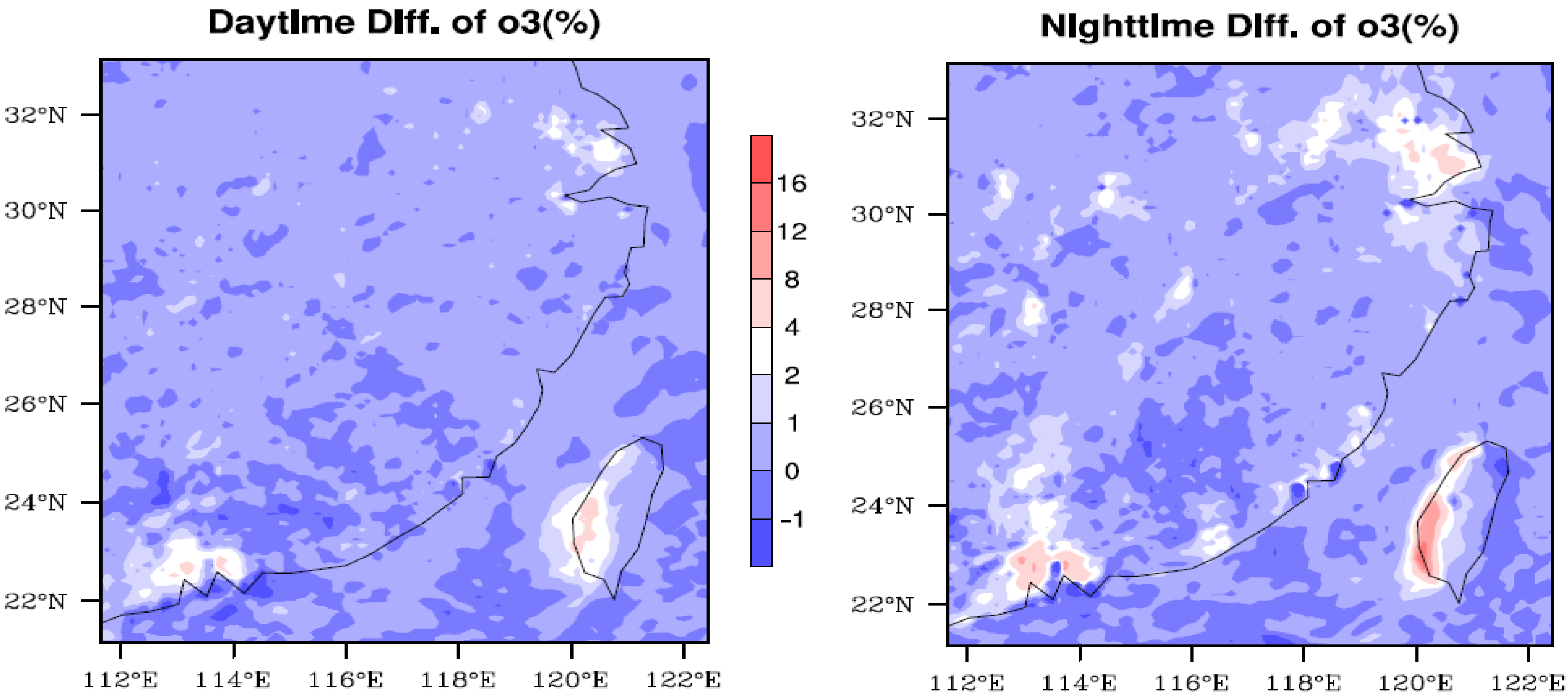
Urbanization Decreases both Day- and Night-time 10-m Wind Speed





PRD has larger decrease of 10-m wind speed than YRD, and daytime reduction in wind speed is larger

Urbanization Increases Surface Ozone Concentration



Urbanization increases surface ozone (more for nighttime)
PRD has larger increase than YRD

Urban canopy model (UCM) can be coupled into meso-scale models, but UCM model requires further evaluation /improvement.

For 32 urban land surface schemes, No individual model performs best for all fluxes. Poor choice of parameter values can cause a much worse performance.

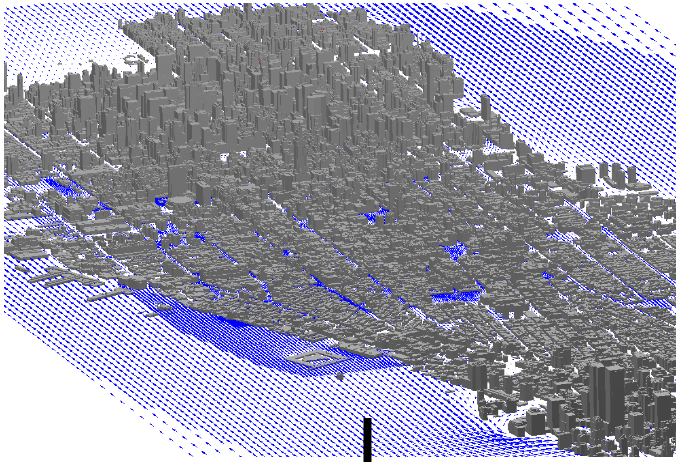
Initial results from Phase 2 of the international urban energy balance model comparison

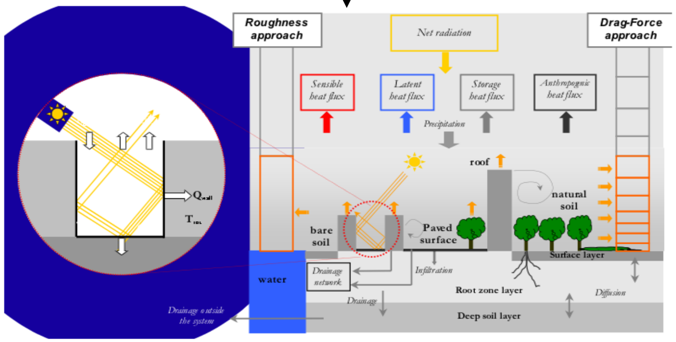
C. S. B. Grimmond,[a*] M. Blackett,[a] M. J. Best,[b] J.-J. Baik,[c] S. E. Belcher,[d] J. Beringer,[e] S. I. Bohnenstengel,[d] I. Calmet,[f] F. Chen,[g] A. Coutts,[e] A. Dandou,[i] K. Fortuniak,[j] M. L. Gouvea,[a] R. Hamdi,[k] M. Hendry,[b] M. Kanda,[l] T. Kawai,[m] Y. Kawamoto,[n] H. Kondo,[o] E. S. Krayenhoff,[p] S.-H. Lee,[c] T. Loridan,[a] A. Martilli,[q] V. Masson,[r] S. Miao,[s] K. Oleson,[h] R. Ooka,[n] G. Pigeon,[r] A. Porson,[b,d] Y.-H. Ryu,[c] F. Salamanca,[q] G.J. Steeneveld,[t] M. Tombrou,[i] J. A. Voogt,[u] D. T. Young[a] and N. Zhang[v]

ABSTRACT: Urban land surface schemes have been developed to model the distinct features of the urban surface and the associated energy exchange processes. These models have been developed for a range of purposes and make different assumptions related to the inclusion and representation of the relevant processes. Here, the first results of Phase 2 from an international comparison project to evaluate 32 urban land surface schemes are presented. This is the first large-scale systematic evaluation of these models. In four stages, participants were given increasingly detailed information about an urban site for which urban fluxes were directly observed. At each stage, each group returned their models' calculated surface energy balance fluxes. Wide variations are evident in the performance of the models for individual fluxes. No individual model performs best for all fluxes. Providing additional information about the surface generally results in better performance. However, there is clear evidence that poor choice of parameter values can cause a large drop in performance for models that otherwise perform well. As many models do not perform well across all fluxes, there is need for caution in their application, and users should be aware of the implications for applications and decision making.

KEY WORDS urban climate; energy balance; surface atmosphere exchanges; land surface modelling; sustainable cities; radiation; turbulent heat fluxes; evaporation

Challenge: from Real World to UCM

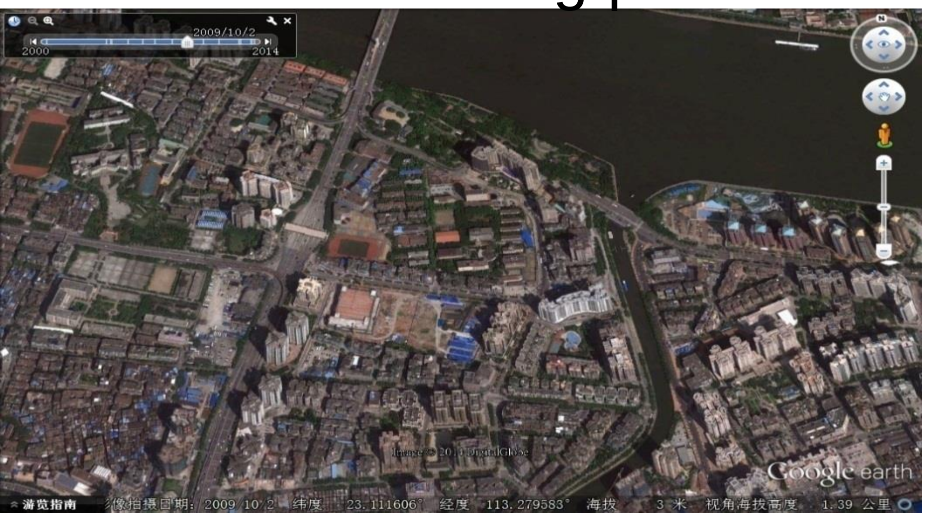




Urban canopy model (UCM) parameter space

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

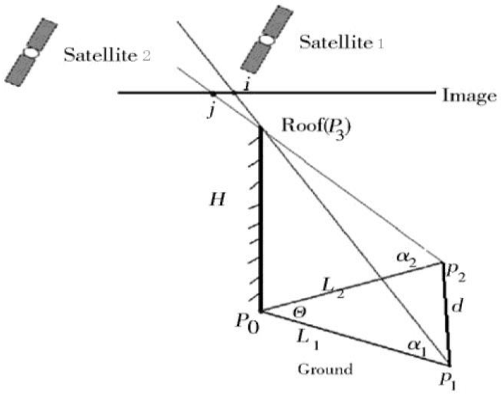
α:18°, θ:144°

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



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

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

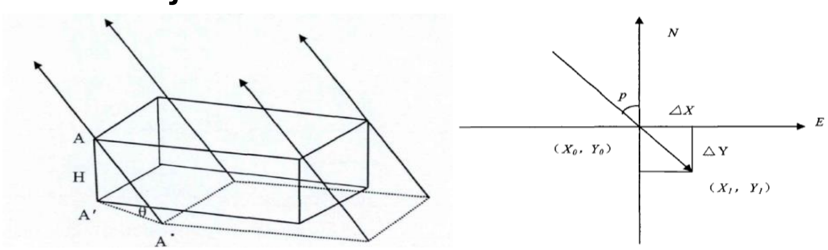
$$K = \sqrt{\cot(\alpha_1)^2 + \cot(\alpha_2)^2 - 2\cos(\theta)\cot(\alpha_1)\cot(\alpha_2)}$$

H: building height, GSD: cell size

θ: azimuth difference between two images

α_1: satellite1 elevation , α_2: satellite2 elevation

Adjustment of roof shift



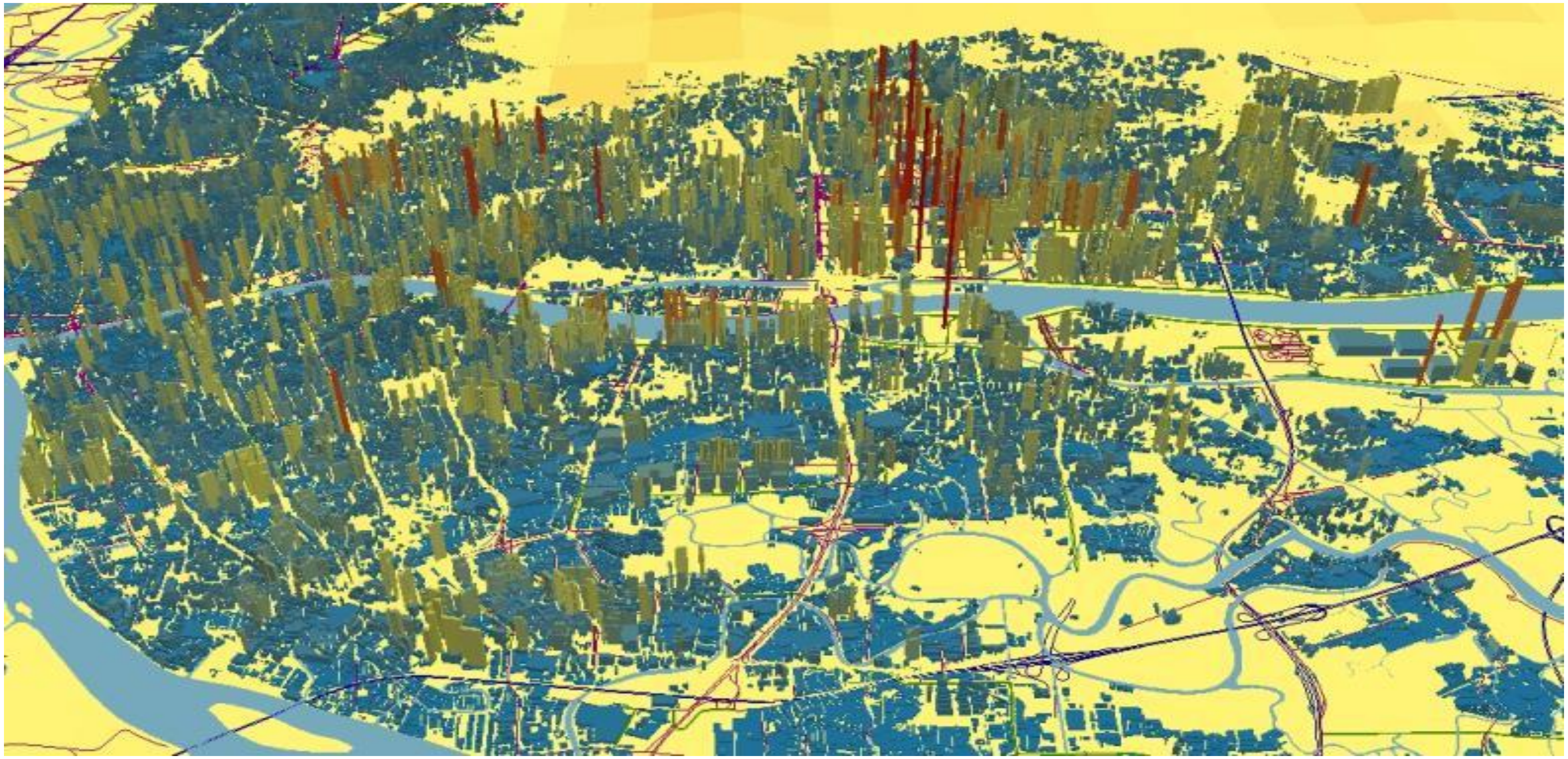
$$\begin{cases} \Delta X = H \sin p / \tan\theta \\ \Delta Y = H \cos p / \tan\theta \end{cases}$$

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



Dai W. and Wang X.M., 2015

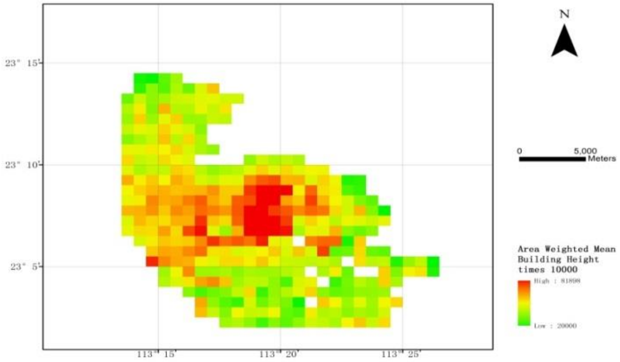
Over 77 thousand 3D building models

Urban Morphology Parameters

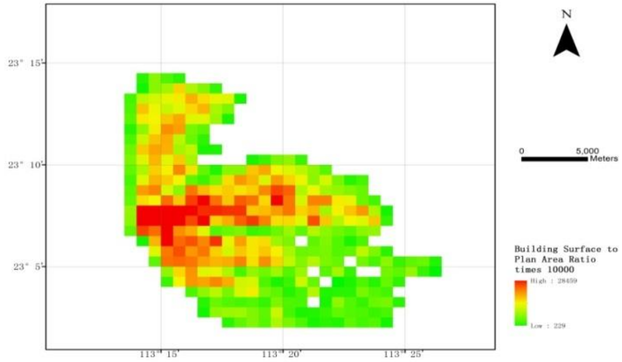
- mean building height: $\bar{h} = \frac{\sum_{i=1}^{N} h_i}{N}$
- mean building height weighted by building plan area: $\bar{h}_{AW} = \frac{\sum_{i=1}^{N} A_i h_i}{\sum_{i=1}^{N} A_i}$
- building plan area fraction: $\lambda_p = \frac{A_p}{A_T}$
- Building Plan Area Density: $a_p(z) \cong \frac{\lambda_p(z)}{\Delta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

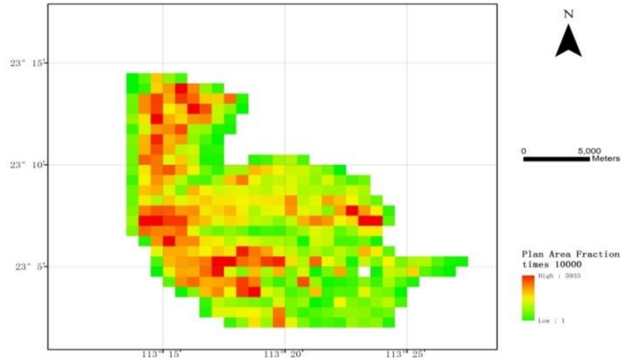
1-km UCPs in Guangzhou



Area weight mean build height

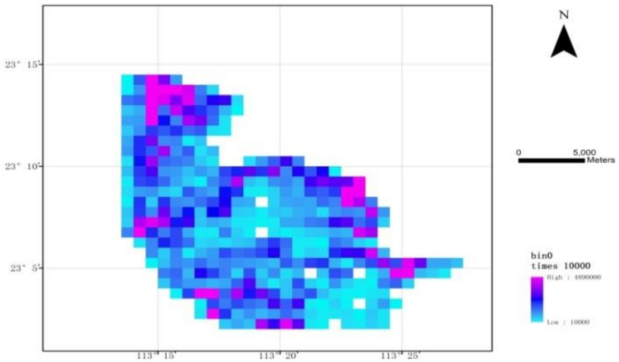


Building Surface to Plan Area Ratio

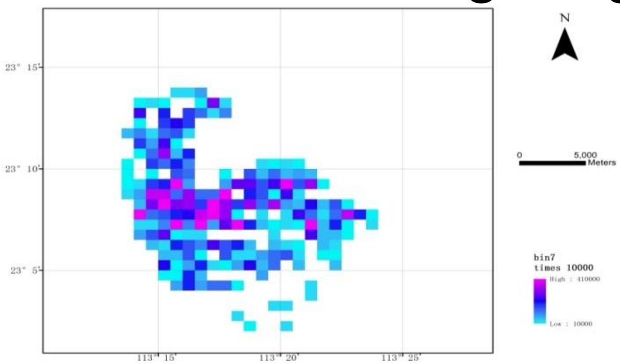


Plan Area Fraction

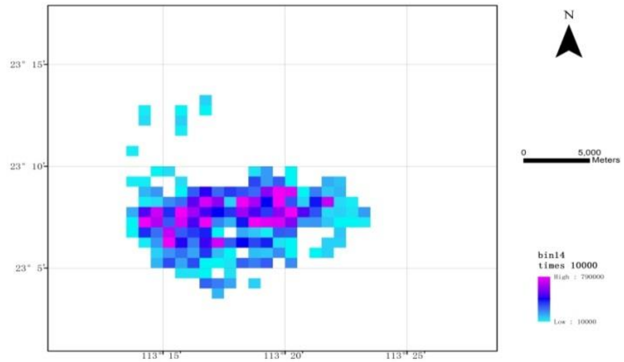
Distribution of building heights



5m



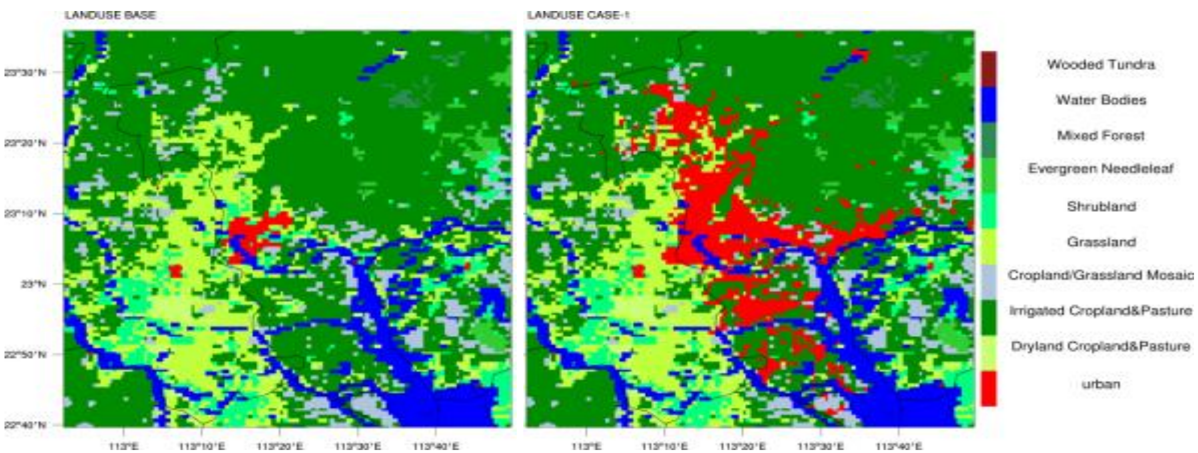
35m



70m and more

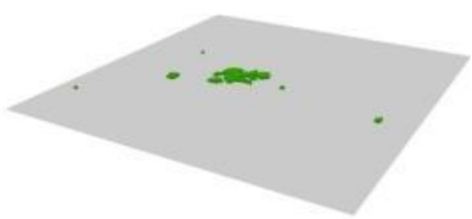
Dai W. and Wang X.M., 2015

WRF-Urban Experiment Setup

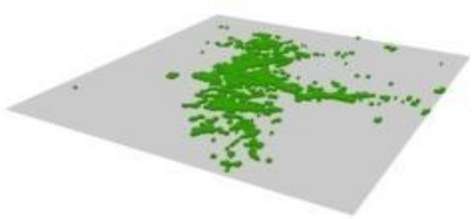


Base Case1 & Case2

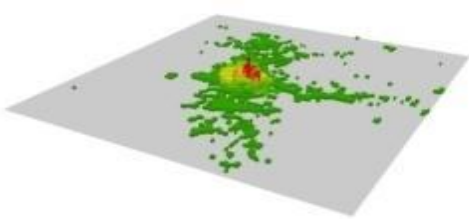
- Base: Before rapid urbanization (USGS 1993)
- Case1: Urbanized Guangzhou city (MODIS 2001)
- Case2: Urbanized Guangzhou city with GZ-UCPs



Base



Case1



Case2

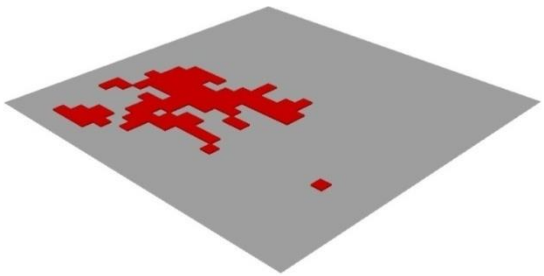
Dai W. and Wang X.M., 2015

UCPs in WRF-urban replaced by GZ-UCPs

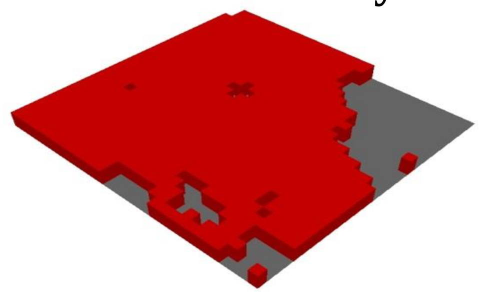
Model BEP variable	GZ-UCPs (new)		URBPARM.TBL (old)	
LF_URB2D	Plan area fraction	LamP		Function of Street width & Building width
HGT_URB2D	Area weighted mean building height	awaHT		Function of building Distribution
HI_URB2D	Distribution of building heights	Histogram	Building Distribution	5 m : 33 % 10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

Improved the Simulation of Wind Speed

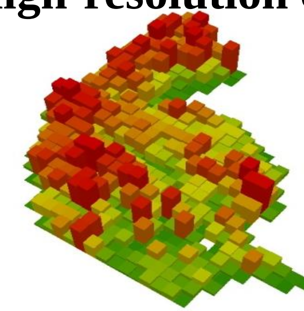
Highly simplified city

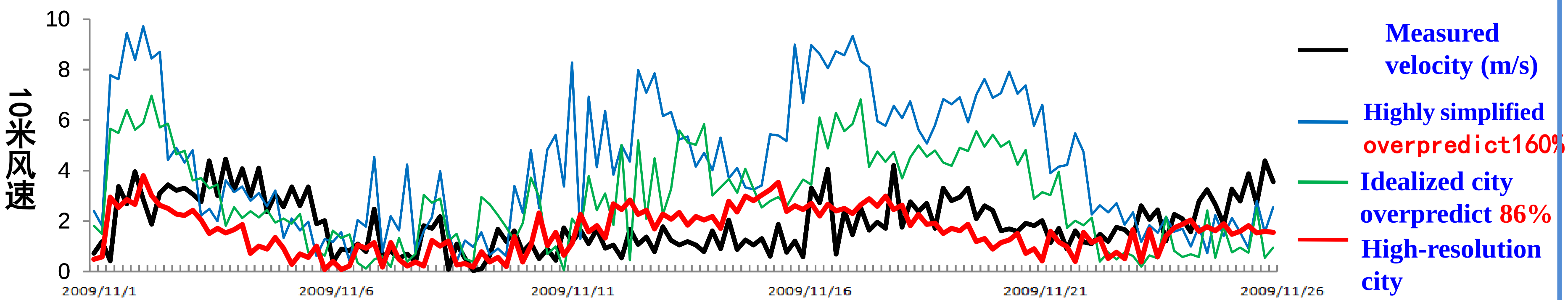


Idealized city



High-resolution city



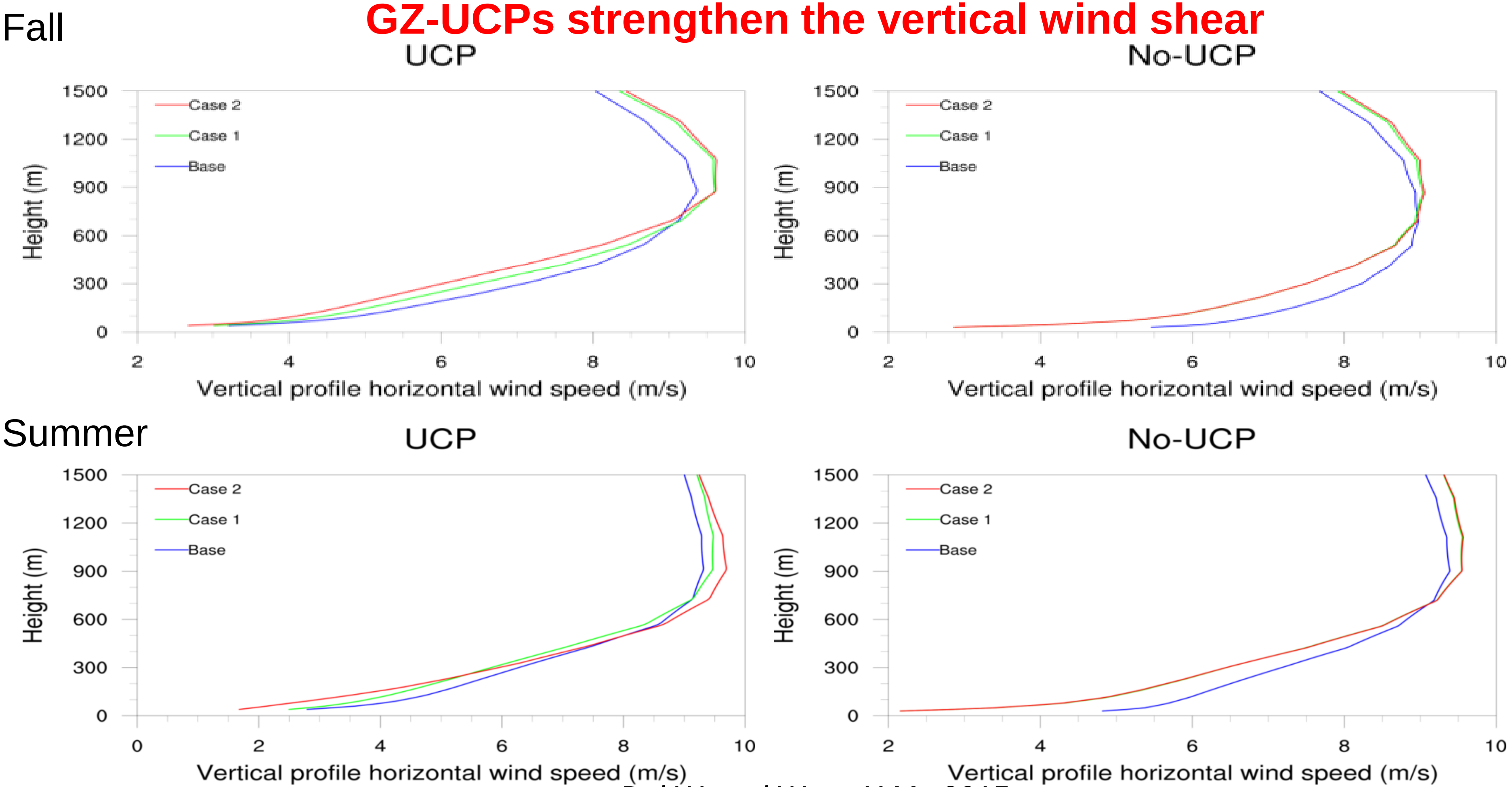


Work by my team： With the high-resolution urban canopy model coupled with WRF, the accuracy of wind prediction in cities are much improved.

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

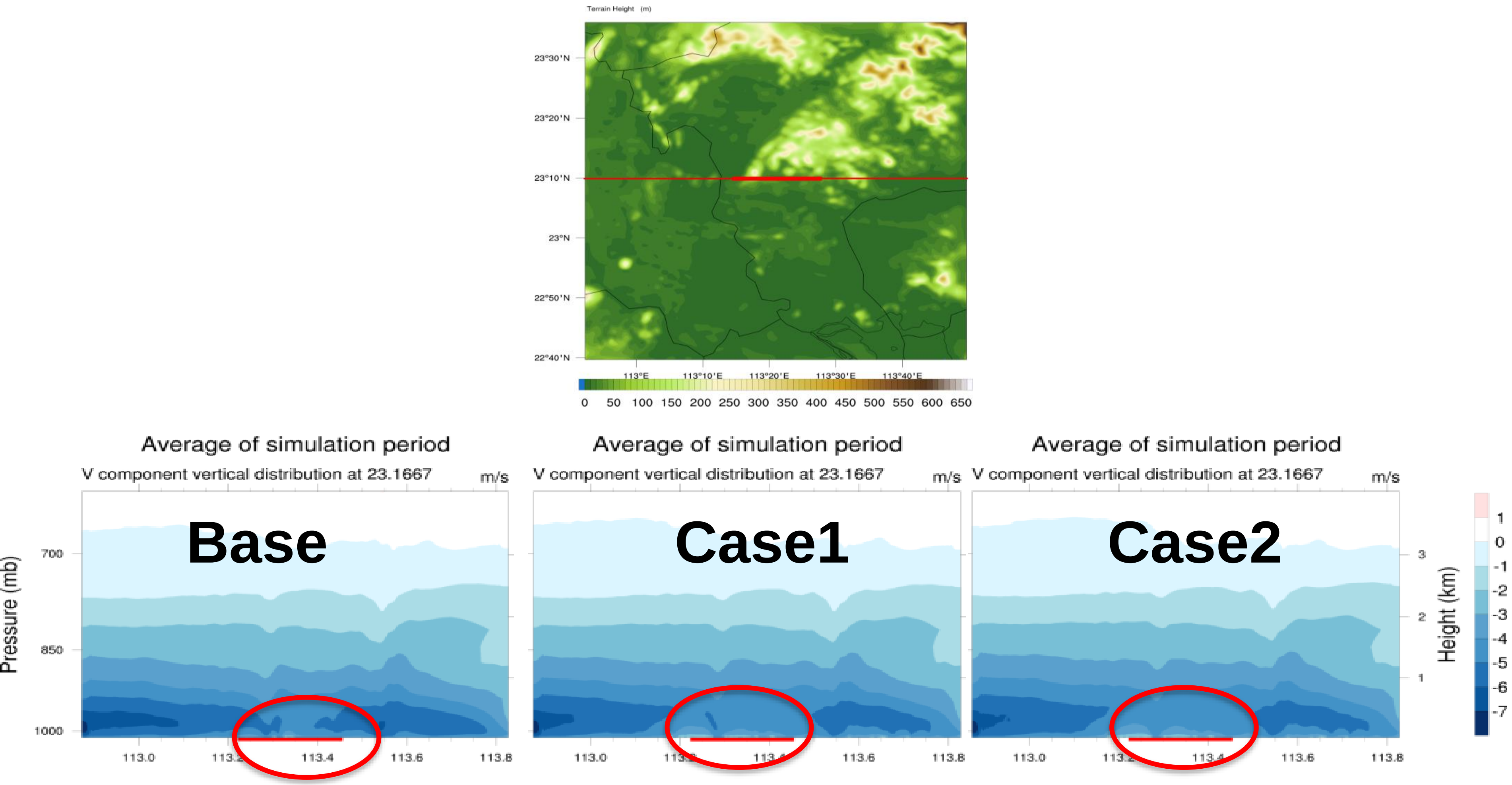
Vertical distribution of wind speed

GZ-UCPs strengthen the vertical wind shear



Dai W. and Wang X.M., 2015

Vertical section of V wind distribution

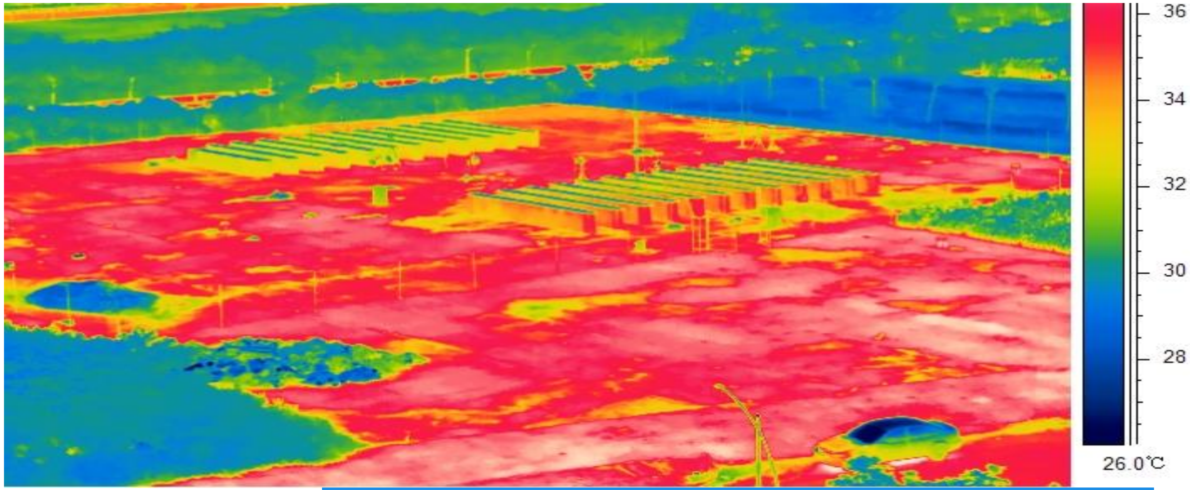


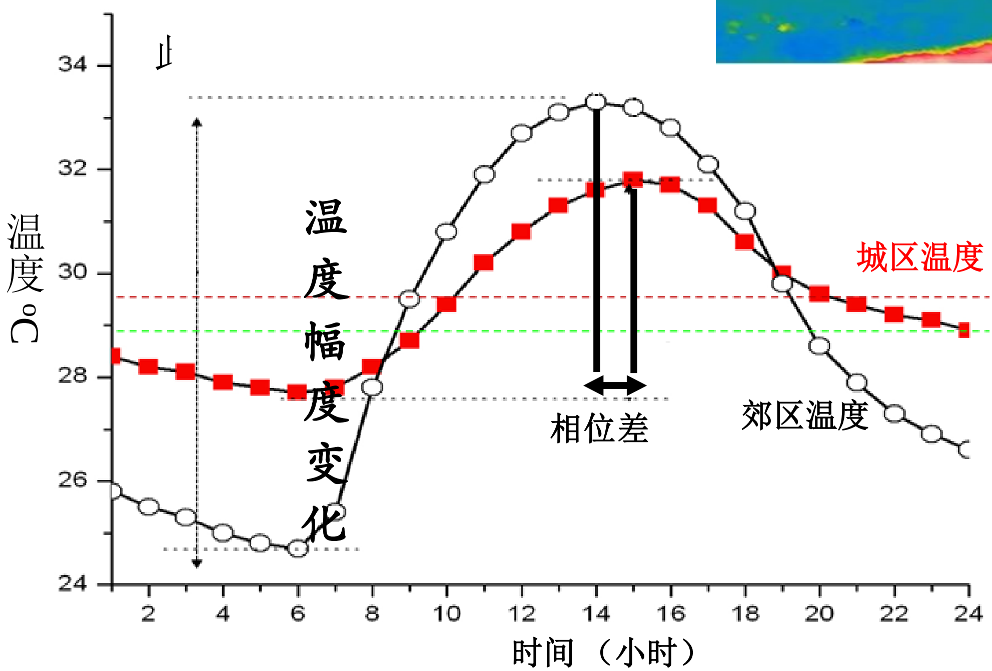
Wide range of network measurement with sufficient resolution are needed and challenge

Outdoor field measurements setup in my group

Lead by Dr. Jian Hang

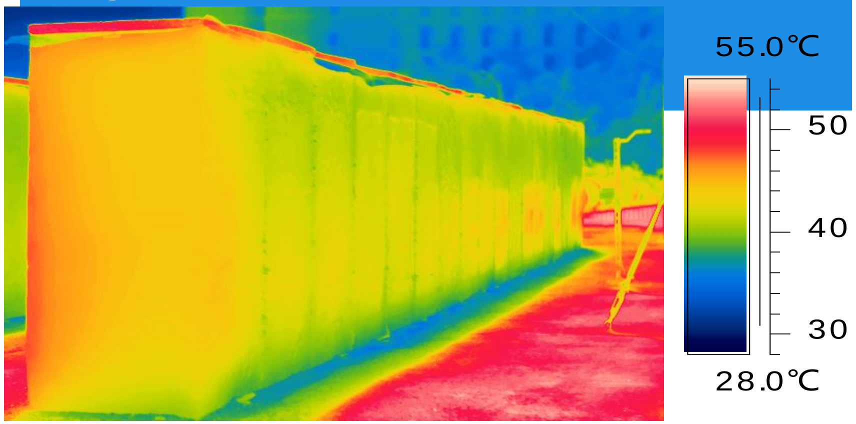
Experiments on building density, thermal storage, and color etc. to investigate the turbulence and and thermal environment.





Temperature diurnal in different land-use

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



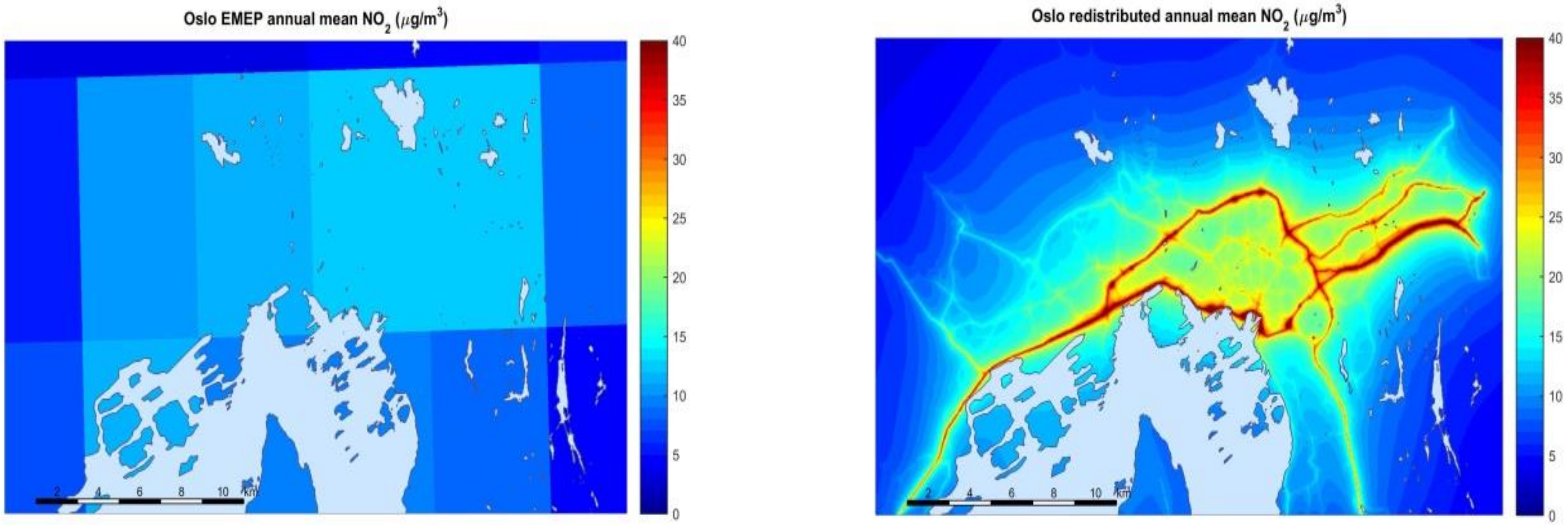
Jinan University's role in AIRQUIP

- Improvement of regional Air quality forecasts (WP 2.2 and 2.3)
  - Improvement of diurnal variation of NO_2 and O_3
  - Improvement of chemical scheme with respect to PM
  - Improvement of high resolution input data
- Assist to Operational downscaling method in PRD (WP 4.2)
  - Operational downscaling of PANDA data for Chinese megacities
- Assist to Outreach (WP6)
  - Organization of user meetings
  - Reporting

Jinan University's role in AIRQUIP

- New downscaling method will be used in this project

1. Gaussian dispersion models
2. Redistributes existing model concentrations at high resolution within the model grid.



EMEP grid concentrations (left) and redistributed traffic concentrations (right) using the uEMEP redistribution methodology for Oslo (EMEP, 2016).

Thank you