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

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## 1. Introduction

With the global trends in urbanization, in 2014, 54 percent of world's population lived in the urban area (United Nations, 2014) that was expended as twice rate as globe population growth (Seto et al., 2012). The urban areas particularly mega-city regions could affect the climate change and have significantly modified local and regional meteorological conditions. In cities, urban region is the major global greenhouse-gas (GHG) emission source (Solecki et al., 2012), the natural ground is replaced by artificial surfaces, which increase the heat storage capacity of surfaces so as to affect the energy balance. Bituminous roads and roof of buildings reduce the surface albedo and impervious materials cut down evaporative cooling. In addition, human and industrial activities produce anthropogenic heat and moisture to the atmosphere environment. As we know, the difference between urban area and its rural cause urban heat island (UHI) effect. With urban expansion, tall buildings and high building density areas strengthen the surface roughness and the wind speed slow down. Some previous studies revealed that urbanization can increase the frequency and severity of heavy rainfall and reduce the visibility. It can also impress the diffusion of atmospheric pollutants. The study of urban area influence on meteorology is meaningful to improve human comfort and health.

Meteorological observation, remote sensing and numerical simulation are the three major means for the research of urban impact on atmosphere. In present, numerical simulation is widely employed in research of atmospheric environment response to urbanization and climate change. The Weather Research and Forecasting (WRF) model (Skamarock et al., 2008) coupled with urban canopy models was used for studies of heat wave, UHI (Zhang et al. 2011; Theodore et al. 2013; Jinyan et al. 2013) and future urban expansion(Argüeso et al., 2013). However, fine-scale gridded urban canopy parameters (UCPs) are needed to drive the urban canopy models but yet difficult to obtain in cities without detailed urban morphological data.

Guangzhou is the largest city in The Pearl River Delta (PRD), which is the largest urban area in 2010 in terms of both size and population. Rapid urbanization and industrialization change the local climate and air quality, and the real urban morphology needs to be employed in correlation simulation. In this study, we developed a new approach to establish the UCP database of Guangzhou (GZ-UCPS) based on Google-earth imagery, available for free of charge at high resolution (0.61 meter) and frequently updated. After the evaluation of model performance, numerous high-resolution WRF numerical experiments were conducted using various sources of LULC and UCP data to reveal the impacts of GZ-UCPS on regional weather and air quality.

## 2. Development of GZ-UCPS

To exploit the performance advantage of urban canopy models, the NUDAPT (National Urban Data and Access Portal Tool) dataset was introduced in Weather Research and Forecasting (WRF) from the version of 3.5. However, the UCPs provided by NUDAPT are difficult to obtain in cities where the detailed urban morphological data do not exist. Therefore, we developed a new approach to establish UCP database based on Google-earth imageries and calculated urban morphology parameters (e.g., mean building height, building plan area fraction, and building plan area density).

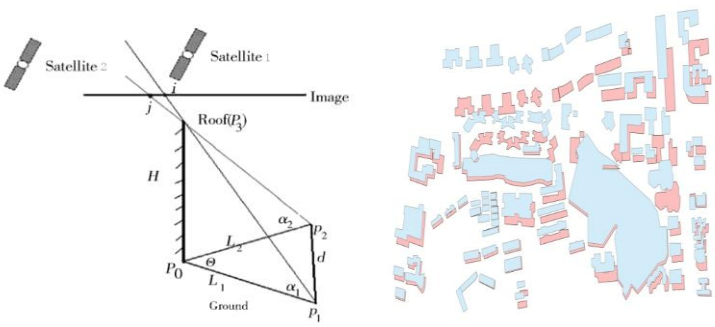



*Fig. 1 The method of building's span and height identification*
*a. The Satellite Geometry; b. Sample features of vectorizing buildings roof*

Two satellites have different orbit parameters (Fig. 1 a), therefore the buildings generate parallax features from different imageries(Fig. 1 b). Two imageries at the same place with different view angles of buildings were used to identify the building span and height, After vectoring images, the distance(d) of two features(the roofs of same building and have same ID index) were calculated by formula(1 to 3), where H is the building's height, GSD is the cell size of imagery.

$$H = d/K \quad (1)$$

Where

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

$$K = \sqrt{\cot(\alpha_1)^2 + \cot(\alpha_2)^2 - 2\cos(\theta)\cot(\alpha_1)\cot(\alpha_2)} \quad (3)$$

In this study, the data source of imagery originated from two different period Google-earth products of different orbit parameters. The satellite orbit parameters of this imagery are obtained from the digital-globe's Website. The parameter θ is the azimuth difference between two satellites. The parameter α1 is satellite1's elevation and α2 is the elevation of satellite2. The parameters x and y are the same points of the same building from different imagery.

The methodology of calculating urban morphology parameters (e.g., mean building height, building span area fraction, building span area density) is according to the study of Burian et al. (2007).Frontal area index was calculated under 8 wind directions with 45-degree intervals. The sky view factor was calculated with 360 slices number of 1-m resolution and no limit rang of extended distance. The improvement of the algorithm of frontal area index, sky view factor and grid cell mesh generating (avoiding the offset between geographical grid cell and vector clipping grid cell) were implemented. Fig. 2 shows the selected GZ-UCPS of Guangzhou's core area with 1km cell size for standard deviation of building height, area weight mean building height, building surface to plan area ratio, Sky view factor, Height to width ratio, plan area fraction and distribution of building heights.

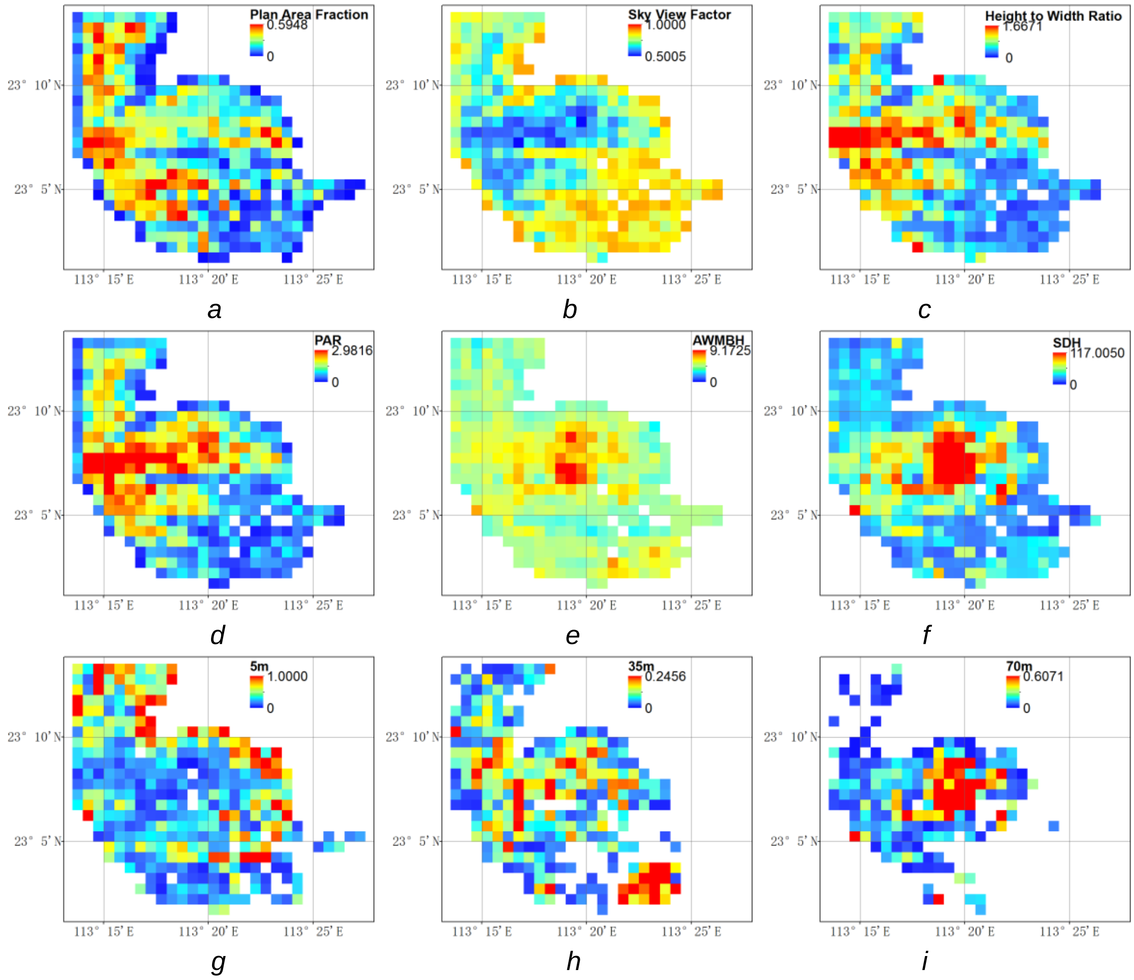



*Fig. 2 Selected GZ-UCPS of Guangzhou's core area with 1km cell size*
*a. Building surface to plan area ratio; b. Sky view factor; c. Height to width ratio;*
*d. Plan area fraction; e. Area weight mean build height; f. Standard deviation of building height.*
*The distribution of building heights at: g. 5m; h. 35m; i. 70m and above.*

### 3. Numerical simulation in Guangzhou

To test the performance of GZ-UCPS and urbanization progress in Guangzhou, a numerical simulation method is implemented in the version 3.5.1 of WRF-ARW coupled with the Unified Noah3.1 LSM (Tewari et al.2009) and the multilayer urban scheme BEP (Kusaka et al. 2001; Kusaka et al. 2004; Tewari et al. 2007) were employed in this study. Including 16 hours for model spin-up, a period of 11 days simulations is performed from 0000LST 31 Oct 2010 to 0000LST 11 Nov 2010.

### 3.1 Model configuration

The Initial and boundary conditions were provided by National Emergency Communications Plan (NCEP) with operational Global Final (FNL) Analyses on a 1.0 by 1.0 degree grid (every 6hrs). Four nesting domains were set up with 500m grid size of internal domain (Fig. 3). A forty vertical layers was set up (Francisco Salamanca et al. 2011) with 50 hPa on the model top. The details of scheme configures are summarized in Table 1.

*Table 1. The setting of WRF parameterizations schemes*

| 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-ObukhovEta scheme | | | |
| Land-surface option | Unified Noah LSM | | | |
| Cumulus parameterization option | KF | G3 | disable | |
| Urban Surface option | Disable | | | BEP |
| Boundary Layer option | MYJ | | | BouLac |

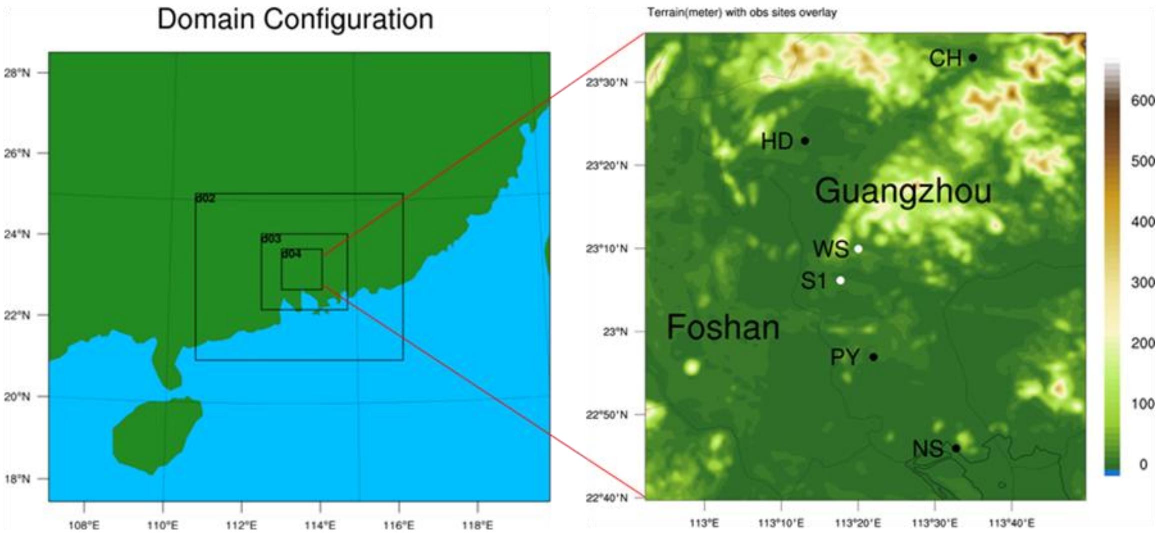



*Fig. 3 Domain configure and topography map with meteorological stations*

The d04 includes the core urban area of Guangzhou with six meteorological stations for model evaluation, and two stations drawn by white point in Fig. 3located in the range of GZ-UCPs area.

According to the observation data from WS meteorological stations (Fig. 3), the averaged 2 meter temperature was 20.3 Celsius degree and the relative humidity was 52% in the simulation period time and a 10 meter wind rose is shown in Fig. 4. There were two days of shower from 5 Oct to 6 Oct.

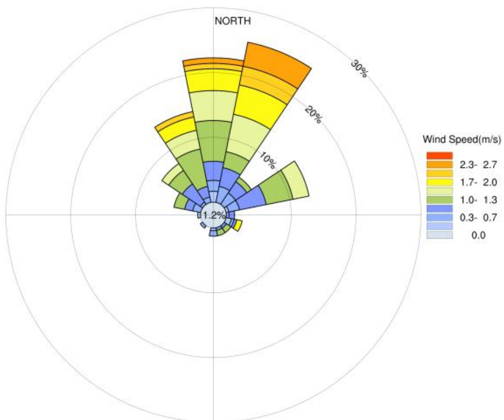



*Fig. 4 The wind rose of 10m wind above ground at WS station*

### 3.2 Urban canopy model

The multilayer urban scheme BEP was selected for this study. The BEP scheme divided the vertical atmosphere to many layer in urban canopy which well represents the structure of building distribution in vertical orientation. The BEP scheme considered two orthogonality streets, and the parameters of building width, building height and street width can be set up, respectively.

### 3.3 Comparison experiments in Guangzhou city

To understand the local climate response to urban expansion which generates in horizontal and vertical ways of megacity, three cases were implemented in Guangzhou city in this study. The base case represents the period of pre-urbanization (Fig. 5a) that the urban area is small with low building at a same height. Other two cases were set to compare the climate responses to the urban canopies before and after urbanization Case1 represents current urbanization progress showing a larger urban area with the same value of building parameters in base case. To remove the climate response to urban expanding of Foshan city, the region of urban area of Foshan in upwind region remain unchanged (Fig. 5b). Case2 was set up with the same urban area as Case1 but building parameters. The GZ-UCPS dataset was employed in Case2 instead of the consistent building parameters in spatial distribution (Fig. 6).

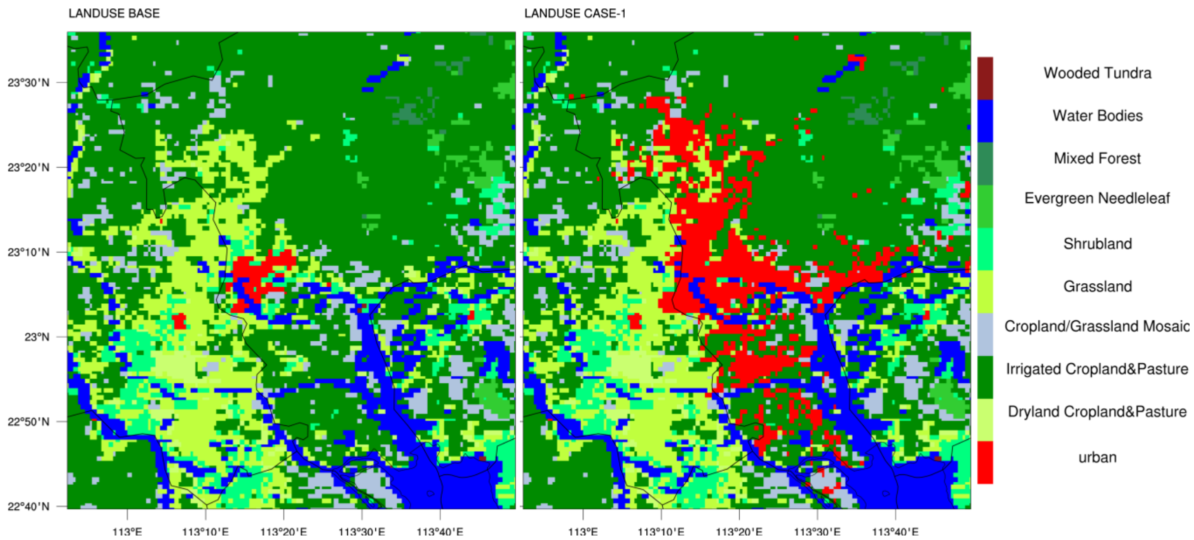
### .3.4 Data input for comparison case experiment

A 30s USGS Land Use and Land Cover (LULC) dataset was employed to integrate dataset of WRF, showing the globe LULC in 1994. Another 1s FROM-GLC (Gong et al. 2013) LULC dataset was used to update the urban area of Guangzhou city to that in recent period, and the urban fraction was also calculated. The dataset of GZ-UCPS was established as introduces in Section 2 above. The details of input data for different cases are shown in Table 2.In order to reveal effects of urban expansion and fine-scale GZ-UCPs on the wind speed, three sensitivity experiments were implemented. The first experiment was executed minusing Case1 by Base case to show that local wind speed response to urban expanding. The second experiment was conducted minusing Case2 byCase1 to reveal the effect of urban vertical growth on the local climate. The third experiment was employed minusing Case2 minus by Base case to show the influence on climate of Guangzhou megacity to surrounding area especially in downwind region.

*Table 2. The input data of sensitivity experiments*

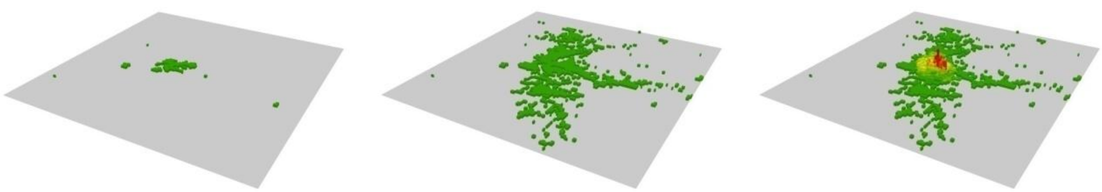
| Input Data | Base | Case1 | Case2 |
|---|---|---|---|
| Landuse | USGS | USGS + GZ expands urban area | |
| Urban param/urban fraction | Look-up table | | GZ-UCPS (30s)* |

** Look-up table for missing value*




*a* *b*

*Fig. 5 Landuse data for Base & Cases*
*a. Base; b. Case1&Case2.*



*a* *b* *c*

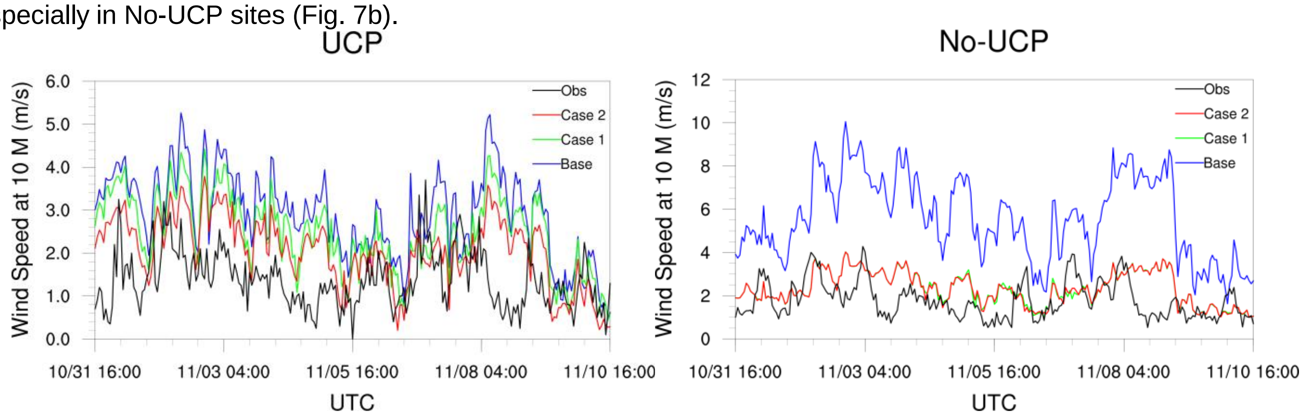
*Fig. 6 3D views of urban mean building height of guangzhou city*
*a. Base; b. Case1; c. Case2.*

To modify the default value of mean building height in the URBPARM.TBL file, an average building height of 10 meter was employed. Both building width and street width in the URBPARM.TBL were set to 15 meters.

## 4. Impacts of urban expansion and fine-scale GZ-UCPs on surface wind speed

### 4.1 Temporal variations

Urbanization also increases the surface roughness over the urban area. The friction and drag of buildings will decrease the near-surface wind speed in the urban area. Two data groups were setup to investigate the temporal variations. UCP represents the WS and S1 located in the GZ-UCPs area, and No-UCP represents the sites outside the GZ-UCPs area. Fig. 7 shows the time series of wind speed at 10 meter. It can be seen that simulated wind speed over estimate compared with observation at three cases while case2 with fine-scale UCPs is much closer to the observations (Fig. 7a). Case2 in UCP sites show smaller wind speed compared with case1, indicating that the building heights have apparent influence on wind. Wind speed decreases very fast after urban expansion, especially in No-UCP sites (Fig. 7b).




*a* *b*

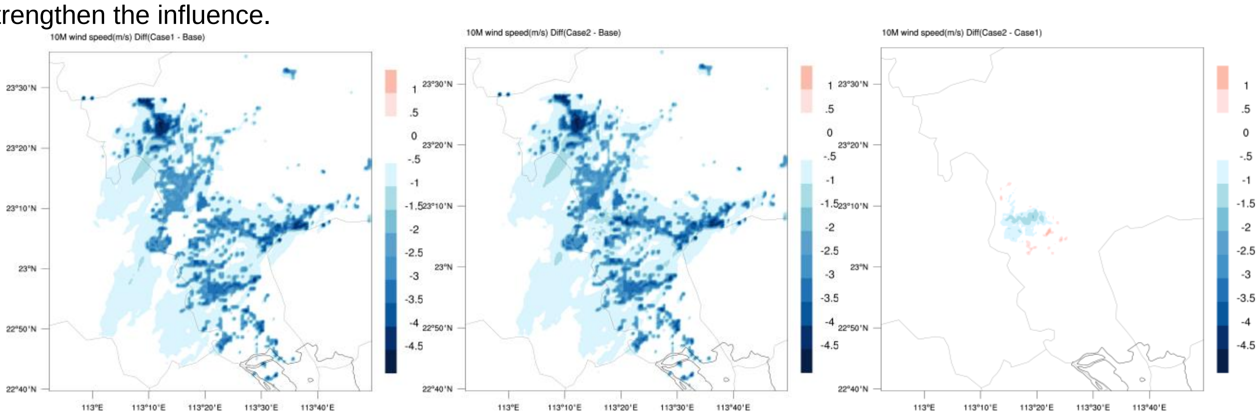
*Fig. 7 Time series of wind speed at 10 meter. (a) UCP sites; (b) No-UCP sites*

### 4.2 Spatial variations

The regional influence of urbanization can be described by the EI (effect index), defined as follows (Zhang et al., 2010):

$$\mathrm{EI}(x) = A_{\mathrm{change}}(x)/A_{\mathrm{urban}} \quad (4)$$

Where x can be any meteorological parameter such as averaged temperature, maximum/minimum temperature and wind speed, etc. Achange (x) is the area where x changed and Aurban is the area land-use modified from other types to urban cover. An EI(x) of 1 indicates that only the urbanized area is affected. EI(x)<1 indicates that only part of the urbanized area is affected, and EI(x)>1 means that an area in addition to the urban area will be impacted. Our simulations show that wind speed decreases in both daytime and nighttime. Fig. 8 shows the averaged difference of surface wind speed for the three cases. In urban area, the decrease may reach 1.5 ms−1-4.5 ms−1, while in UCP area, the decrease could reach 1.0-1.5 ms−1 after fine-scale UCP data were used. The urbanization causes 50%-80% wind speed loss over urbanized area. The decrease of wind speed also happens on a regional scale. From base to case1, EI (WS10m) is 3.0, the indicates urbanization leads to a “urban shadow” phenomena in this area. From base to case2, EI (WS10m) is 3.3 which reveal the high density and fine-scale urban structure can strengthen the influence.




*a* *b* *c*

*Fig.8 The average difference of 10mwind speed*
*a. Case1-Base;b. Case2-Base; c. Case2-case1.*

## 5 Conclusions

In this study, we developed a new approach to derive UCP database of Guangzhou from Google-earth imagery. Two images at the same place with different view angles of buildings were used to identify the building span and height and to calculate urban morphology parameters (e.g., mean building height, building plan area fraction, building plan area density). New LULC data and UCP data were used to investigate the influence of urban expansion and fine-scale UCP data on surface wind speed. The results show that the surface wind speed from the new UCPs can match very well with the observations. New UCP data revealed that the building heights have apparent influence on wind. The regional influence with new UCP data is larger than new LULC data.

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