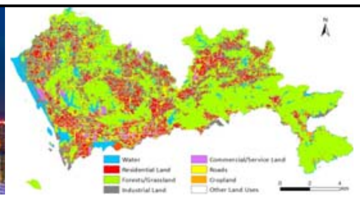




High Spatial-temporal Resolution Mapping of Urban CO_2 Emissions: Megacity-Shenzhen

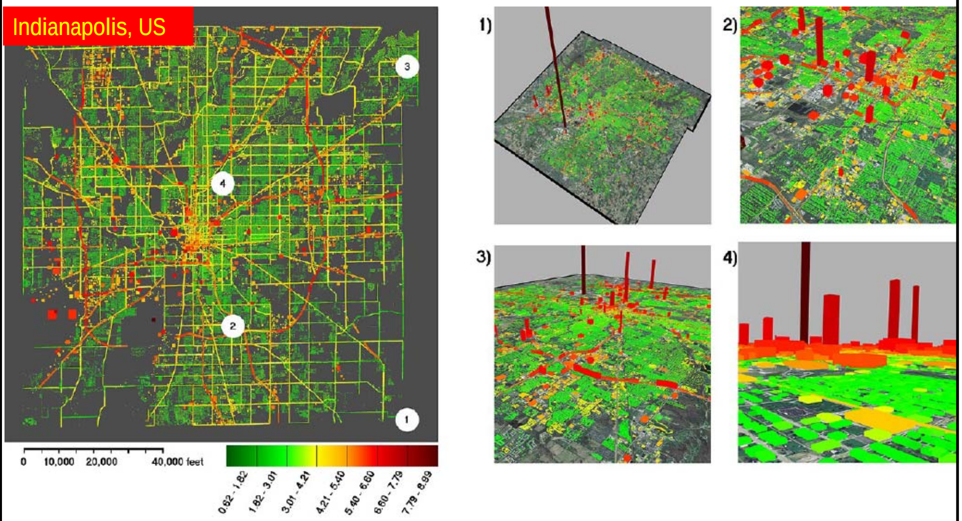
Jun Wang
PKU-Shenzhen, China
September 21, 2015

Outline

- **Overview of the urban carbon project in Shenzhen**
- **The approach for mapping carbon inventory of the megacity-Shenzhen**
- **Anthropogenic systems**
  - **Sector I: urban buildings**
  - **Sector II: urban transportation**
  - **Sector III: urban industries**
- **Natural systems**
- **Progress of the other parts of the urban carbon project in Shenzhen**

2

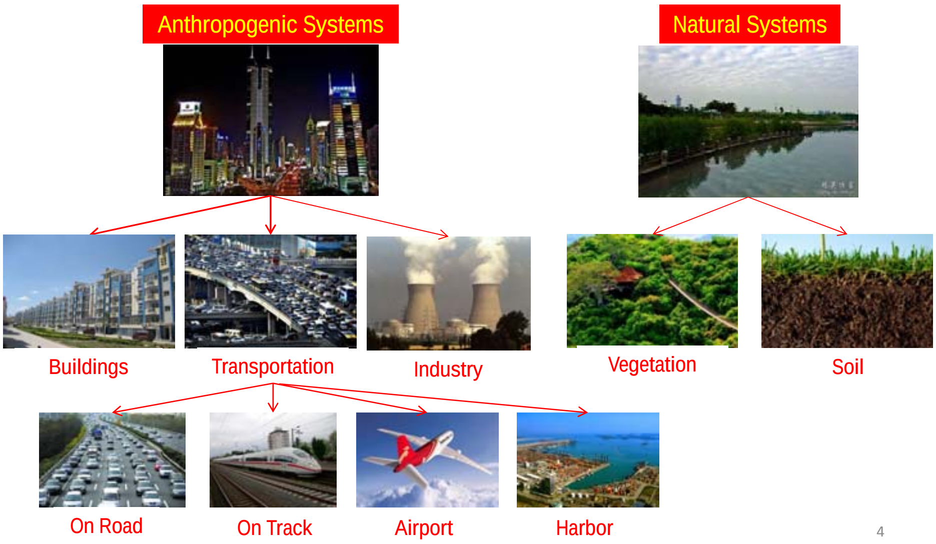
High Resolution Mapping of Urban Carbon Emissions



Gurney et al., 2012

3

A Bottom-up Approach for Mapping Urban Carbon Inventory



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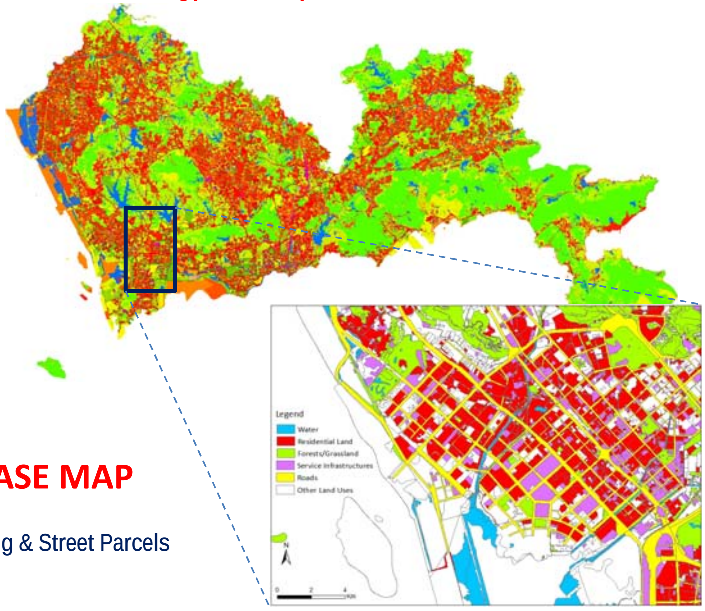
Anthropogenic Systems:
Energy Consumption & Carbon Emissions

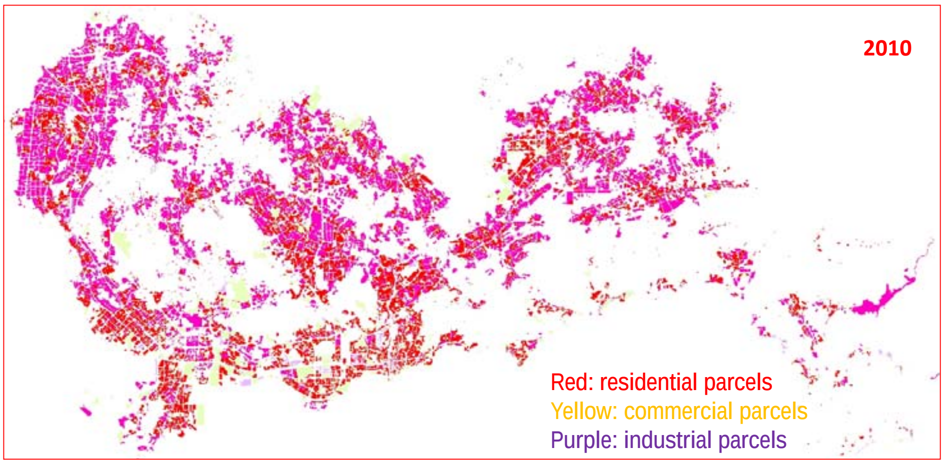


BASE MAP

Building & Street Parcels

5

Sector I: Urban Building – Parcel Feature



6

Urban Building Classification

- Urban buildings are assigned into four types: residential, commercial, institutional, and industrial buildings.
  - Residential buildings
    - Urban villages, old apartments (without elevators), new apartments (high), and single-family houses
  - Commercial buildings
    - Shopping malls, grocery stores, retail stores, food sale, restaurant, and hotels
  - Institutional buildings
    - Schools, universities, governmental buildings, and public infrastructures (e.g., hospitals, libraries, sport centers)
  - Industrial Buildings
    - Office buildings, production buildings, and warehouse.

Urban Buildings in Each Category (Shenzhen)

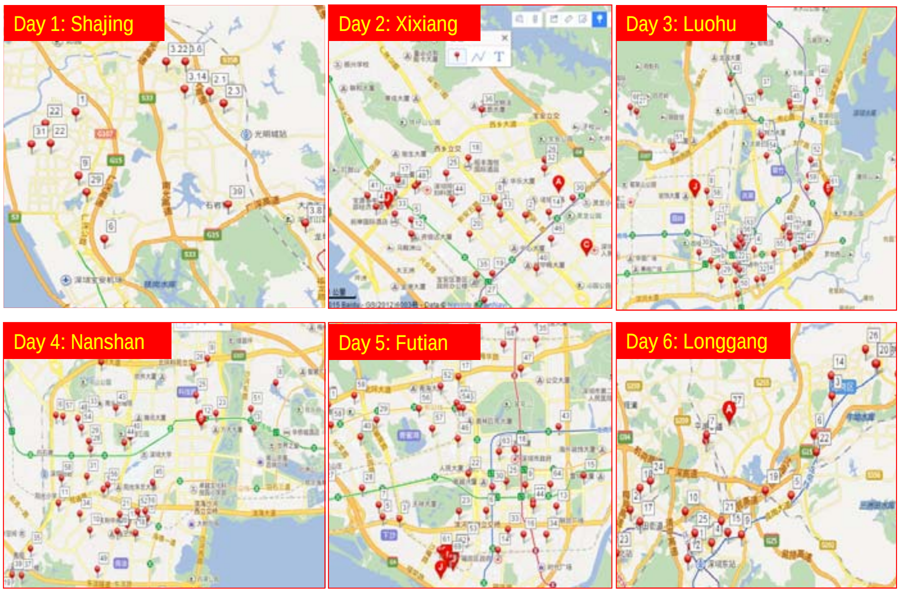
9

Modeling Hourly Carbon Emissions of Urban Buildings

- We surveyed each typical type of urban buildings in the four categories and use building energy consumption models to estimate energy use per floor area (energy use intensity) for the typical types of buildings.
- The model derived empirical building emission factors were used for calculating carbon emissions of buildings in each typical type.
- Besides total building carbon emissions, we also studied the temporal carbon emission patterns of the typical types of urban buildings.
- Finally, we build a geodatabase to store the carbon emission patterns of the 200,000 geocoded buildings in Shenzhen.

10

Field Surveys about Energy Use Patterns of Urban Buildings

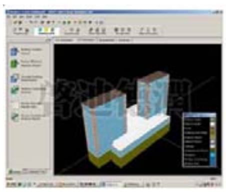


11

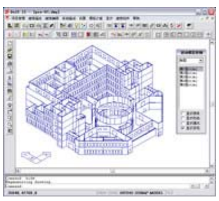
Modeling Hourly Carbon Emissions of Urban Buildings

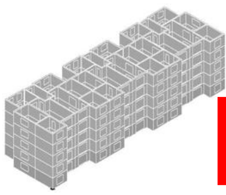
- **eQUEST Model: developed by the Laurent and Berkeley National Lab (LBNL) and used for simulating hourly building energy consumption.**

eQUEST



- **DeST Model: developed by Prof. Jiang Yi Group at Tsinghua University.**



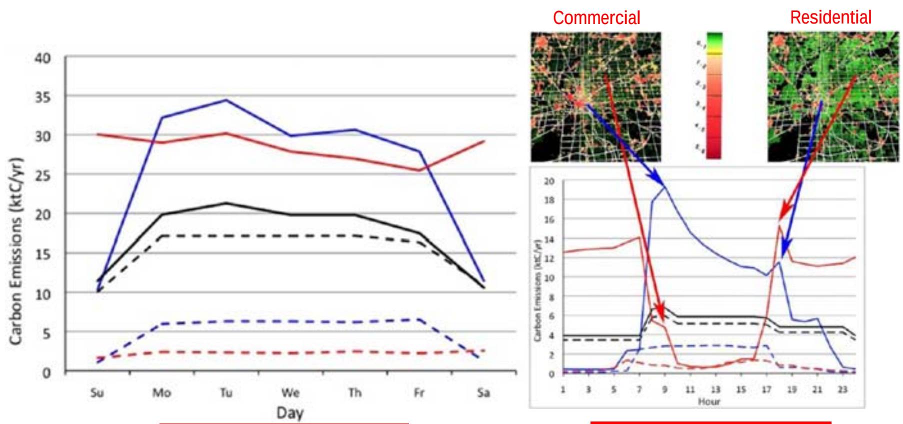


Other software:

DOE-2, EnergyPlus

12

Carbon Emission Patterns of Urban Buildings, Indianapolis



Daily Emissions in a Week

Hourly Emissions in a Day

Blue (commercial); red (residential); black (industrial)
Solid lines (winter); dashed lines (summer)

Gurney et al., 2012

Sector II: Urban Transportation – Line Feature

Urban Transportation Classification

- On-road transportation
  - Roads are categorized into four main types: highways, main roads, branch roads, streets
  - Vehicles are assigned into 28 types to differentiate their emission factors.
- On-track transportation
  - Subways: running sector & station sector
  - Railways: running sector & station sector
- Airports and harbors (parcel features)

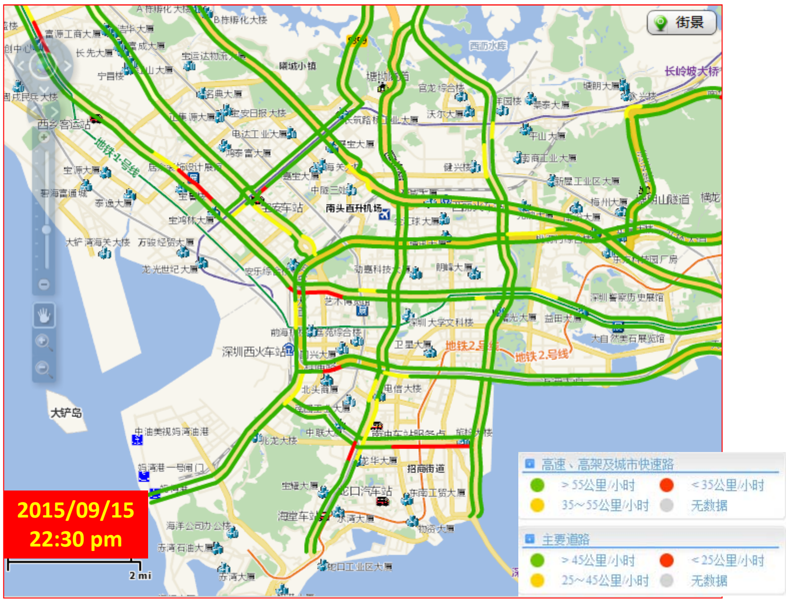
15

On-Road Transportation: Real-time Monitoring Data

16

On-Road Transportation: Real-time Monitoring Data

On-Road Transportation: Real-time Monitoring Data



19

Field Surveys about On-Road Transportation: Site 1

20

Field Surveys about On-Road Transportation: Site 2

21

Field Surveys about On-Road Transportation: Site 3

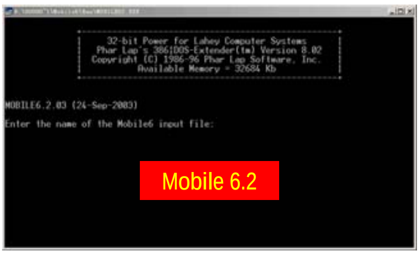
22

Field Surveys about On-Road Transportation: Site 4

Modeling On-Road Transportation Emissions

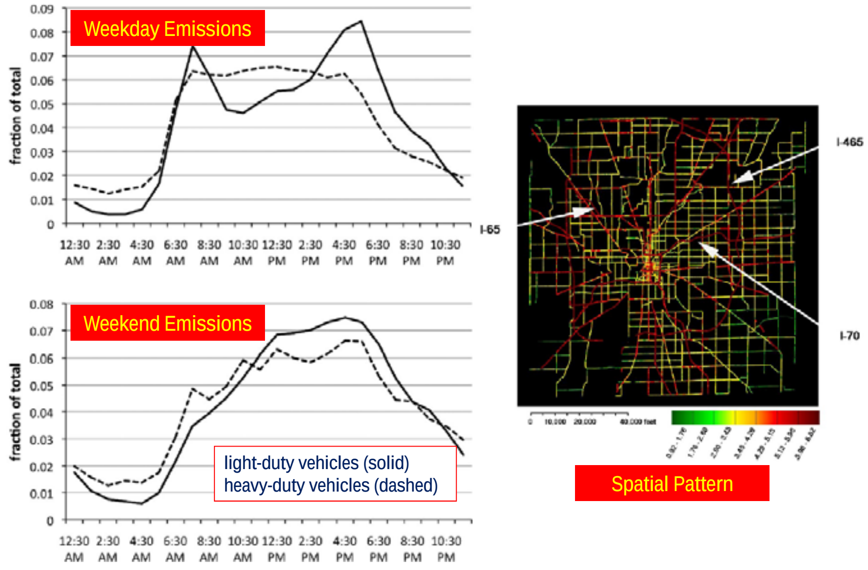
- First, we use real-time transportation monitoring data to estimate the **amount of vehicle per time period**, **vehicle speed**, and **vehicle types** in each segment of each road.

Hourly CO_2 Emissions of Each Segment of a Road
= Vehicle Amount * (vehicle_1 percent * EF1 +vehicle_2 percent * EF2 + ...+ vehicle_n percent * EFn) * Segment Length



Mobile 6.2 is developed by EPA to simulate emission factors of various types of motor vehicles under different environmental settings.

Carbon Emission Patterns of On-Road Transportation, Indianapolis



Gurney et al., 2012

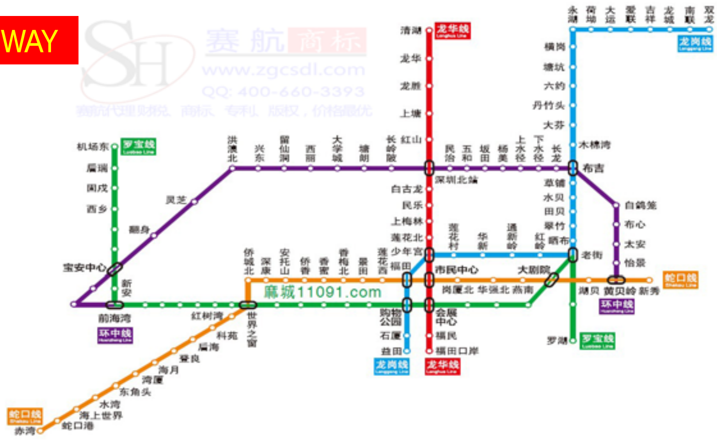
25

Estimating On-Track Transportation Emissions

- Carbon emissions of subway systems
  - Running sector
    - energy consumption of engines, air conditioning systems, light systems, and other electronic facilities.
  - Station sector
    - Stations are assigned into five types (airport/railway station, major exchange station, exchange station, major station, and normal station)
    - Air conditioning systems, light systems, elevators
- Carbon emissions of railway systems
  - Running sector
  - Station sector

26

SUBWAY




Running Sector


Station Sector


Station Sector

27

RAILWAY


Running Sector

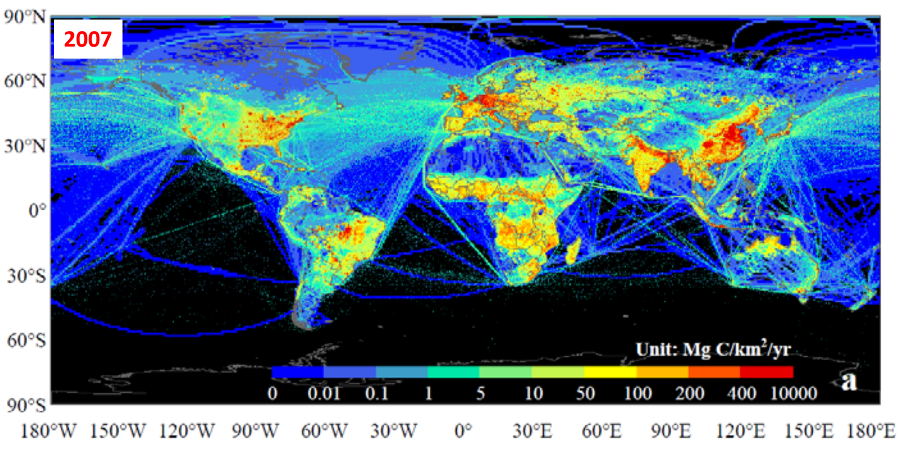

Station Sector


Station Sector

28

29

PKU Fuel and CO_2 Emission Inventory



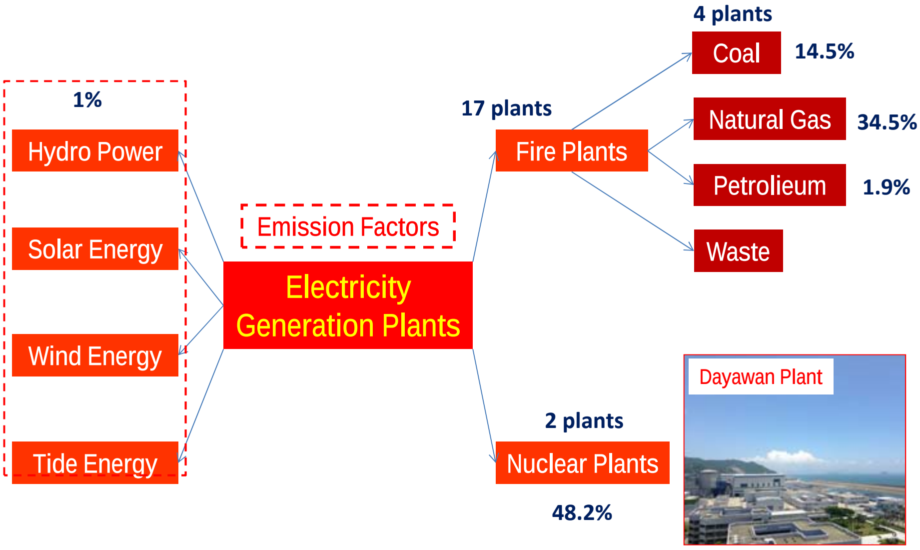
Source: Wang et al., 2013

30

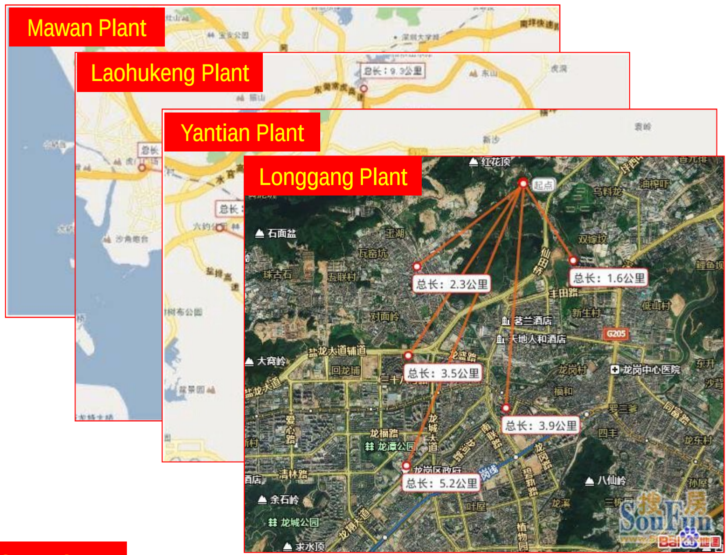
Sector III: Urban Industry – Point Feature

- **Electricity generation**: burning coal, nuclear, waste, and new energy
- **Industrial processes**: emissions from chemical processes
- **Waste processing**: emissions from processing waste water & solid waste

In Shenzhen, electricity generation is the largest CO_2 emission source in the industry sector (about 41% of total CO_2 emissions)



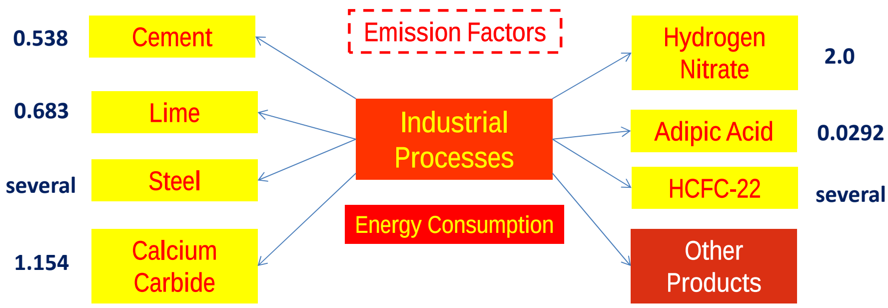
Electricity generation from burning coal, nuclear, and waste



ELECTRICITY

33

The urban-scale carbon emissions from industrial processes in Shenzhen were mainly classified into eight types based on the provincial-scale GHG emission inventory guidelines of China.

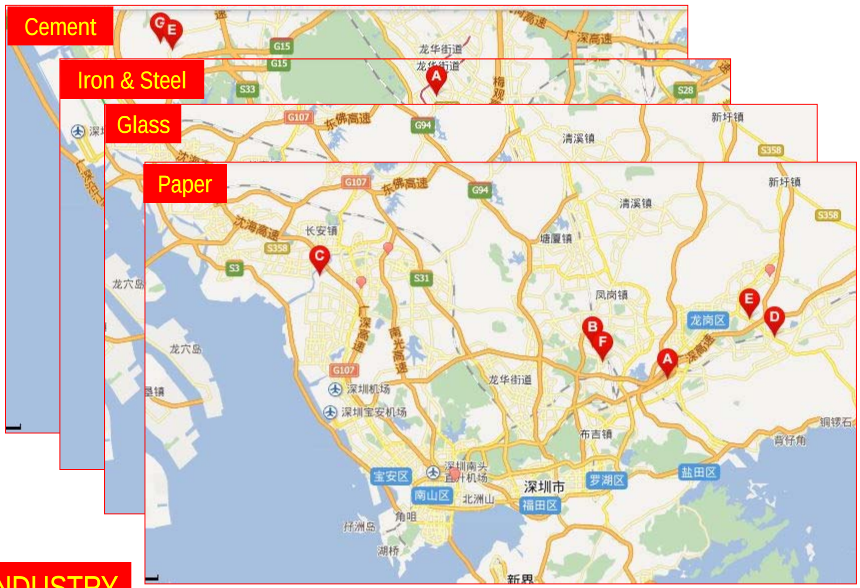


Emission factors for the above industrial products in Shenzhen have been defined.

Emissions of the industry sectors account for about 30% of total urban carbon emissions of Shenzhen.

34

Industrial Processes: Cement, Lime, Steel, …

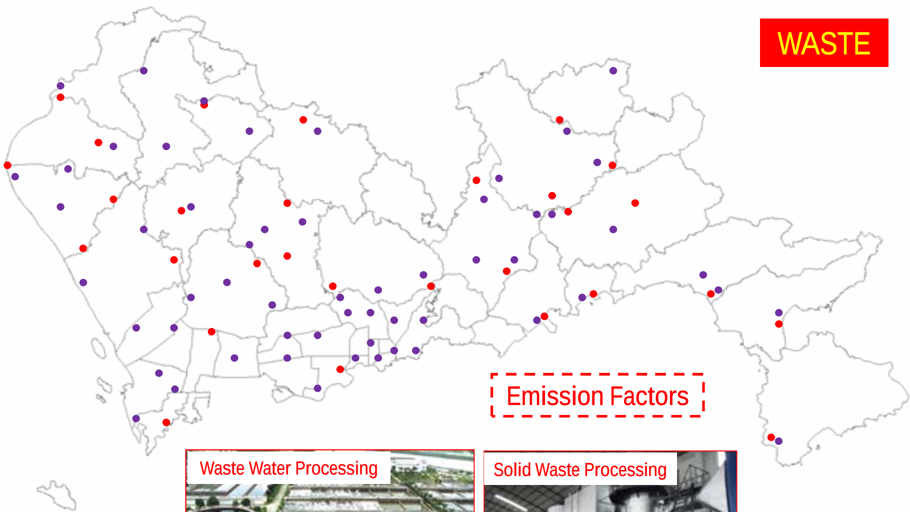


INDUSTRY

35

Waste Processing Stations: Waste Water (red) & Solid Waste (blue)

WASTE



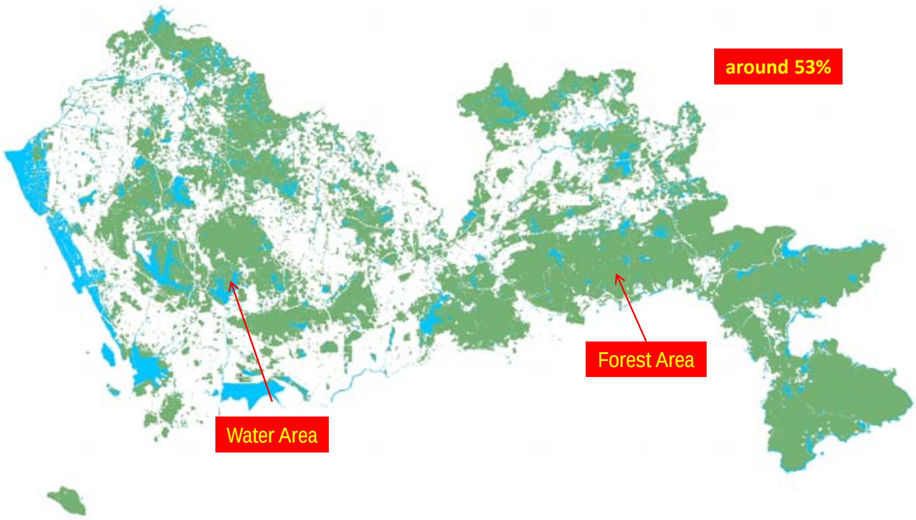
Emission Factors


Waste Water Processing


Solid Waste Processing

36

Natural Systems: Carbon Fluxes of Vegetation and Soil



37

Natural Systems: Carbon Fluxes of Vegetation & Soil

The Vegetation Photosynthesis and Respiration Model (VPRM), Mahadevan et al., 2008

$$GEE = \lambda \times T_{\text{scale}} \times P_{scale} \times W_{scale} \times \frac{1}{(1 + PAR/PAR_0)} \times PAR \times \text{EVI}$$

Temperature sensitivity $$T_{scale} = \frac{(T - T_{min})(T - T_{max})}{[(T - T_{min})(T - T_{max}) - (T - T_{opt})]^2}$$

Leaf-age sensitivity $$P_{\text{scale}} = \frac{1+LSWI}{2} \rightarrow 1$$

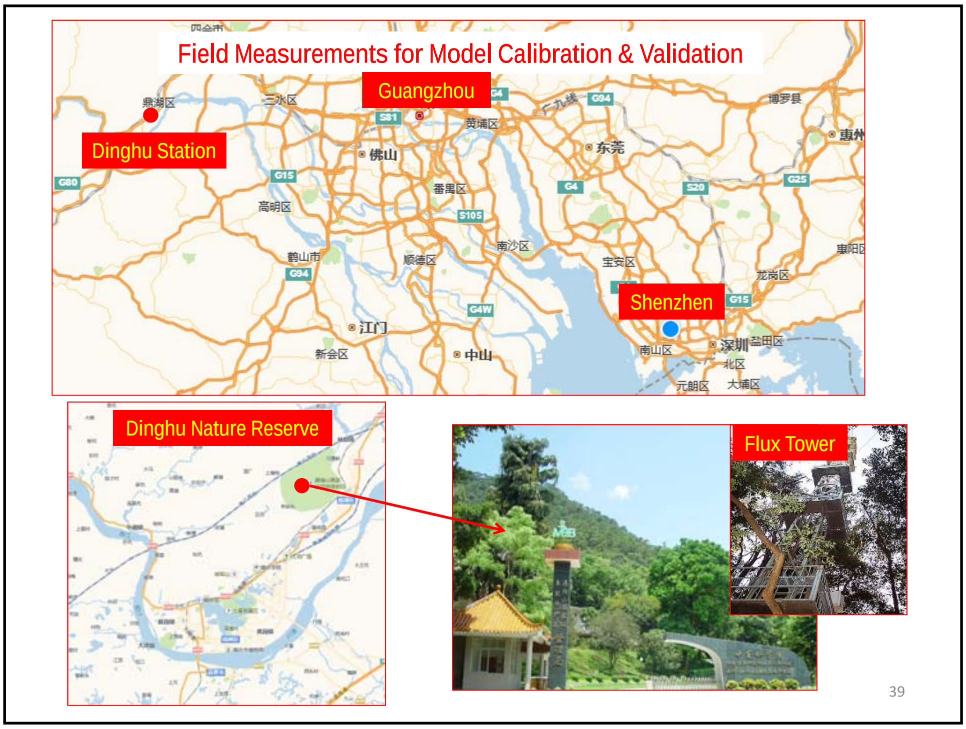
$$\text{LSWI} = \frac{\rho_{nir} - \rho_{swir}}{\rho_{nir} + \rho_{swir}}$$

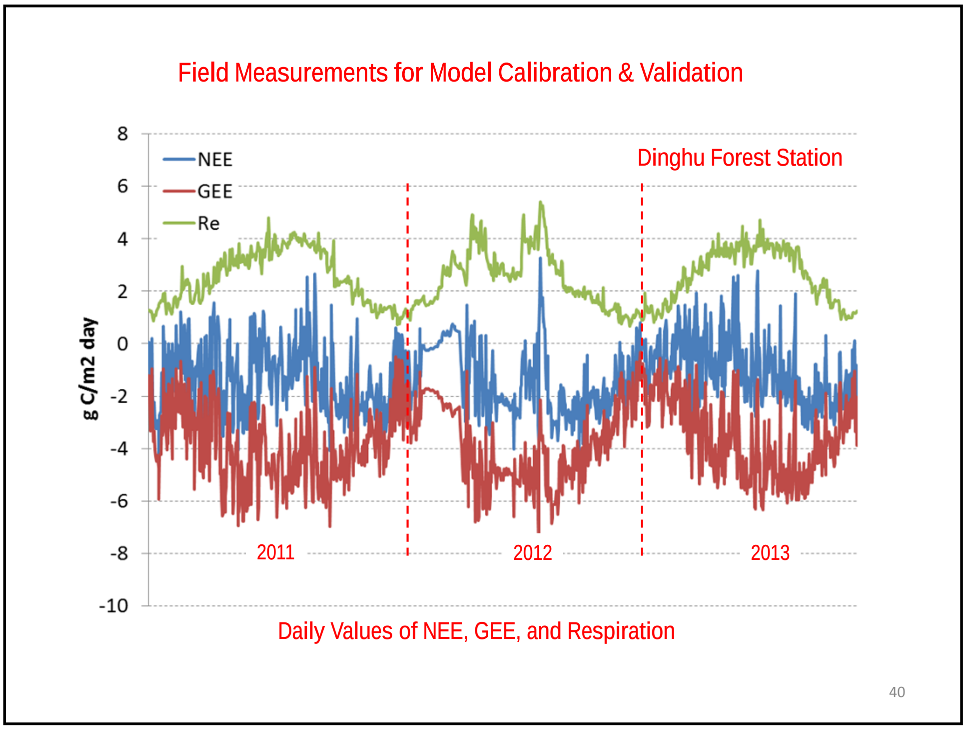
VPD sensitivity $$W_{scale} = \frac{1 + LSWI}{1 + LSWI_{max}}$$

$$NEE = -\lambda \times T_{\text{scale}} \times P_{scale} \times W_{scale} \times \frac{1}{\left(1 + \frac{PAR}{PAR_0}\right)} \times PAR \times \text{EVI} + \alpha \times T + \beta$$

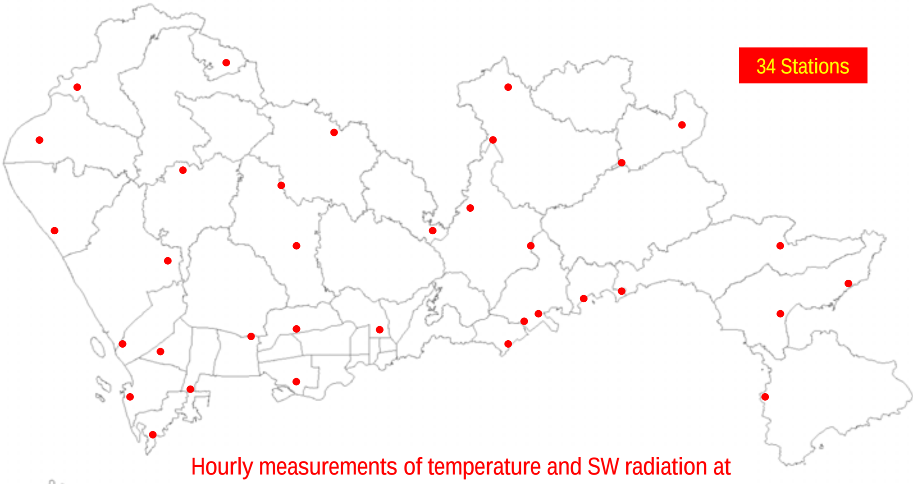
Remote sensing-based light use efficiency (LUE) model

38


Field Measurements for Model Calibration & Validation
Guangzhou
Dinghu Station
Shenzhen
Dinghu Nature Reserve
Flux Tower
39


Field Measurements for Model Calibration & Validation
NEE
GEE
Re
Dinghu Forest Station
8
6
4
2
0
-2
-4
-6
-8
-10
g C/m2 day
2011
2012
2013
Daily Values of NEE, GEE, and Respiration
40

Inputs of hourly SW radiation and temperature allow the VPRM to closely track hourly variations of NEE (of CO_2).



Hourly measurements of temperature and SW radiation at the field meteorological stations in Shenzhen

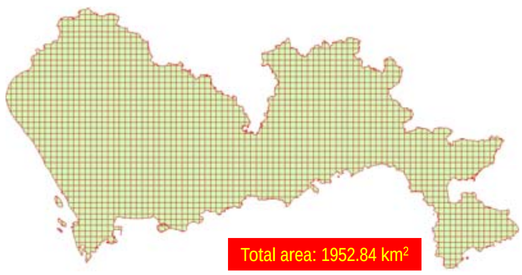
41

High Resolution Mapping of Urban Carbon Inventory

- **Parcel features: residential, commercial, institutional and industrial buildings**
- **Line features: on-road and on-track transportation**
- **Point features: electricity generation & industrial processes**

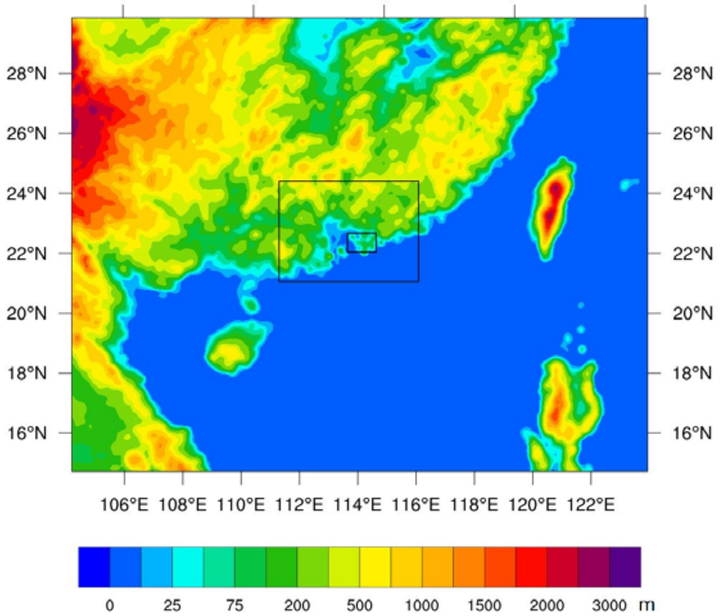
- **Spatial and temporal resolutions**
  - **Spatial resolution: 1-km**
  - **Temporal resolution: 1 hour**

Spatial Resolution:
1 km × 1 km

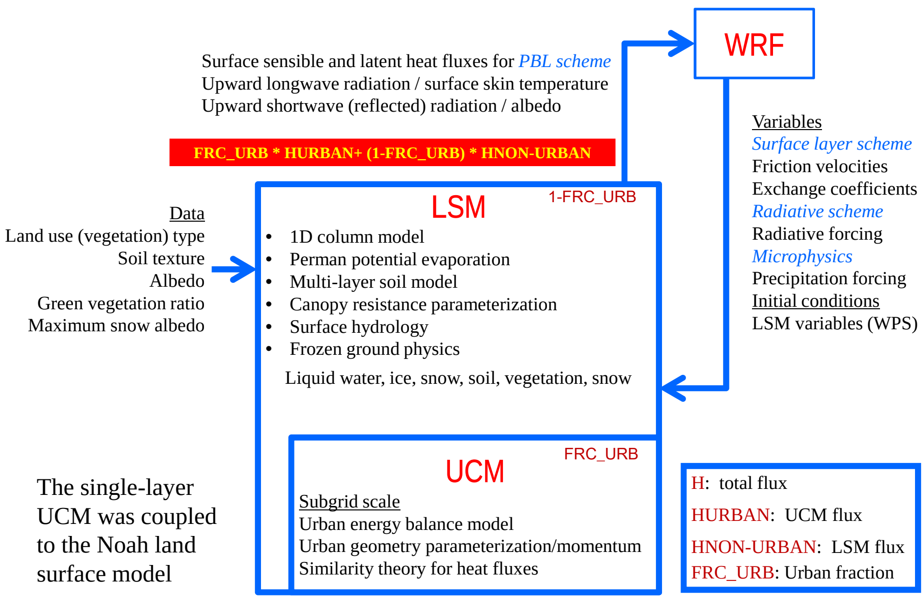


42

WRF Simulations of Meteorological Fields around Shenzhen

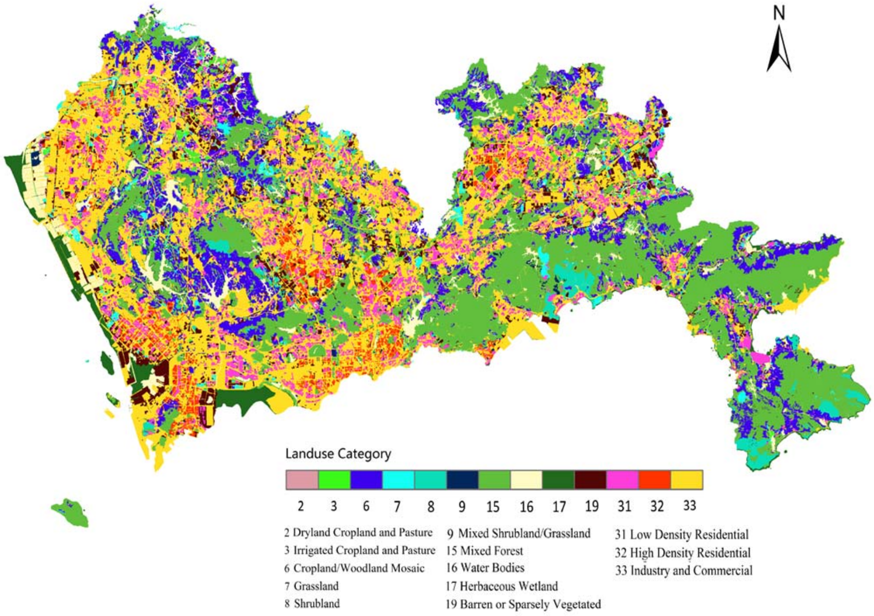


Coupling urban canopy schemes in the mesoscale meteo model WRF



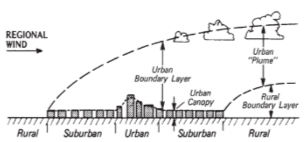
The single-layer UCM was coupled to the Noah land surface model

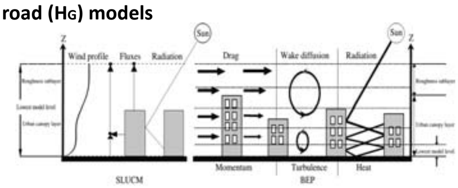
Integrating high-resolution land use and topographic data into WRF



Urban Canopy Model (UCM)

- UCM treats man-made surfaces
  - **– Urban geometry (orientation, diurnal cycle of solar azimuth), symmetrical street canyons with infinite length**
  - **– Shadowing from buildings and reflection of radiation**
  - **– Anthropogenic heating**
  - **– Multi-layer roof (HR), wall (HW) and road (HG) models**





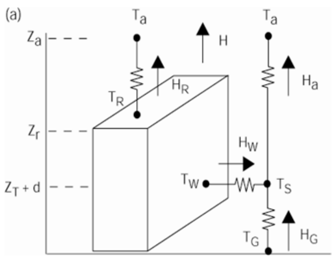


FIG. Schematic of the single layer urban canopy model
Ta : air temperature at reference height Za,
TR : building roof temperature,
Tw : building wall temperature,
TG : road temperature,
Ts : temperature defined at ZT + d,
H : sensible heat exchange at the reference height,
Ha : sensible heat flux from the canyon space to the atmosphere,
Hw : sensible heat flux from wall to the canyon space,
HG : sensible heat flux from road to the canyon space,
HR : sensible heat flux from roof to the atmosphere

Key urban canopy parameters in the WRF/UCM system

Table I. Urban canopy parameters currently in WRF for three urban land-use categories: low-intensity residential, high-intensity residential, and industrial and commercial.

Parameter	Unit	Specific values for: Low-intensity residential	High-intensity residential	Industrial, commercial	SLUCM	BEP
h (building height)	m	5	7.5	10	Yes	No
l_{roof} (roof width)	m	8.3	9.4	10	Yes	No
l_{road} (road width)	m	8.3	9.4	10	Yes	No
AH	$W\ m^{-2}$	20	50	90	Yes	No
F_{urb} (urban fraction)	Fraction	0.5	0.9	0.95	Yes	Yes
C_R (heat capacity of roof)	$J\ m^{-3}\ K^{-1}$	1.0E6	1.0E6	1.0E6	Yes	Yes
C_W (heat capacity of building wall)	$J\ m^{-3}\ K^{-1}$	1.0E6	1.0E6	1.0E6	Yes	Yes
C_G (heat capacity of road)	$J\ m^{-3}\ K^{-1}$	1.4E6	1.4E6	1.4E6	Yes	Yes
λ_R (thermal conductivity of roof)	$J\ m^{-1}\ s^{-1}\ K^{-1}$	0.67	0.67	0.67	Yes	Yes
λ_W (thermal conductivity of building wall)	$J\ m^{-1}\ s^{-1}\ K^{-1}$	0.67	0.67	0.67	Yes	Yes
λ_G (thermal conductivity of road)	$J\ m^{-1}\ s^{-1}\ K^{-1}$	0.4004	0.4004	0.4004	Yes	Yes
α_R (surface albedo of roof)	Fraction	0.20	0.20	0.20	Yes	Yes
α_W (Surface albedo of building wall)	Fraction	0.20	0.20	0.20	Yes	Yes
α_G (surface albedo of road)	Fraction	0.20	0.20	0.20	Yes	Yes
ε_R (surface emissivity of roof)	–	0.90	0.90	0.90	Yes	Yes
ε_W (surface emissivity of building wall)	–	0.90	0.90	0.90	Yes	Yes
ε_G (surface emissivity of road)	–	0.95	0.95	0.95	Yes	Yes
Z_{0R} (roughness length for momentum over roof)	m	0.01	0.01	0.01	Yes[a]	Yes
Z_{0W} (roughness length for momentum over building wall)	m	0.0001	0.0001	0.0001	No[a]	No
Z_{0G} (roughness length for momentum over road)	m	0.01	0.01	0.01	No[a]	Yes

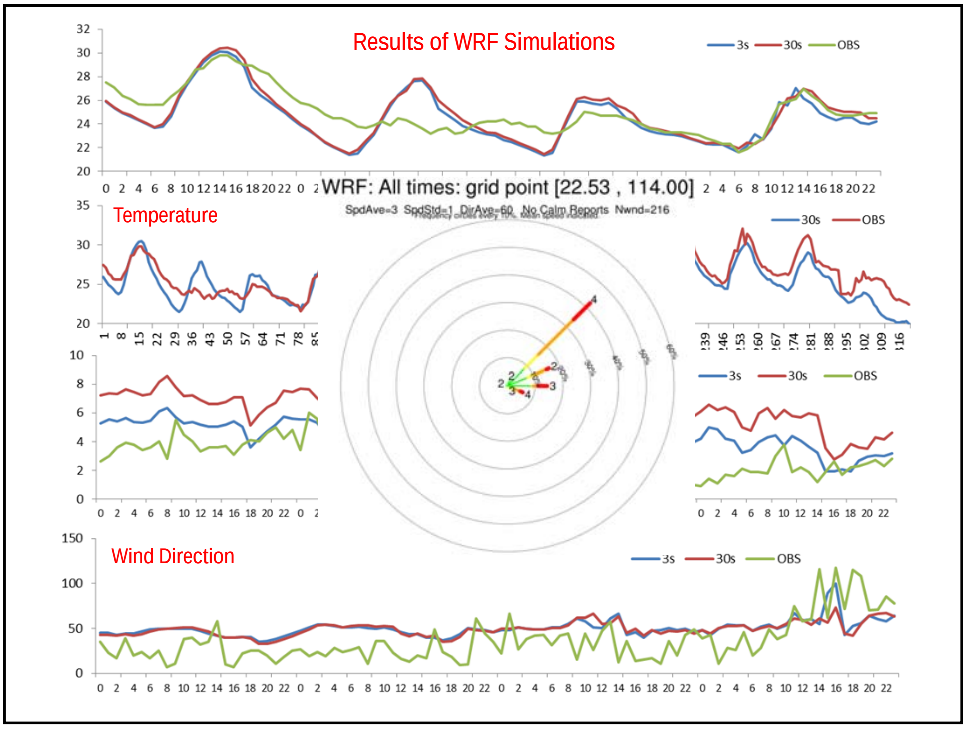
Impact of urbanization on meteorological fields in Shenzhen

- Running Period: 2014.10.01—2014.10.31

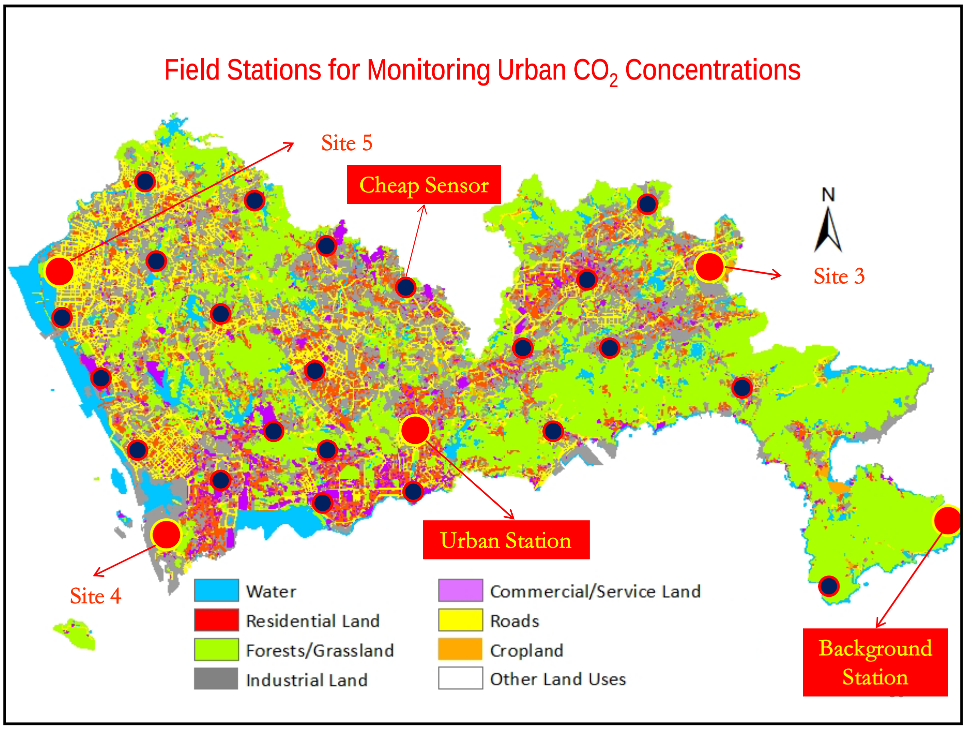
Name	PBL Scheme	Surface Layer	Using UCM	Land Use Data
Reference_YSU	YSU	Monin-Obukhov	No	USGS
Reference_MYNN	MYNN	MYNN	No	USGS
Reference_ACM2	ACM2	Pleim-Xiu	No	USGS
Reference_MYJ	MYJ	Eta scheme	No	USGS
UCM_PKU_YSU	YSU	Monin-Obukhov	Yes	PKU
UCM_PKU_MYNN	MYNN	MYNN	Yes	PKU
UCM_PKU_ACM2	ACM2	Pleim-Xiu	Yes	PKU
UCM_PKU_MYJ	MYJ	Eta scheme	Yes	PKU

Description of WRF settings

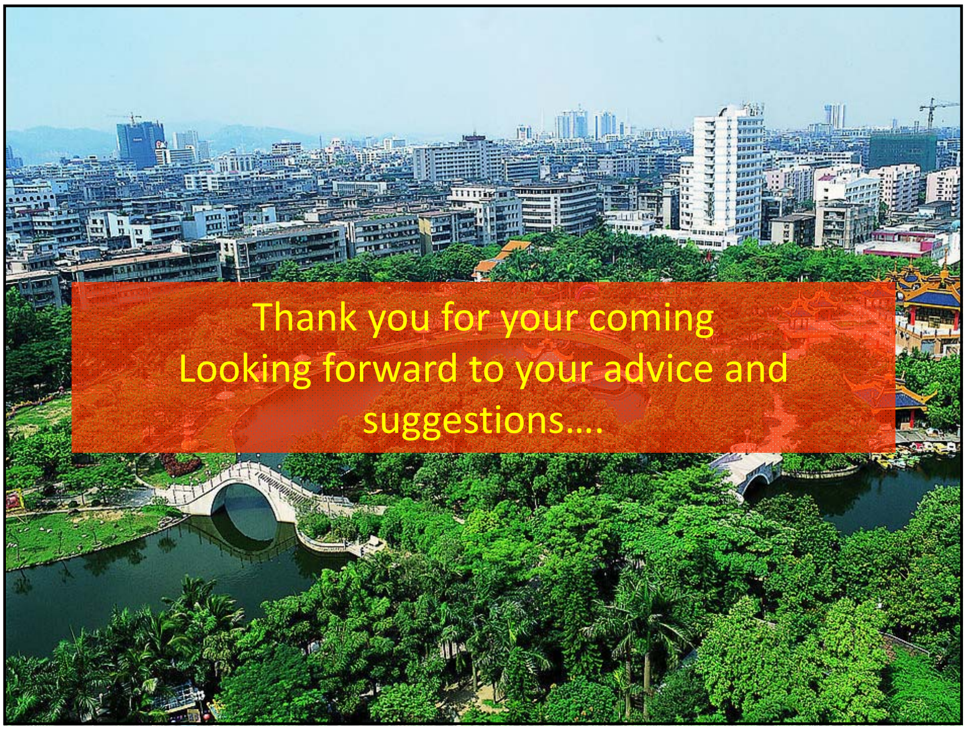
Boundary data	NCEP FNL (Final) Operational Global Analysis Data NOAA 1/12 Degree Daily SST Data
Resolution	Horizontal: 9km, 3km, 1km
	Vertical: 28 levels
Other physical settings	Microphysics: Kessler scheme
	Longwave radiation: rrtm scheme
	Shortwave radiation: Dudhia scheme
	Cumulus parameterization: Grell-Devenyi ensemble scheme
	Land surface: unified Noah land-surface model



Results of WRF Simulations
WRF: All times: grid point [22.53 , 114.00]
Temperature
Wind Direction
3s
30s
OBS



Field Stations for Monitoring Urban CO_2 Concentrations
Site 5
Cheap Sensor
N
Site 3
Urban Station
Site 4
Background Station
Water
Residential Land
Forests/Grassland
Industrial Land
Commercial/Service Land
Roads
Cropland
Other Land Uses


Thank you for your coming
Looking forward to your advice and
suggestions….