香港中文大學
The Chinese University of Hong Kong
太空与地球信息科学研究所
Institute of Space and Earth Information Science

Joint WRF/MPAS Users' Workshop
June 13, 2018
LI, Zhiqiang

Model evaluation of high-resolution urban climate simulation: WRF ARW/LSM/SLUCM model as a case study

Outline

Research Background
- Needs
- Literatures Review
- Motivation

Methodology
- Impact Model and Atmospheric Model
- Experimental Design

Technical Preparation
- Model Setup
- Data Preparation

Model Evaluation and Conclusion
- Model Evaluation
- Conclusion

Research Background – Needs, Literatures Review and Motivation

Needs

Model evaluation is necessary for urban climate simulations to make sure the results are reliable and trustworthy to some of the extents.

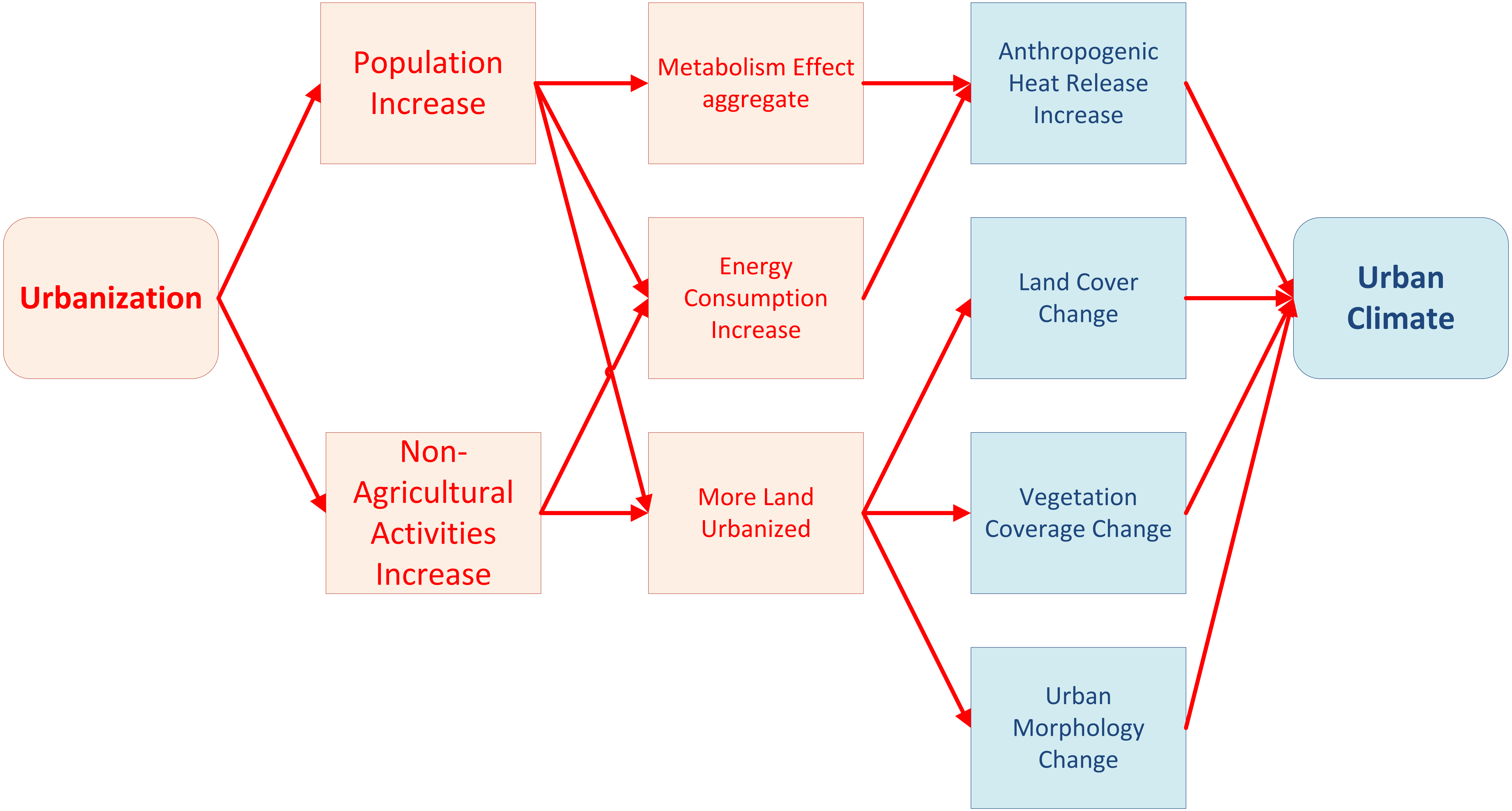
Literatures Review

However, recent efforts understandably paid minimum attention to model evaluation in the community of urban climate modelers. Review of typical evaluation efforts in existing literatures, most of them only conducted some simple comparisons between modelled variables and its corresponding observed ones by drawing its time-history plots.

Motivation

We propose a systematic framework and methods for evaluating model results, to benefit future studies with more choices for model quality control, making urban scale simulation more robust.

Methodology – Impact Model



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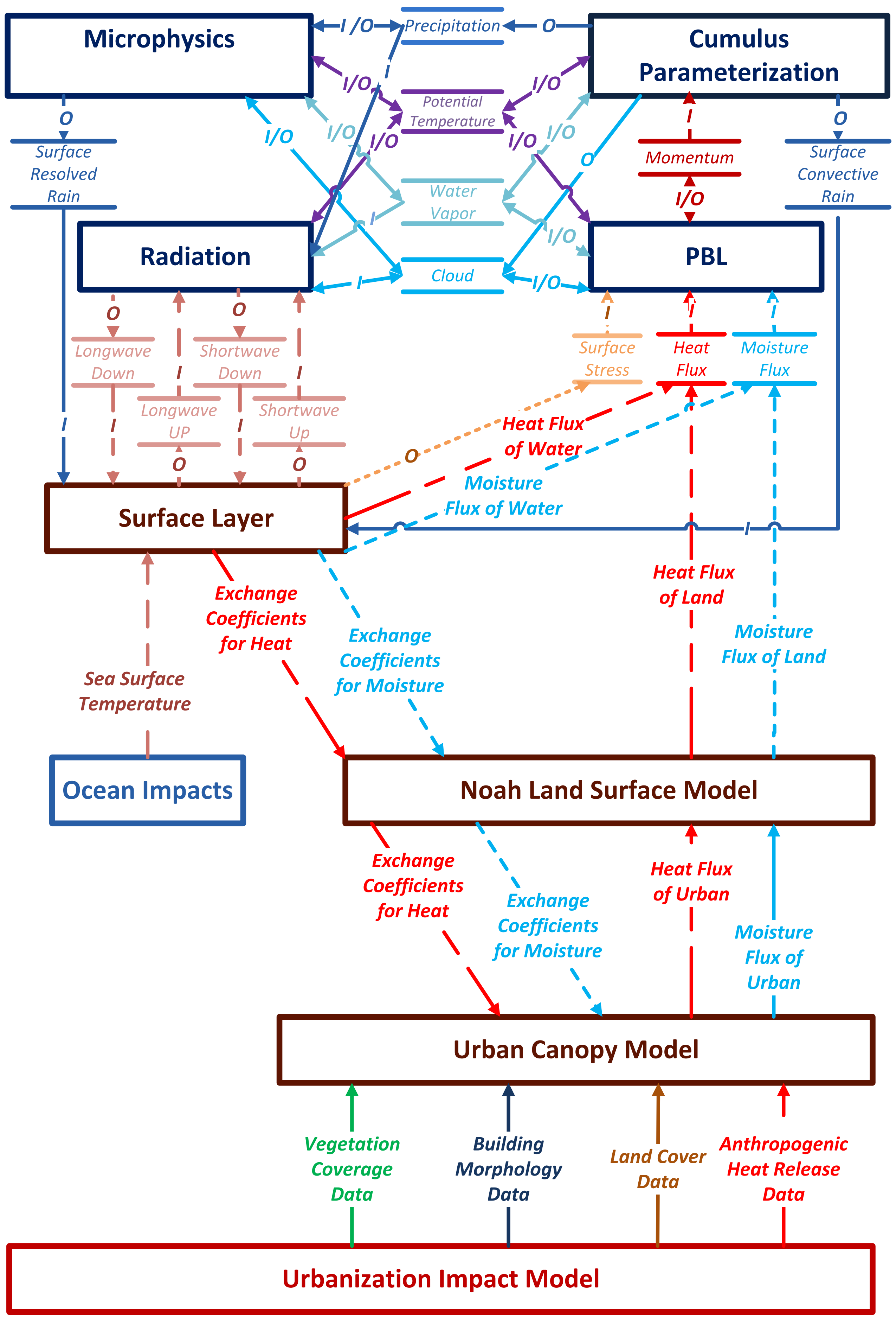
Methodology – Atmospheric Model



Typical Physics Model:

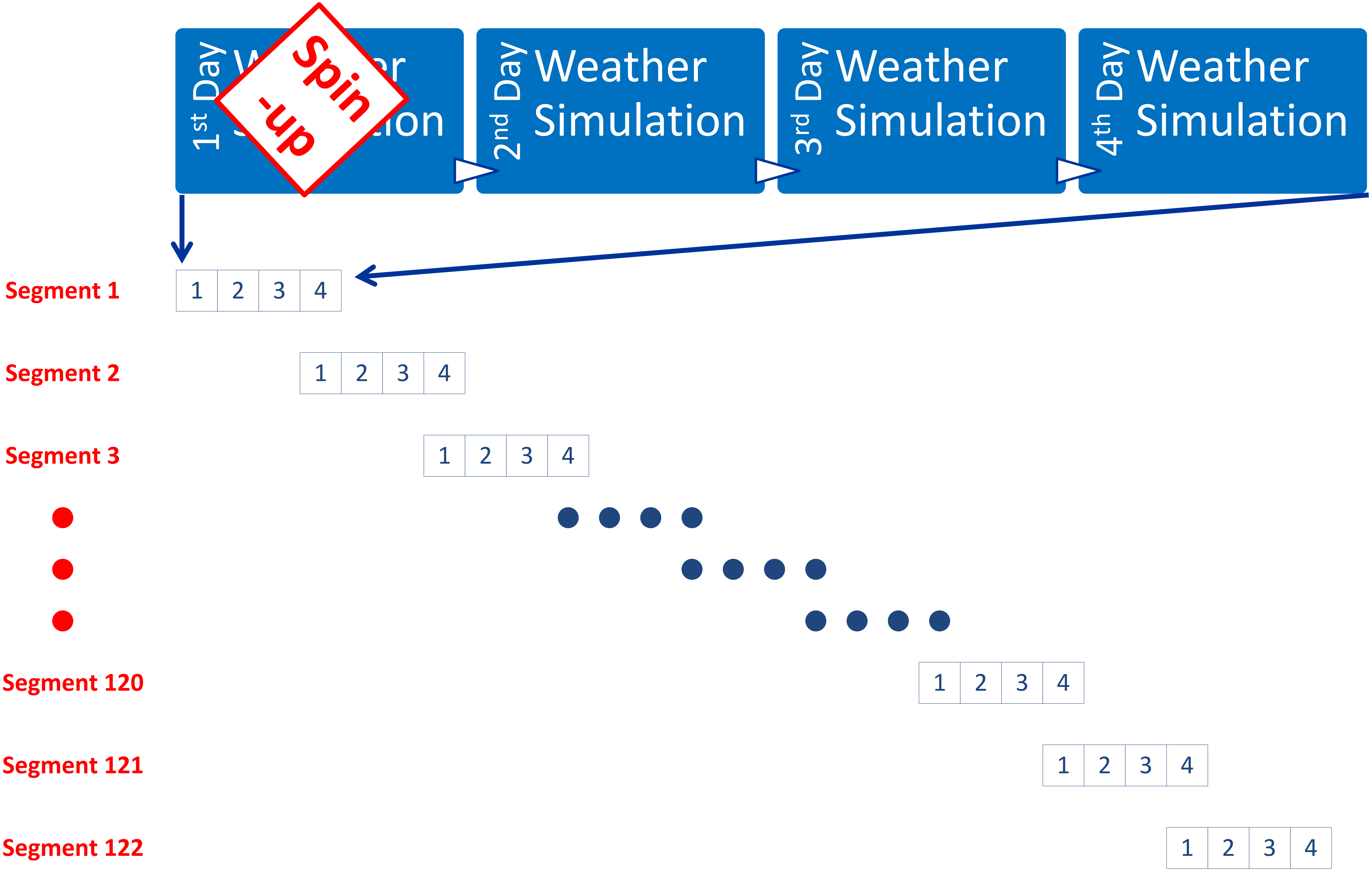
(1)Microphysics
(2)Cumulus Parameterization
(3)Radiation
(4)Planetary Boundary Layer
(5)Surface Driver
(6)Ocean Impacts

(7)Noah Land Surface Model (Noah LSM)
(8)Urban Canopy Model (UCM)

Coupling Urbanization Impact Model with More Inputs:

(1)Vegetation Coverage
(2)Building Morphology
(3)Land Cover
(4)Anthropogenic Heat

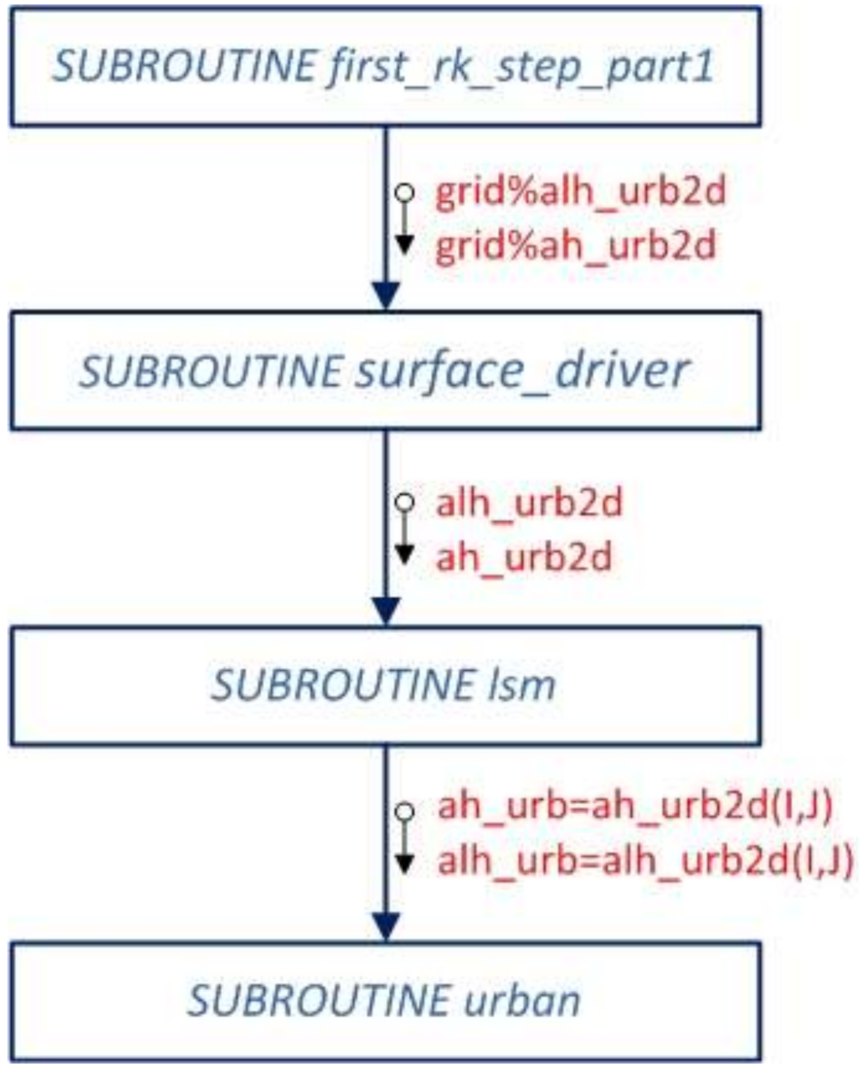
Methodology – Experimental Design



Technical Preparation – Model Setup – Changes in WRF

For 2D Anthropogenic Heat

Path	File Name of Source Code
WRFV3/Registry/	Registry.EM_COMMON
WRFV3/phys/	module_sf_urban.F
WRFV3/phys/	module_sf_noahdrv.F
WRFV3/phys/	module_surface_driver.F
WRFV3/phys/	module_sf_clm.F
WRFV3/dyn_em/	module_first_rk_step_part1.F

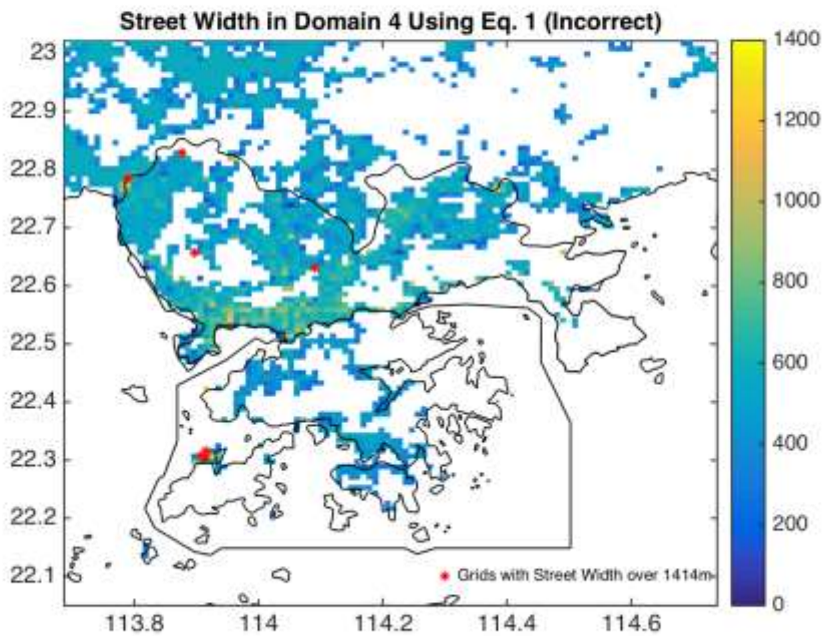


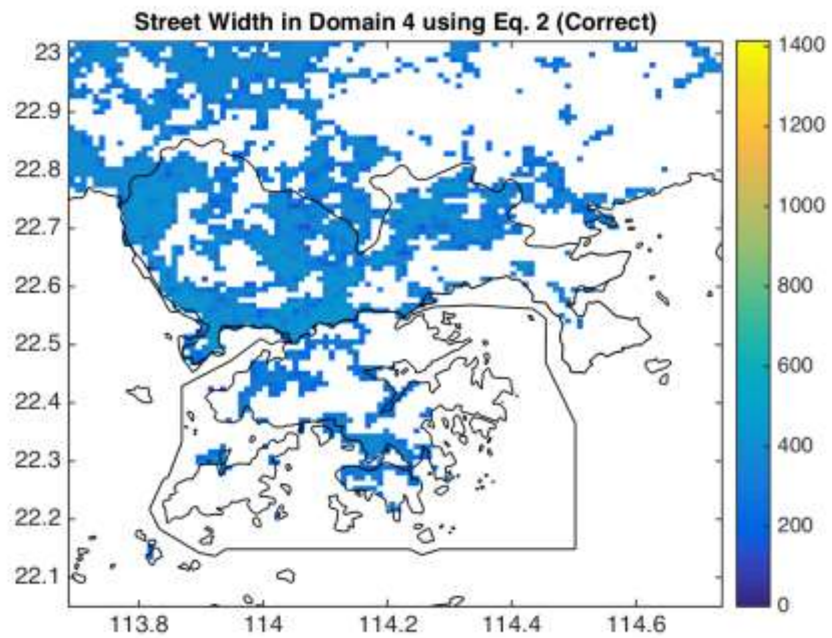
For Fixing a Bug in SUBROUTINE urban

*STW = 2.*hgt_urb*lp_urb*((frc_urb /lp_urb)-1.)/(lb_urb-lp_urb)*

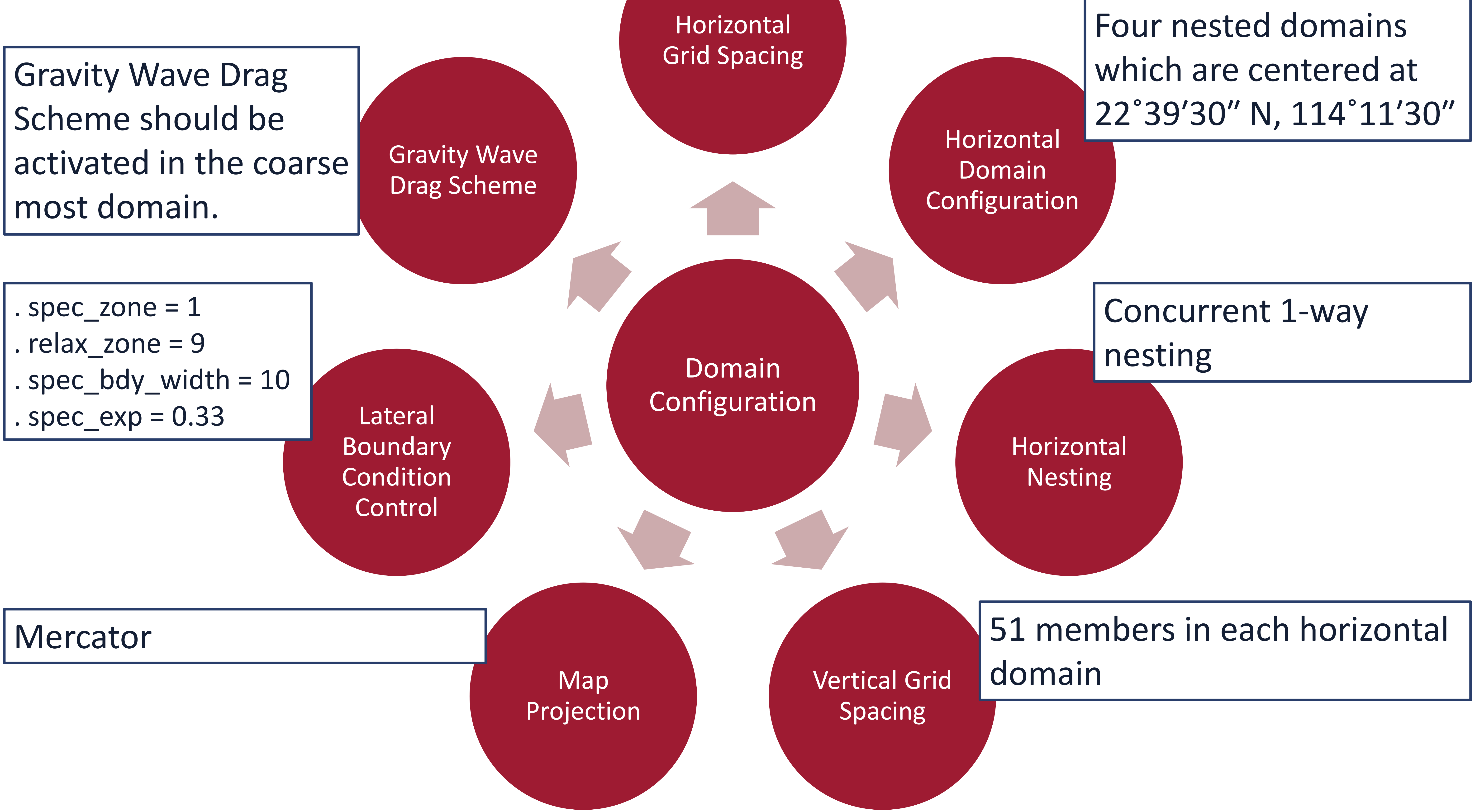
↓

*STW = BW * sqrt((frc_urb-lp_urb)/lp_urb)*



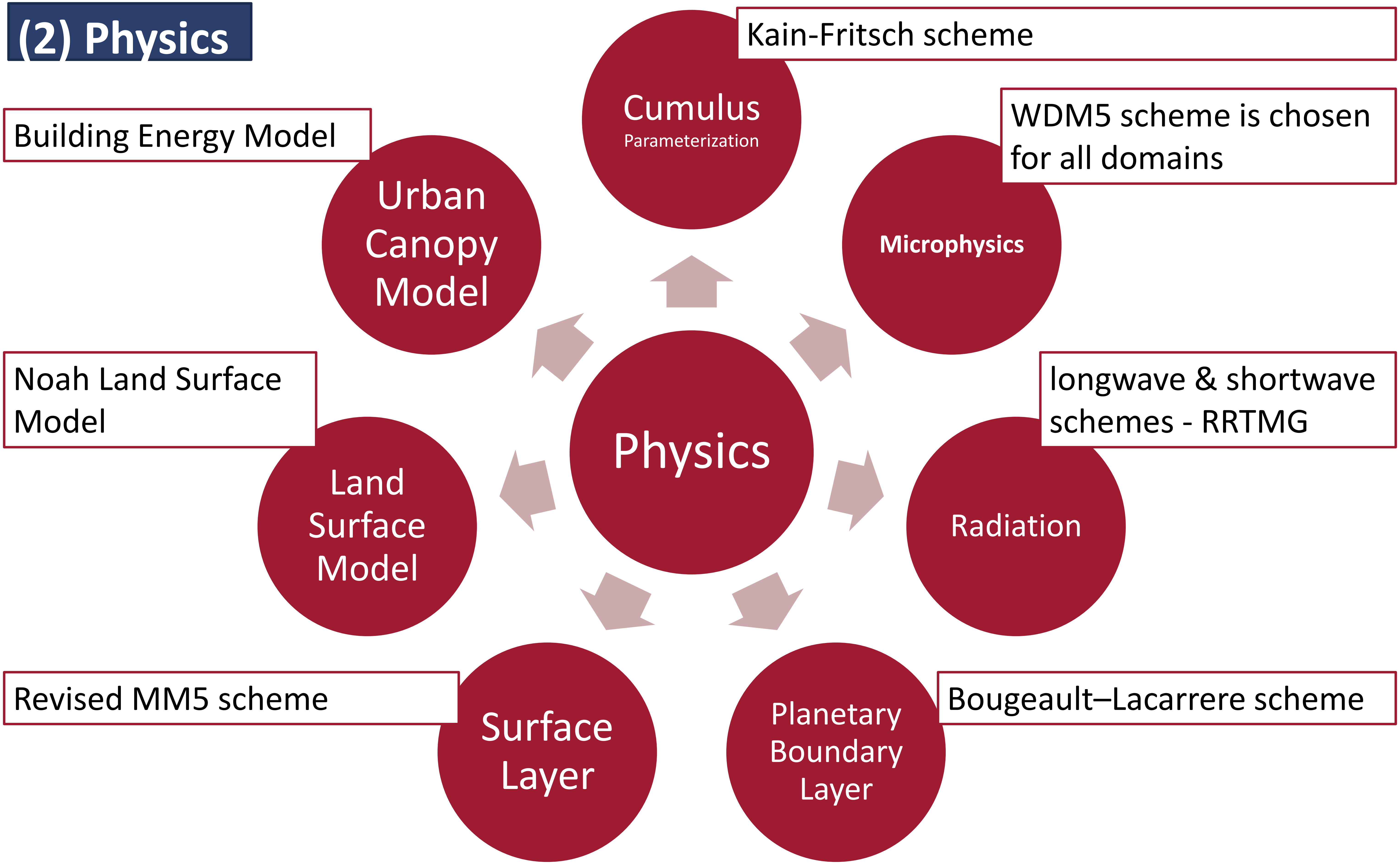


(1) Domain Configuration



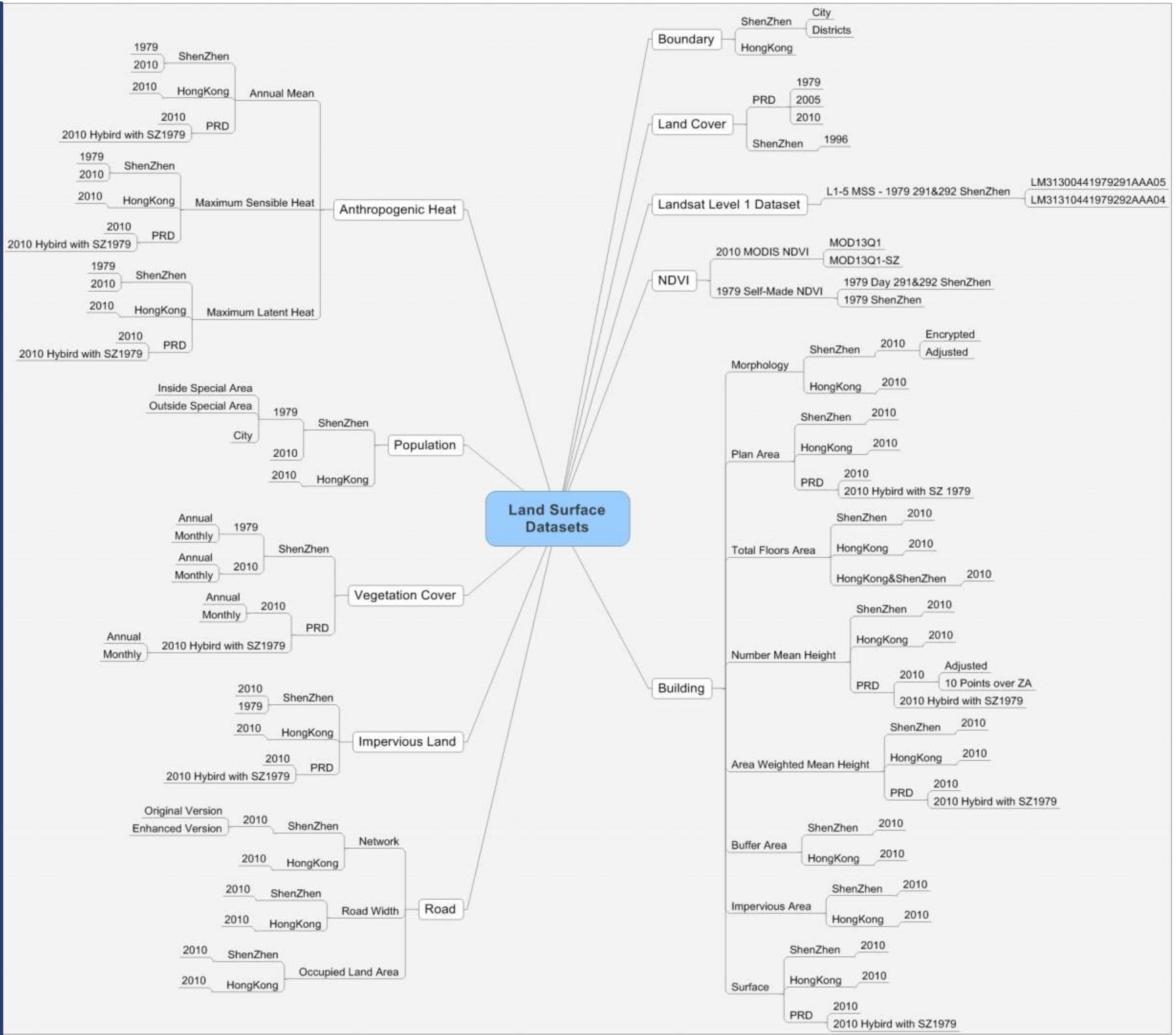
Technical Preparation – Model Setup – WRF Parameters Setting 2

(2) Physics

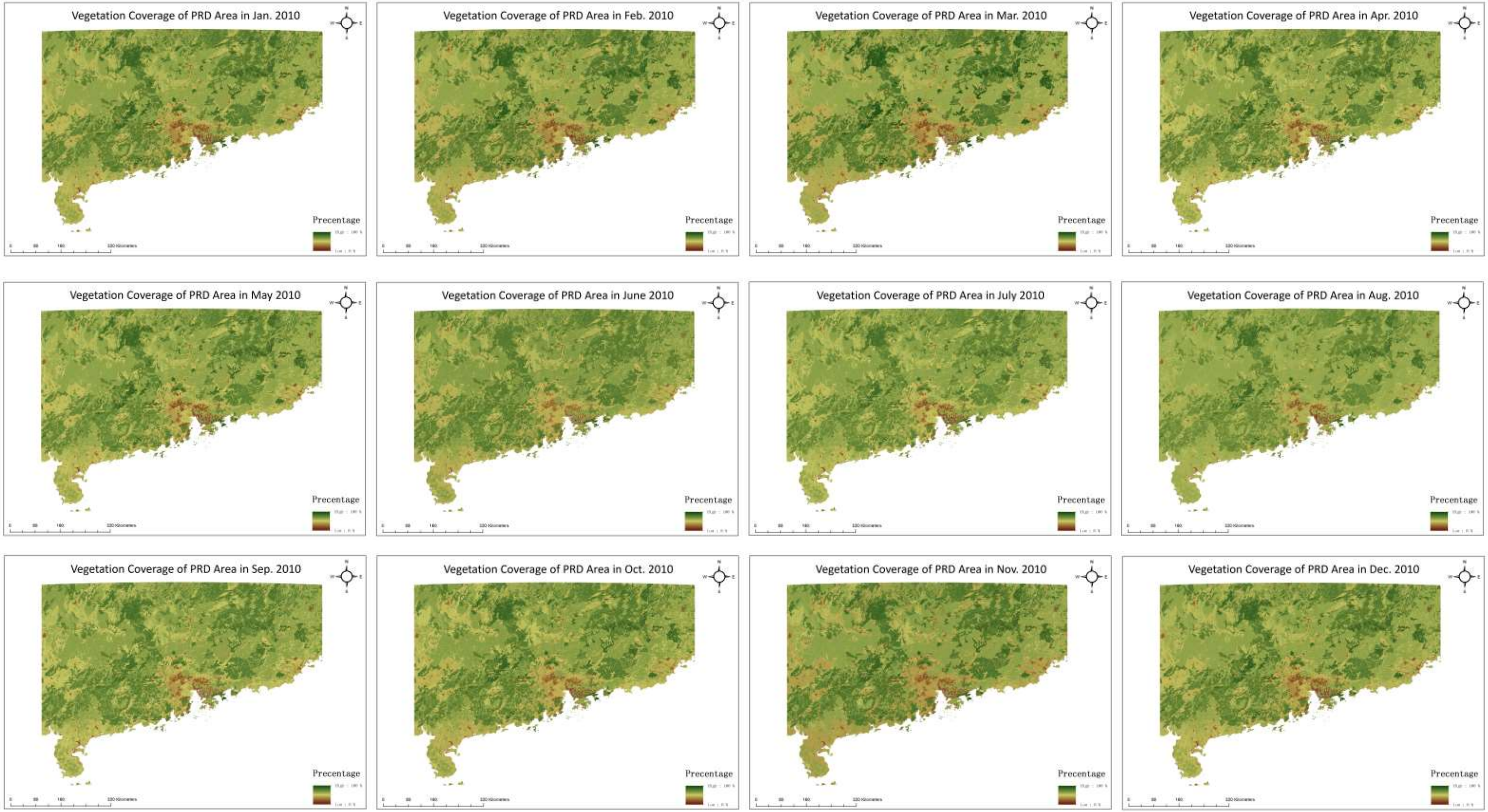


Technical Preparation – Data Preparation - Urban Land Surface Dataset

(1)Boundary of China
(2)Boundary of Shenzhen
(3)Boundary of Shenzhen Districts
(4)Boundary of Hong Kong
(5)2005 PRD Land Cover (CAS2005)
(6)2010 Shenzhen Building Morphology
(7)2010 Hong Kong Building Morphology
(8)2010 Shenzhen Road Network (without width of road)
(9)2010 Hong Kong Road Network
(10)2010 MODIS NDVI Shenzhen Dataset
(11)1979 MODIS Landsat 3 Shenzhen Area Remote Sensing Images

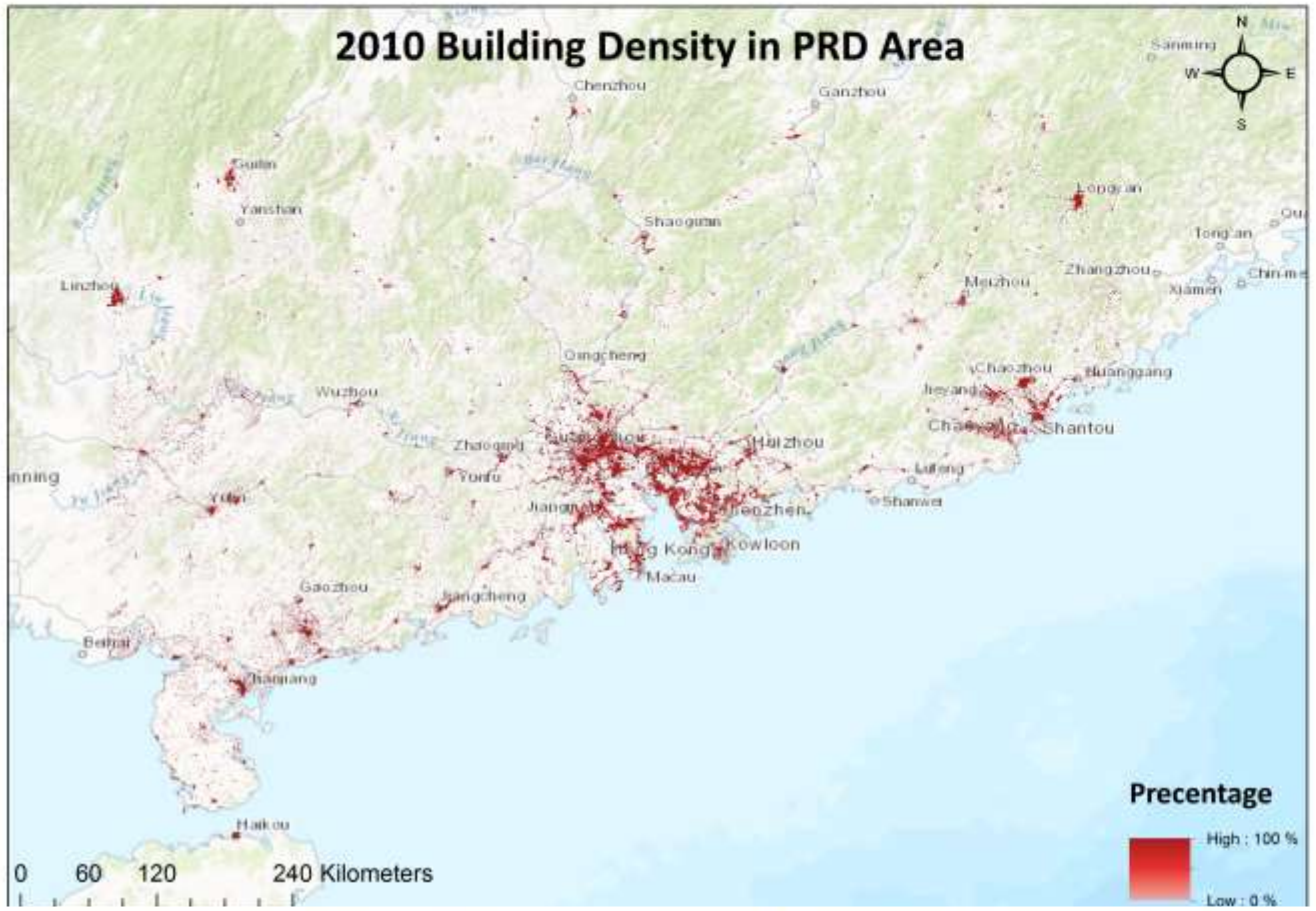


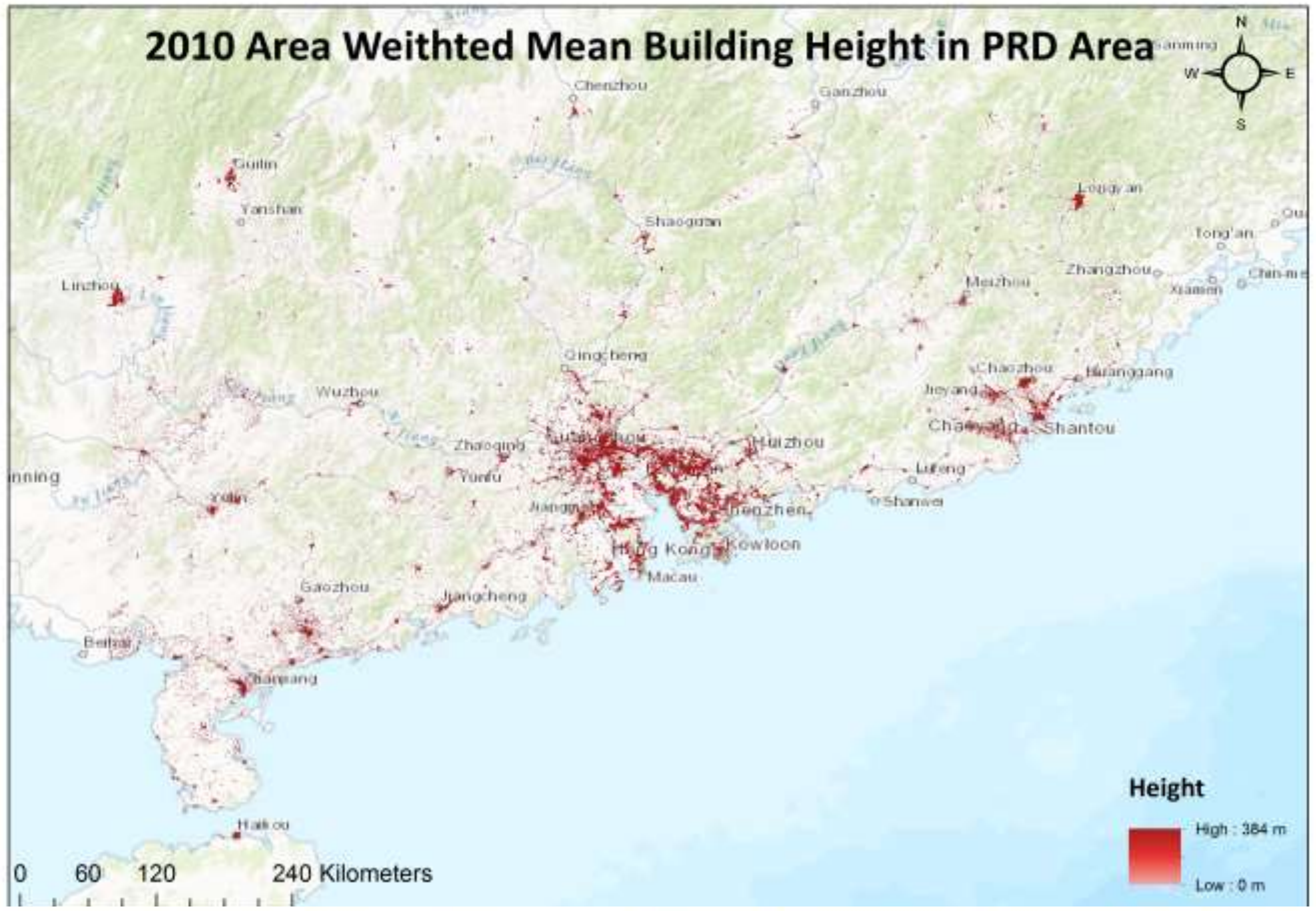
Technical Preparation – Data Preparation -Urban Land Surface Dataset

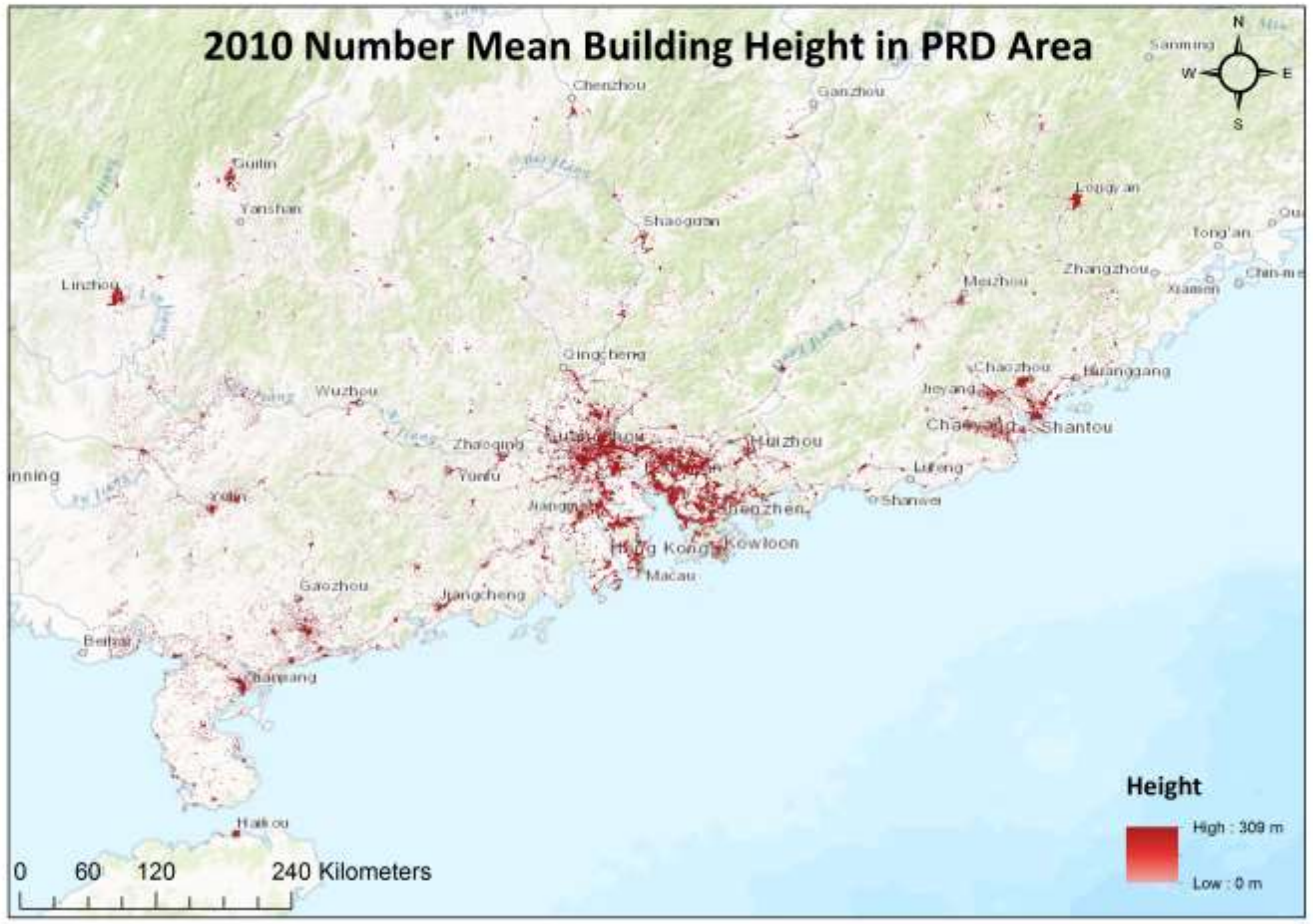


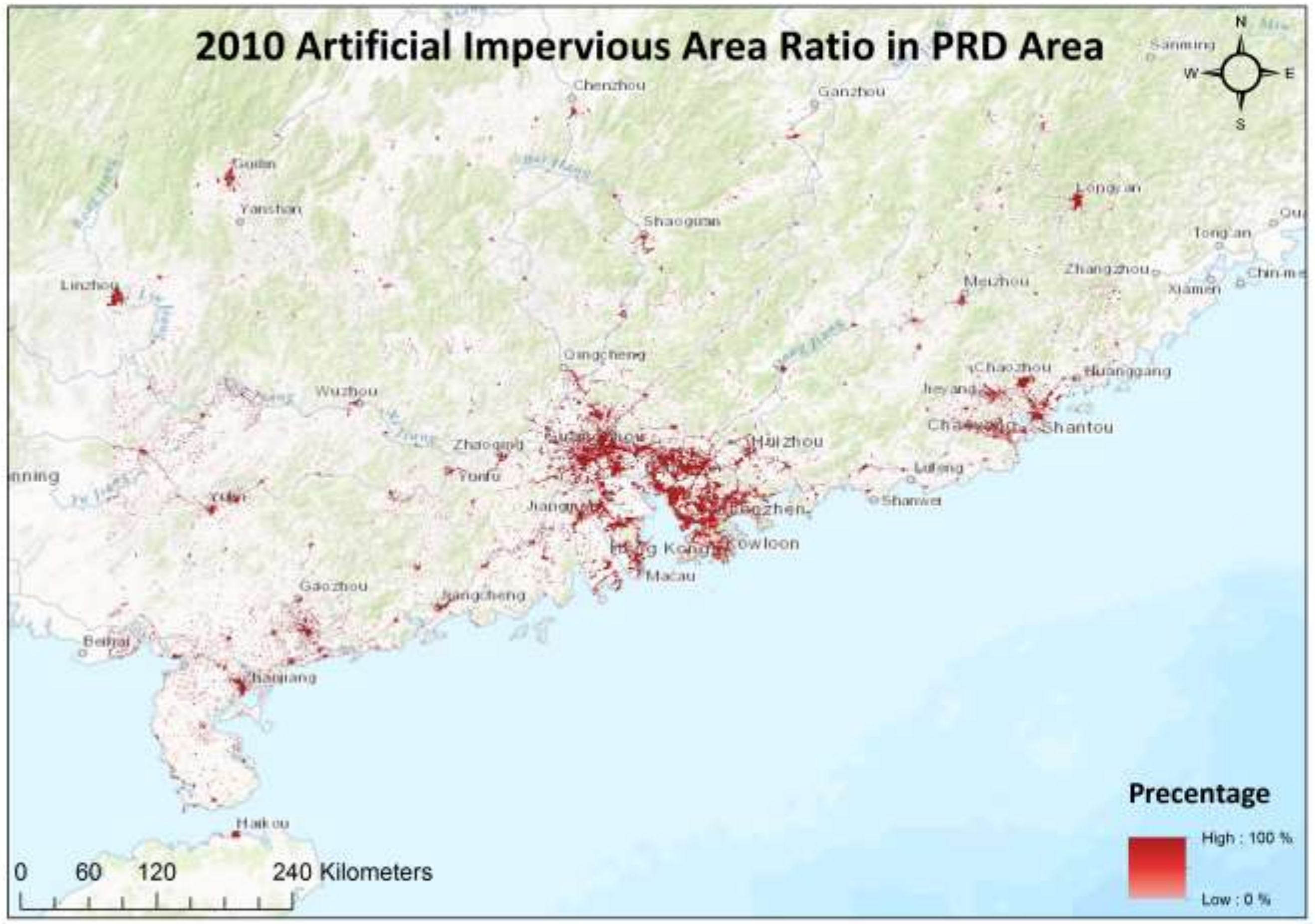
2010 PRD Monthly Vegetation Coverage Maps

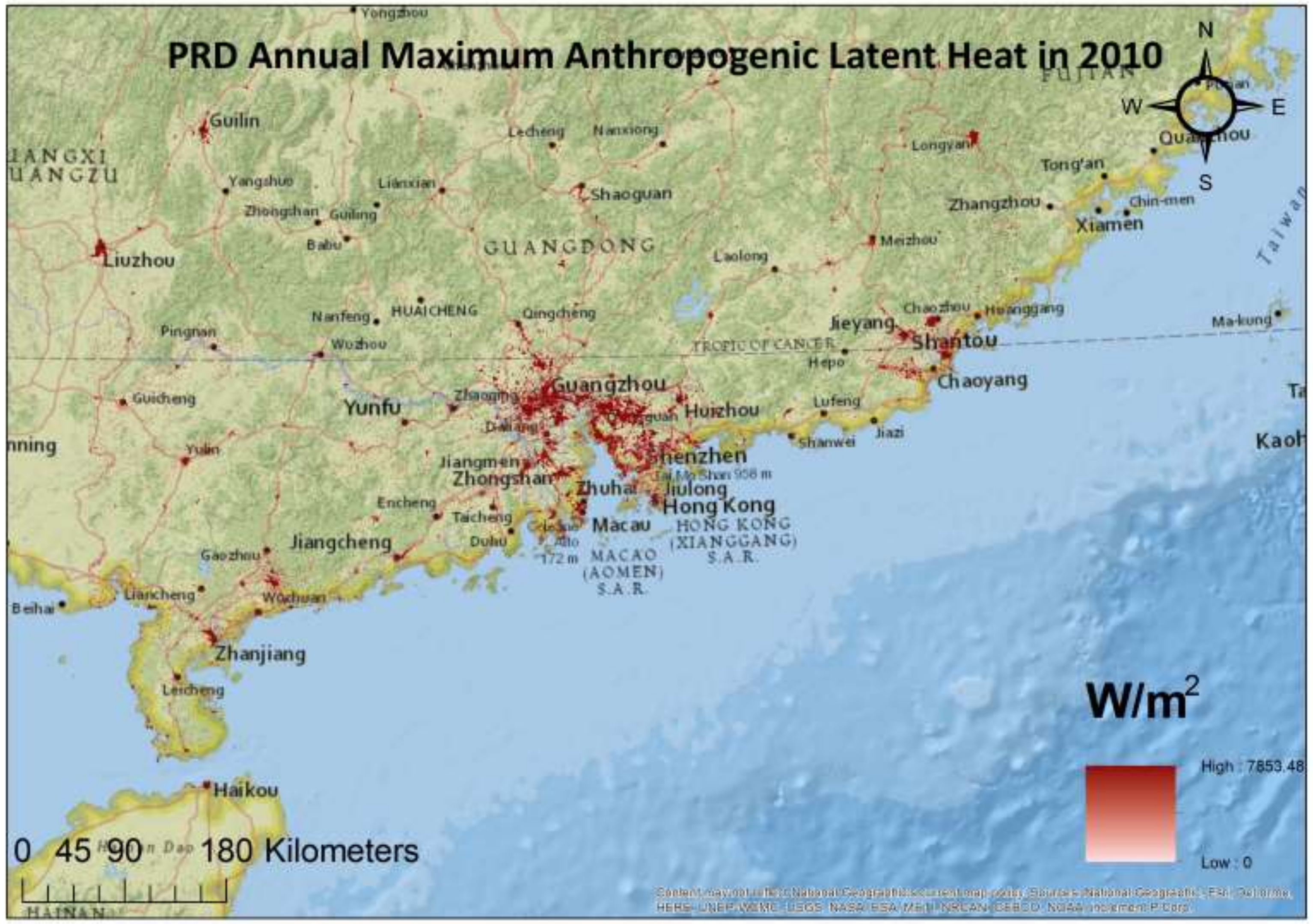
2010 Building & Artificial Impervious Area Maps

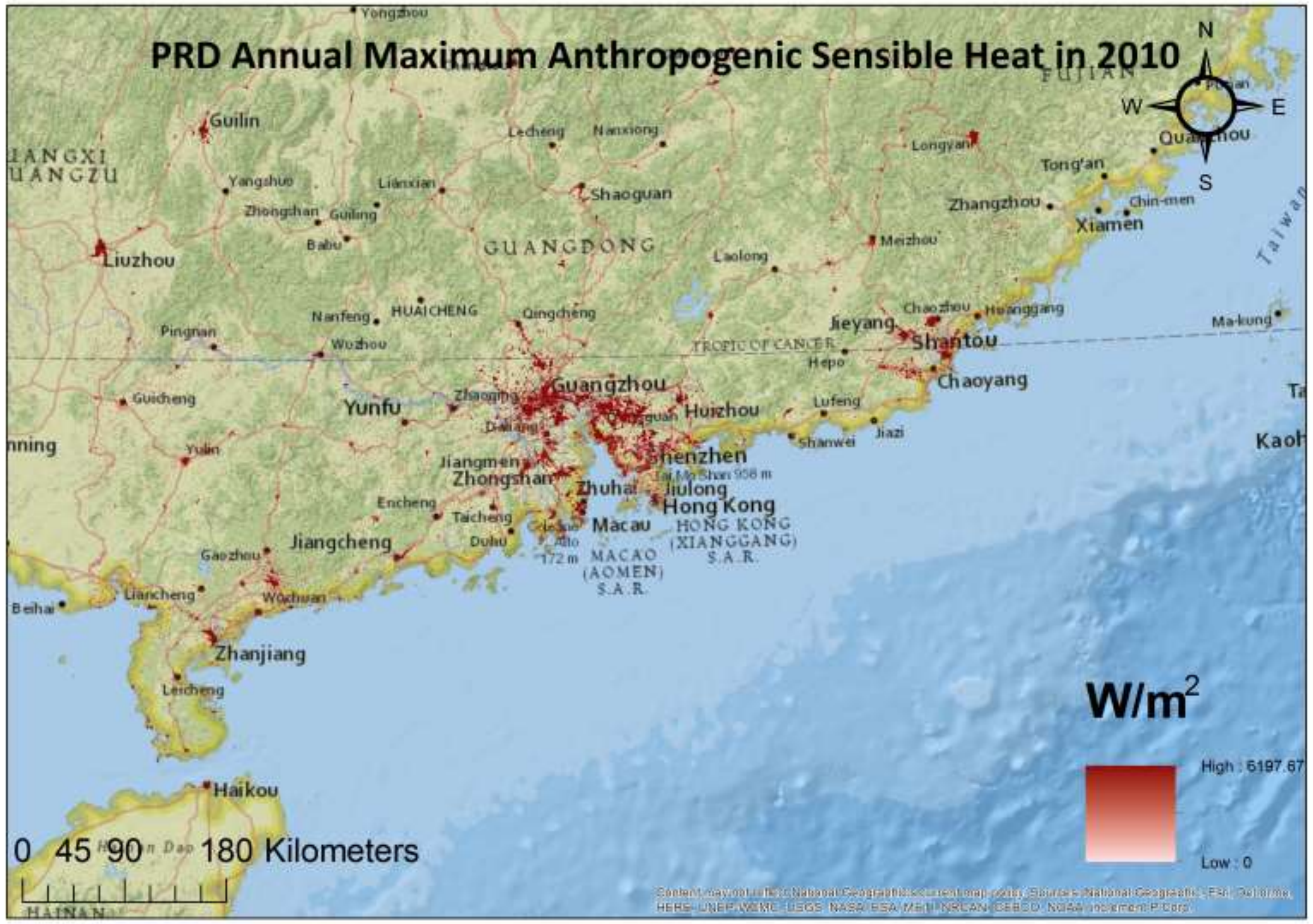












2010 PRD Anthropogenic Heat Maps

Technical Preparation – Data Preparation – Primary Data Processing

- Land Surface Dataset
  - Single Layer Urban Canopy Model (SLUCM)
    - Land Cover Classification Adjustment
    - Urban Classification Refinement
    - Building Morphology 2D Refinement
  - Vegetation Coverage 2D Refinement
  - Anthropogenic Heat 2D Refinement

Use NUDAPT Data Format

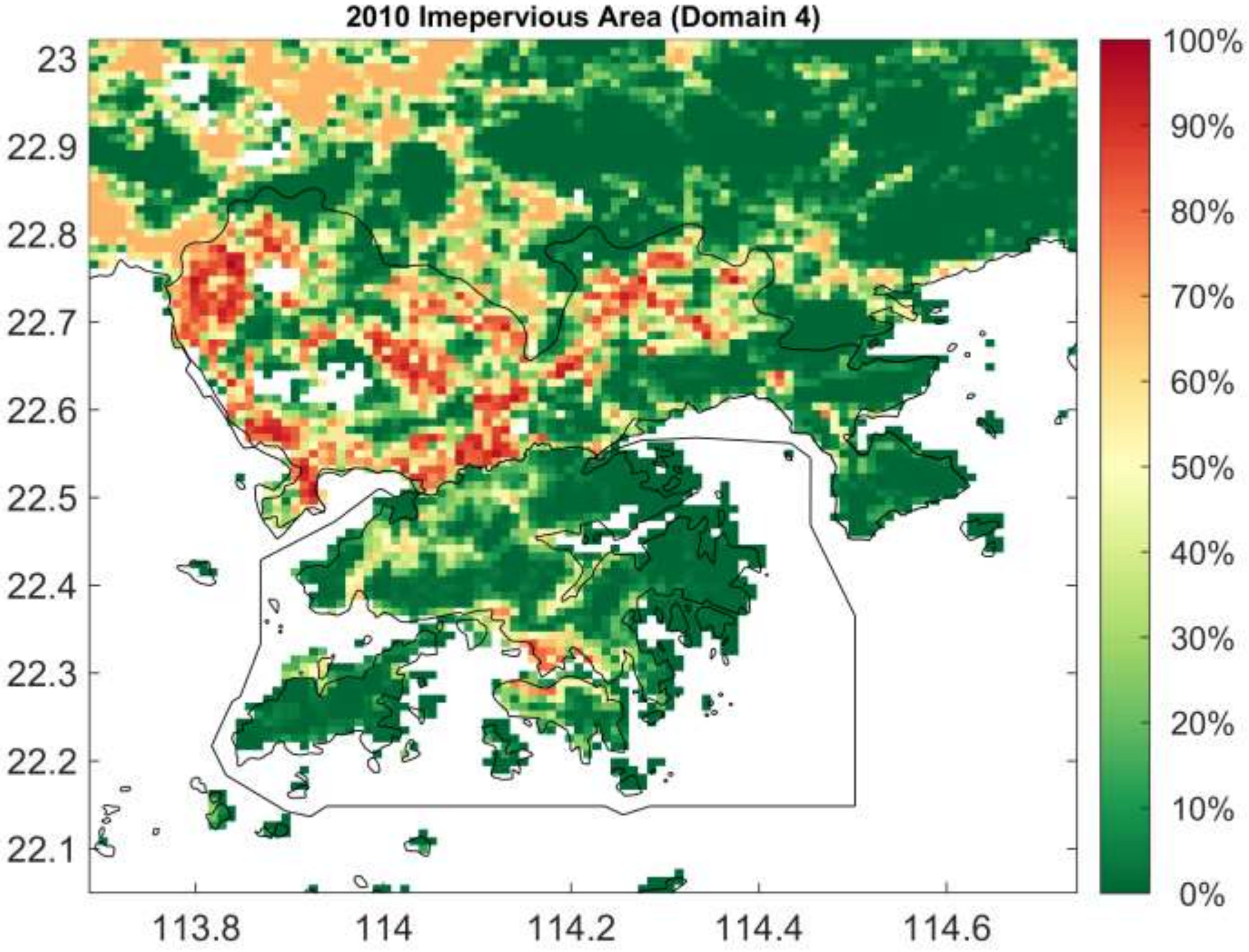
Interpolated Geo-Data

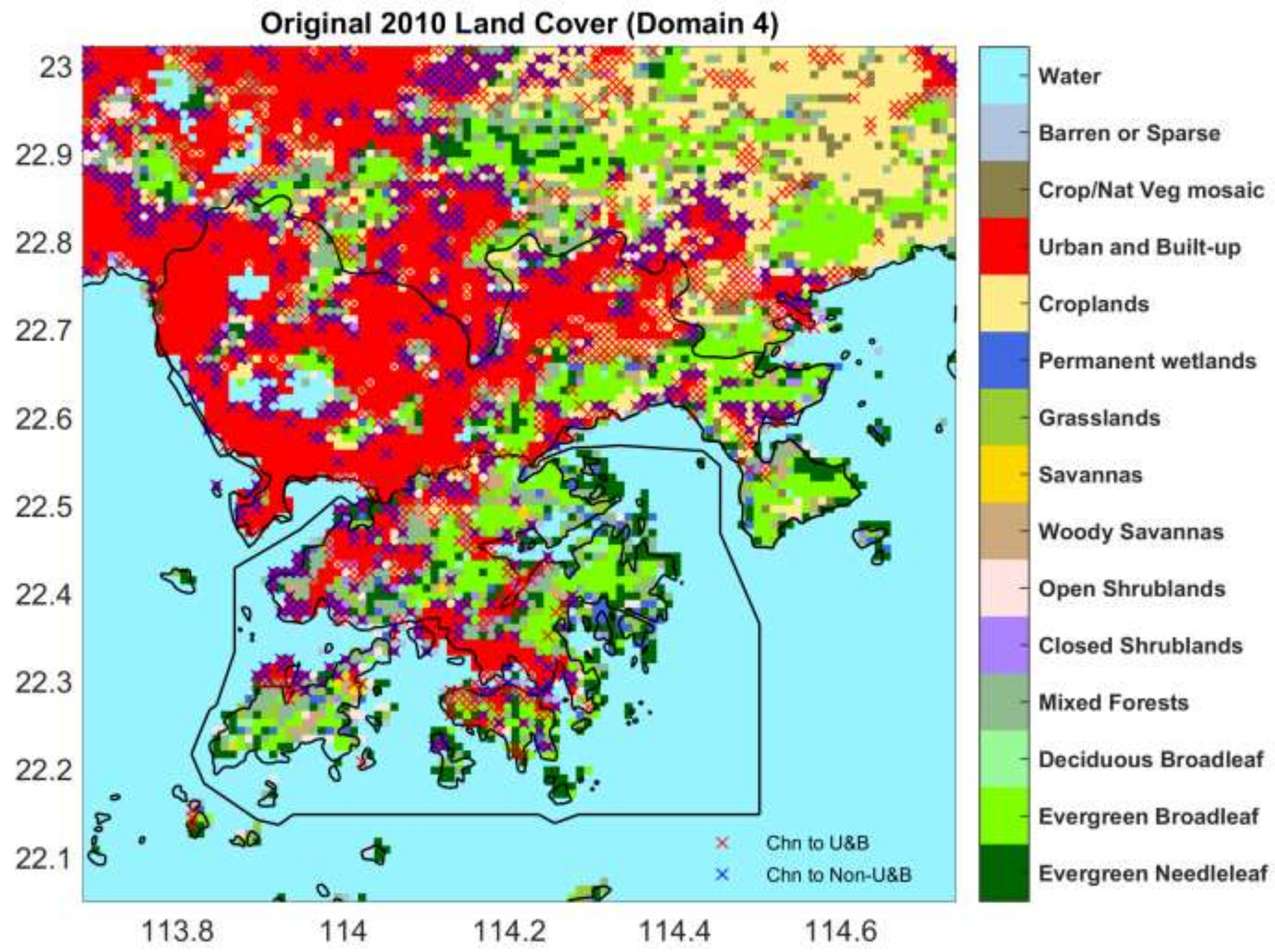
geo_data_refinement
Processing Package

WRF Input Data

wrf_input_refinement
Processing Package

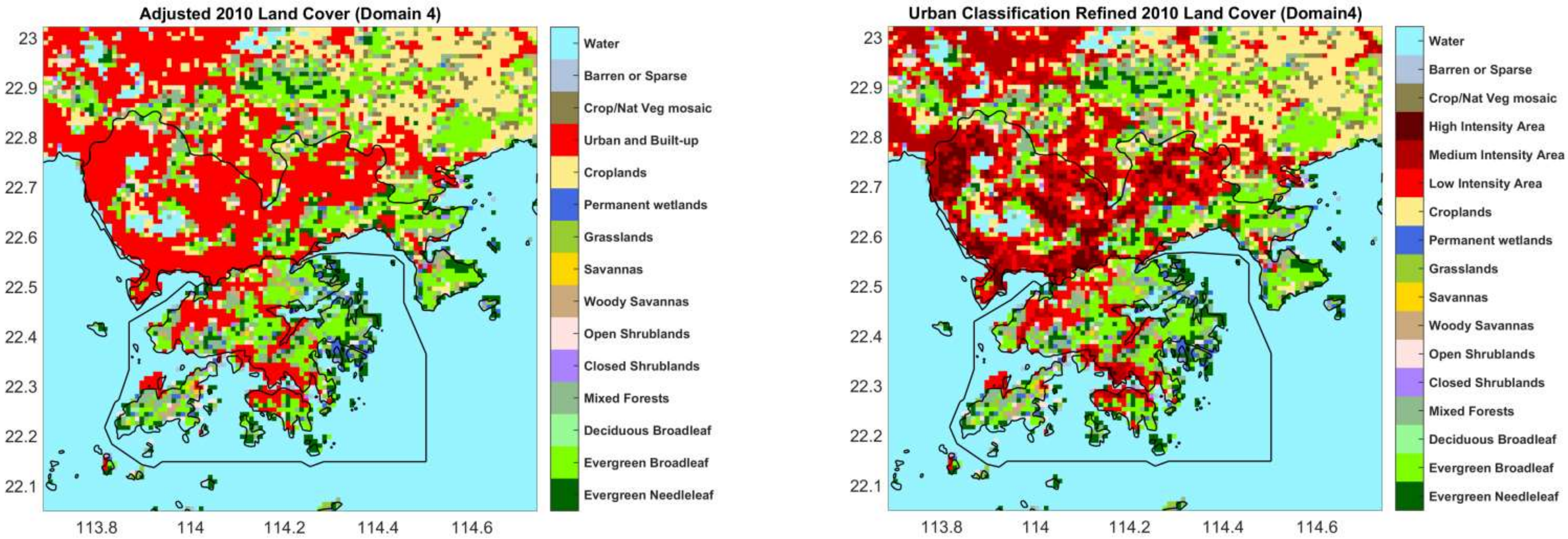
Technical Preparation – Data Preparation – Primary Data Processing





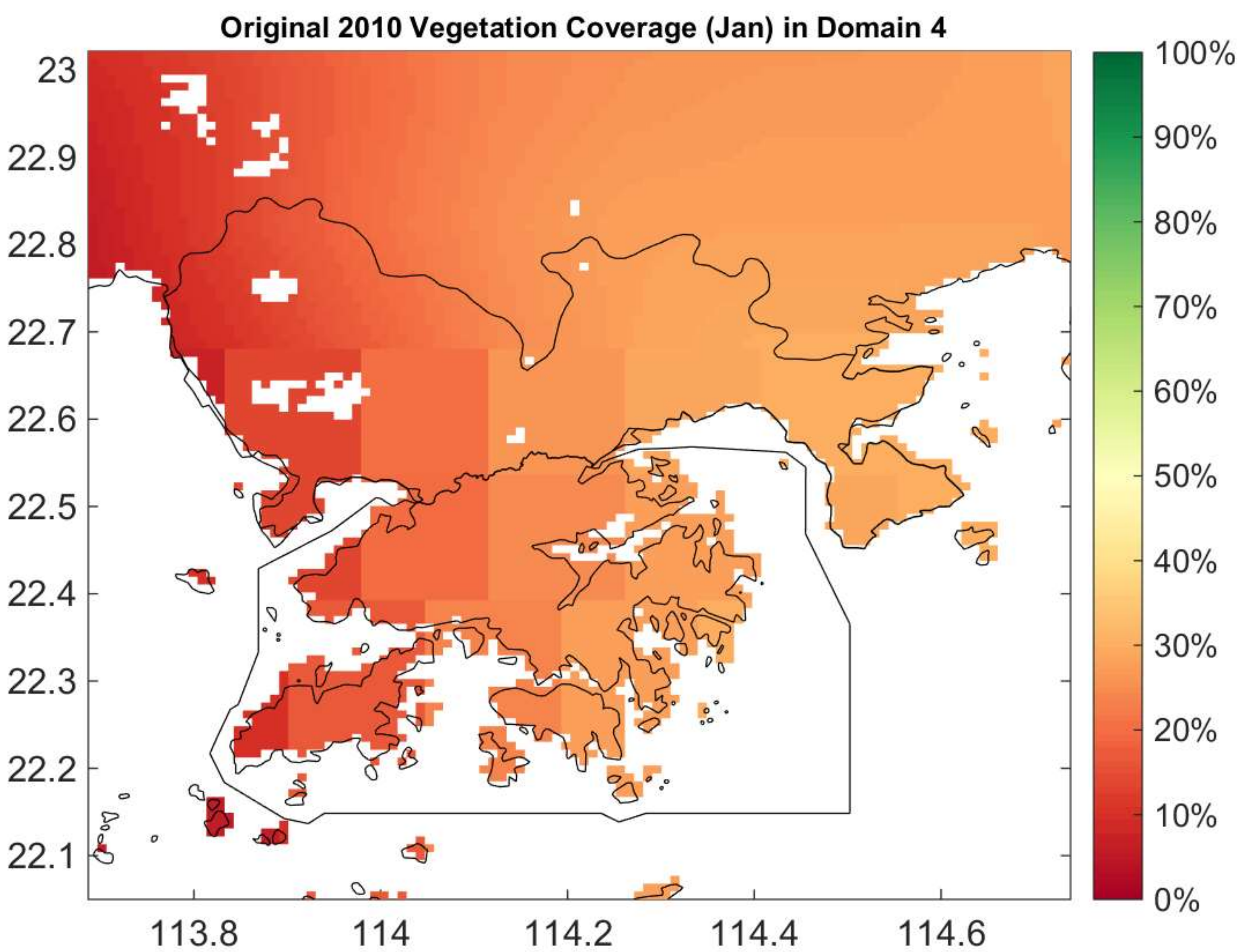
geo_data_refinement **Processing Package**

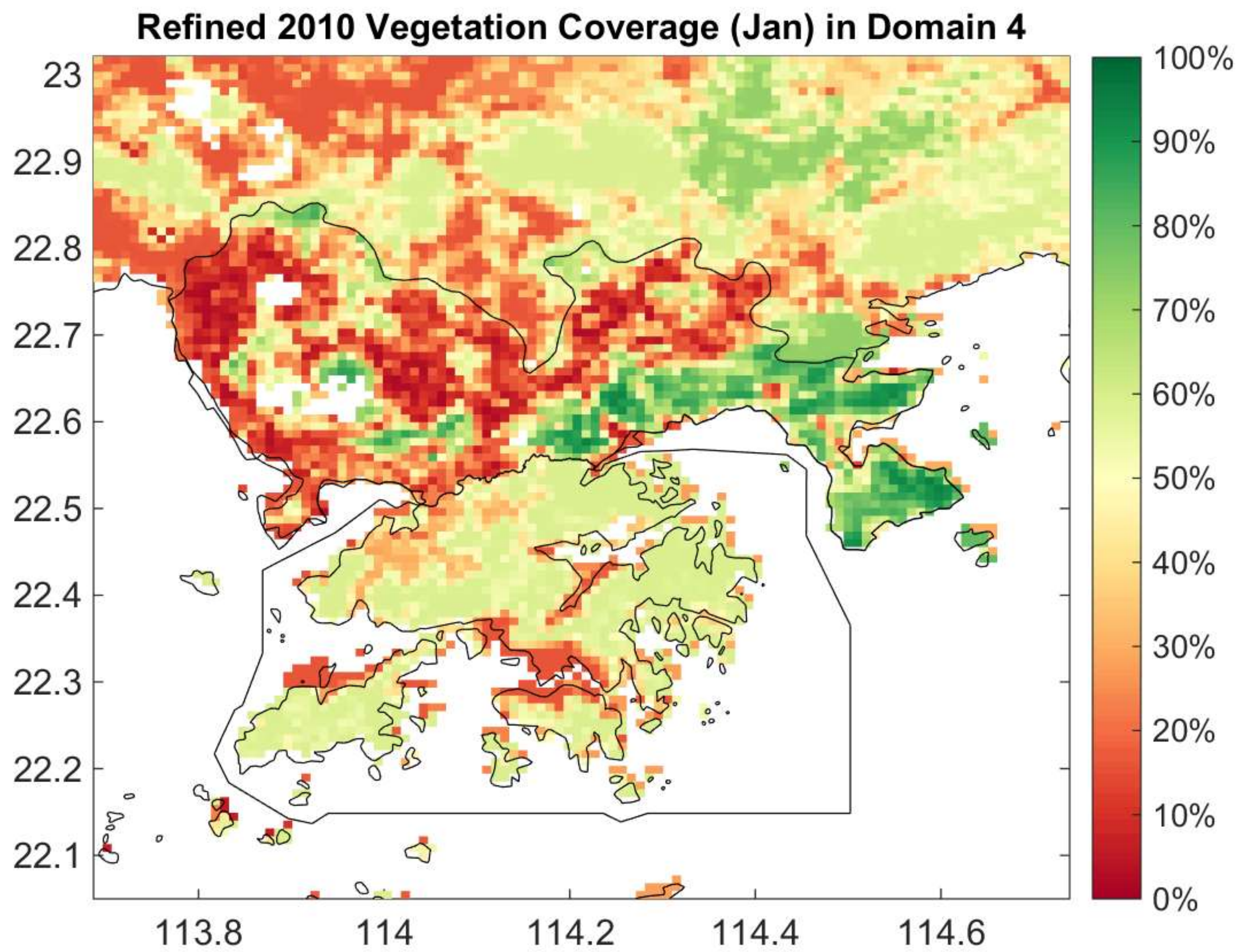
Technical Preparation – Data Preparation – Primary Data Processing



geo_data_refinement **Processing Package**

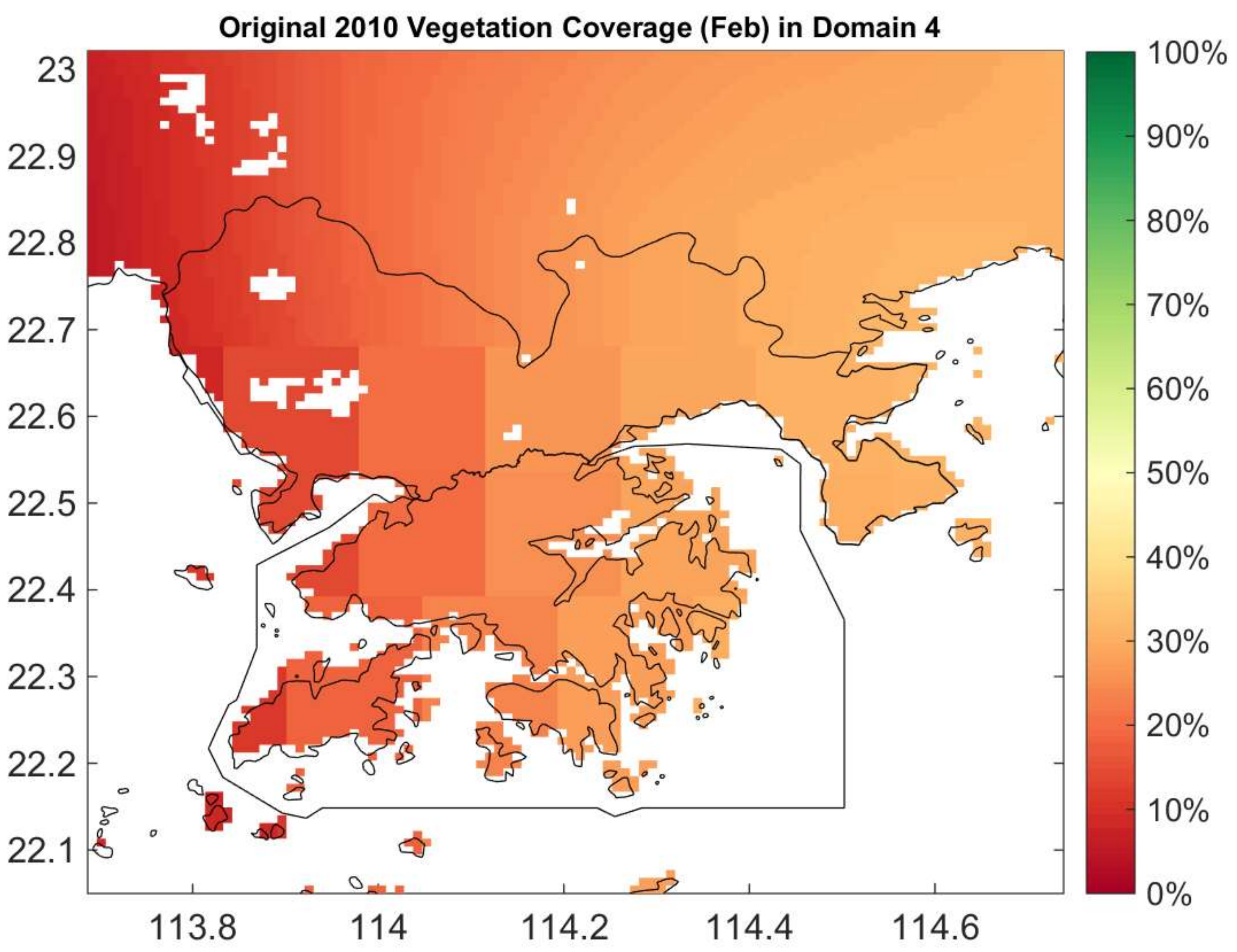
Technical Preparation– Data Preparation – Primary Data Processing

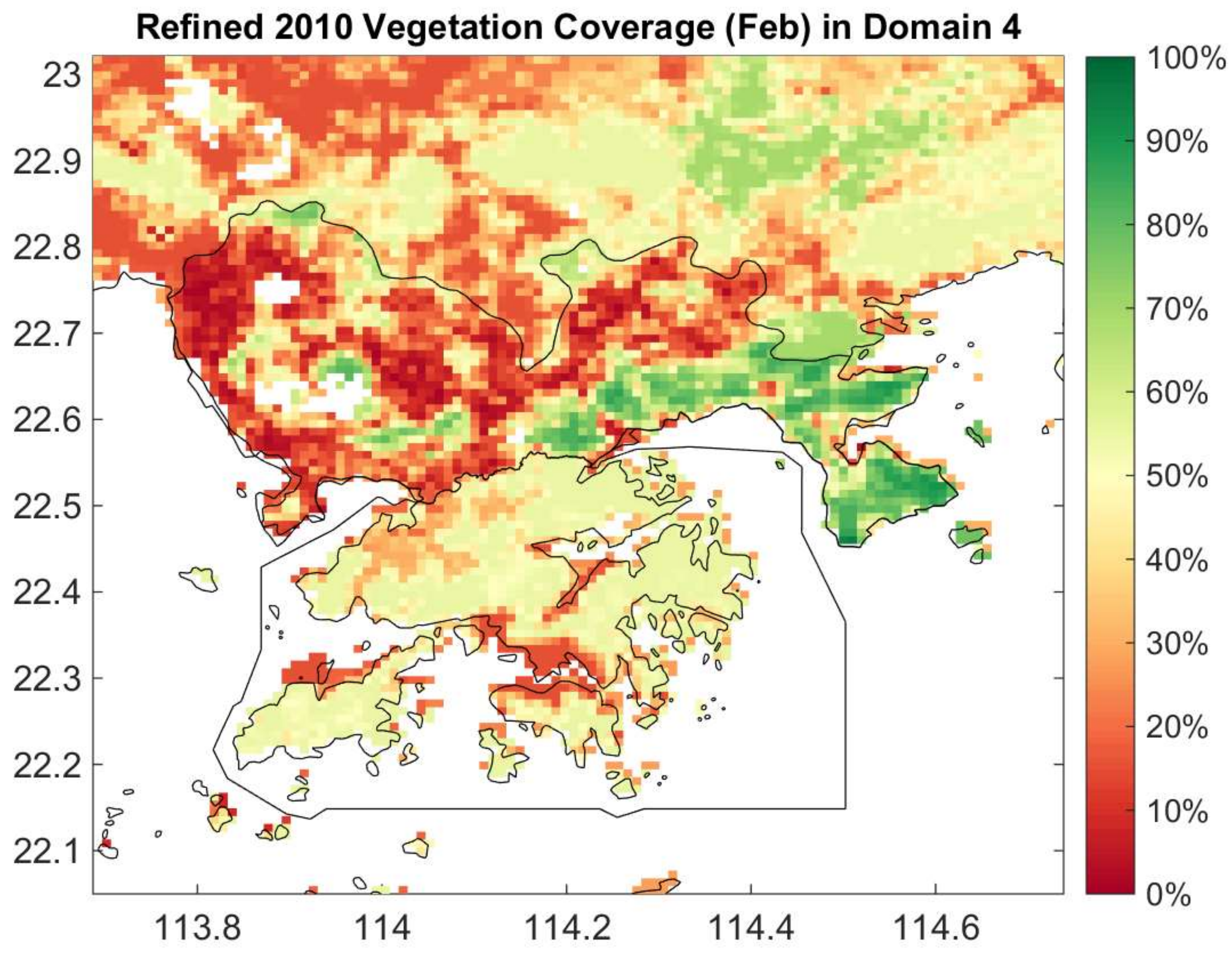




geo_data_refinement **Processing Package**

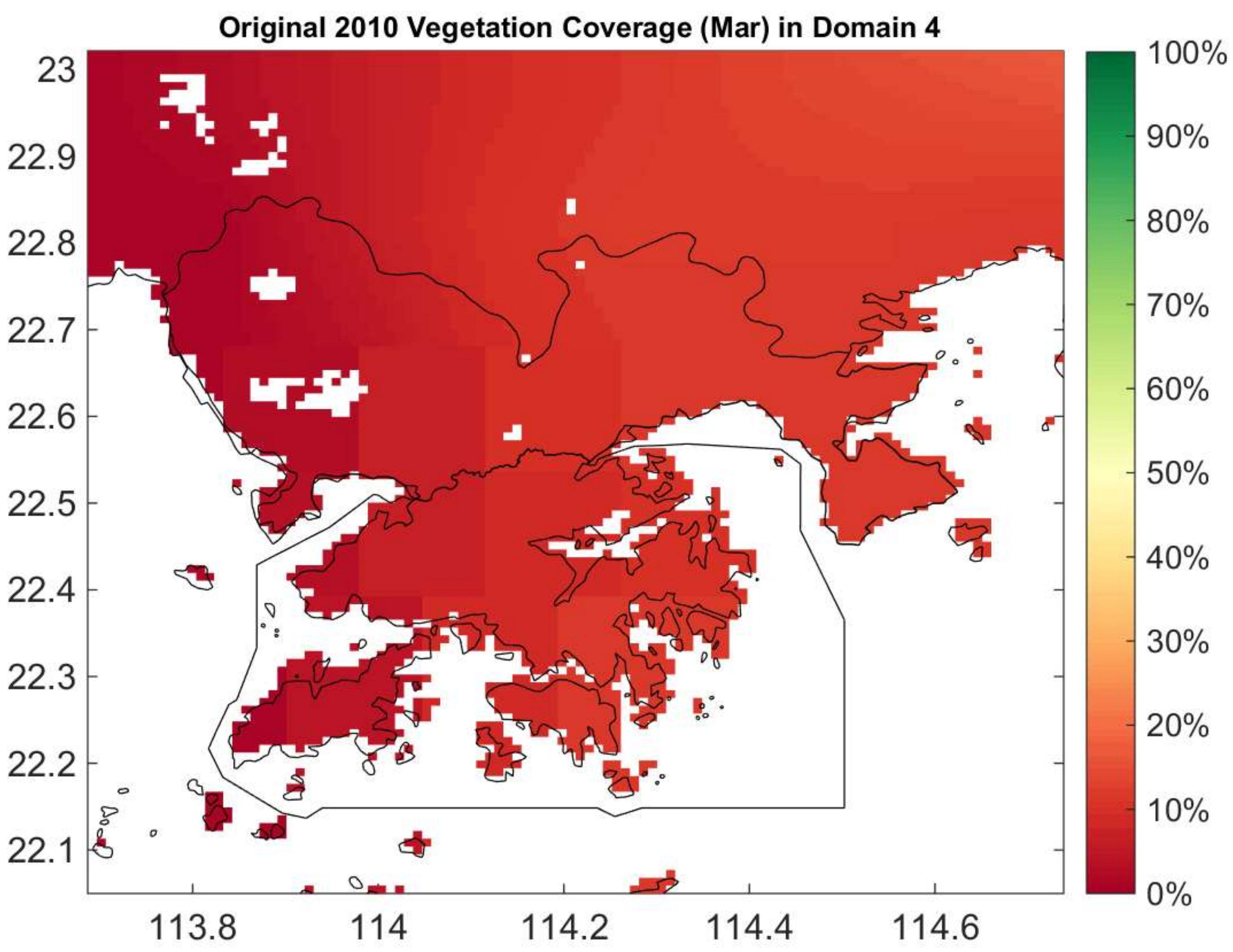
Technical Preparation – Data Preparation – Primary Data Processing

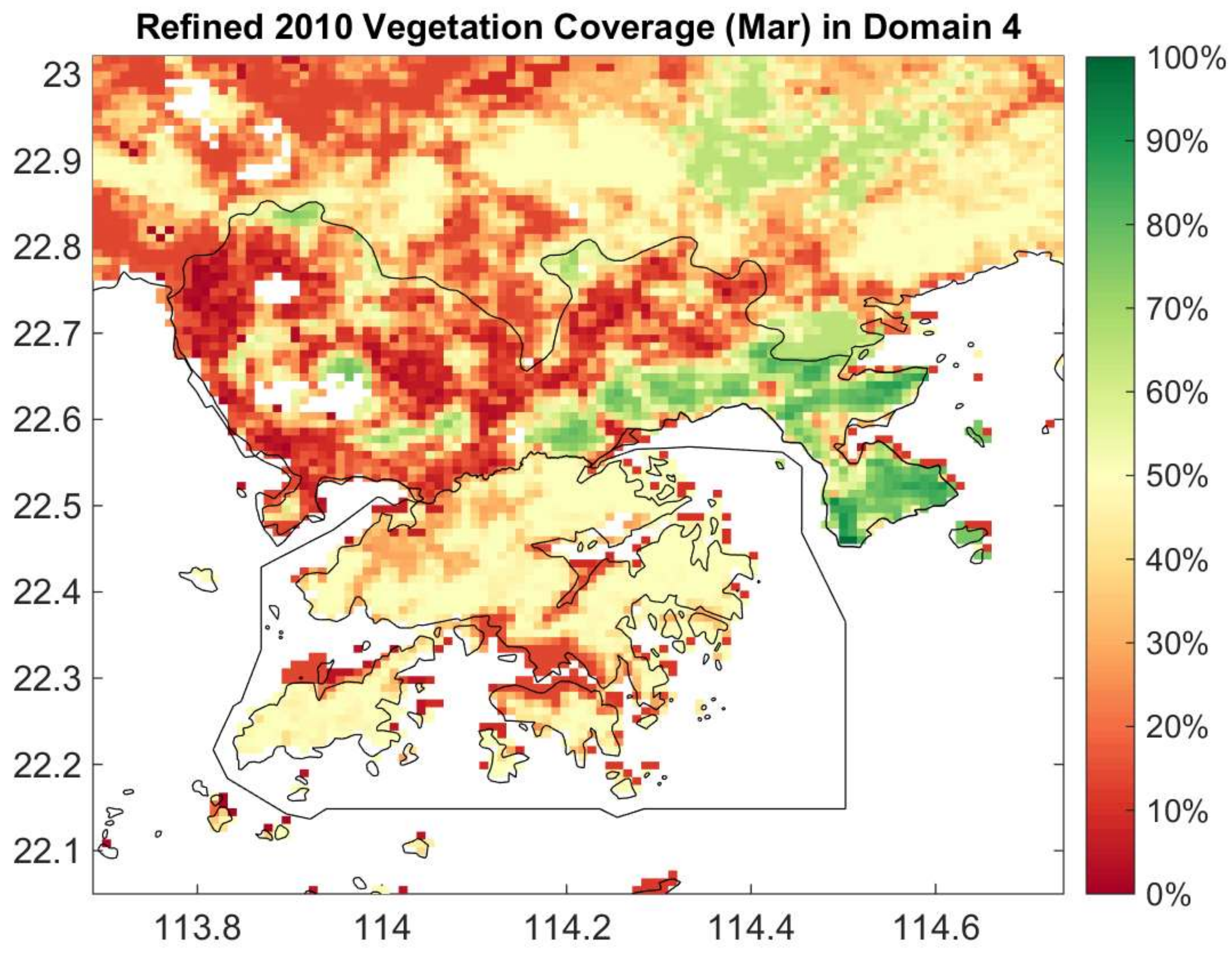




geo_data_refinement **Processing Package**

Technical Preparation – Data Preparation – Primary Data Processing





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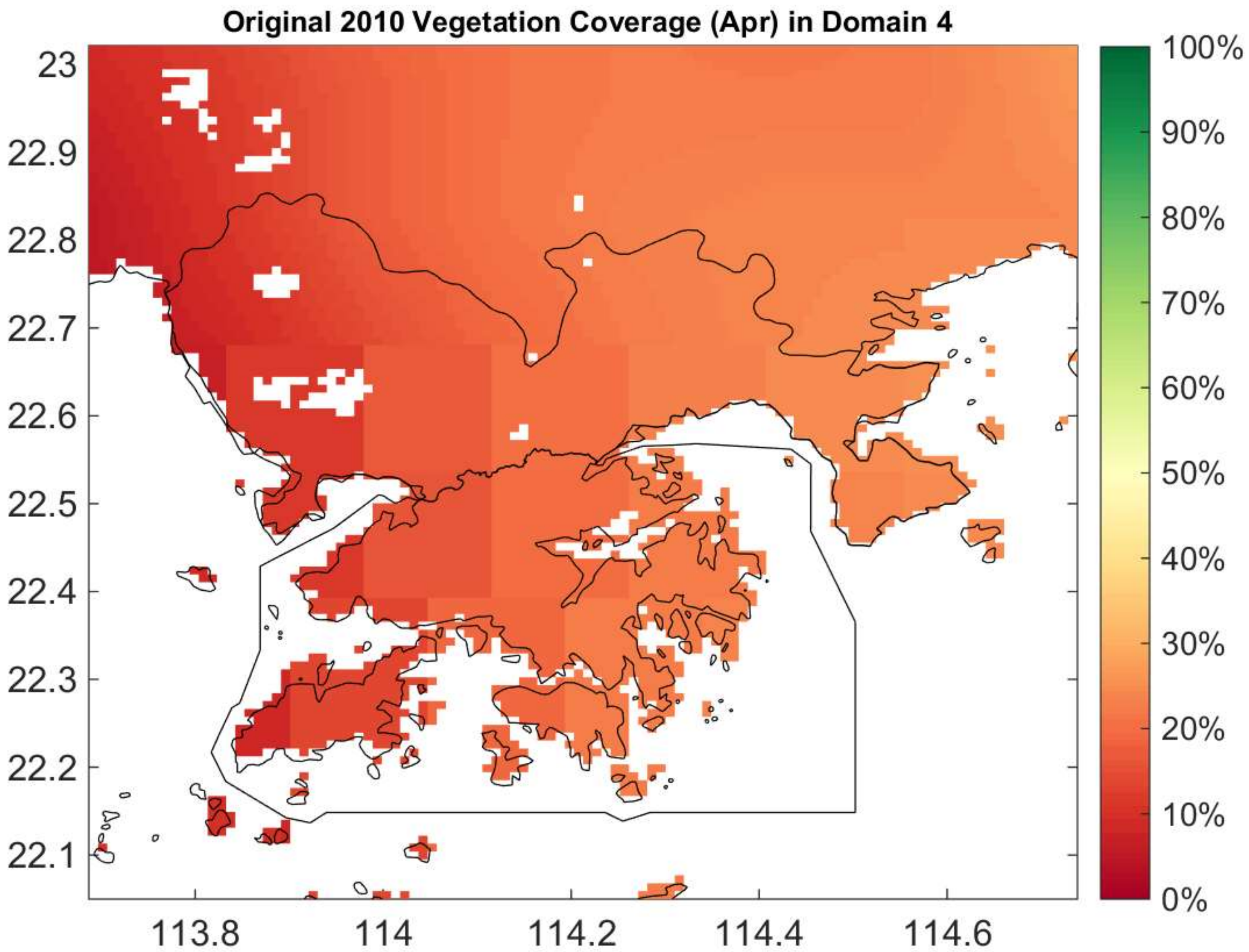
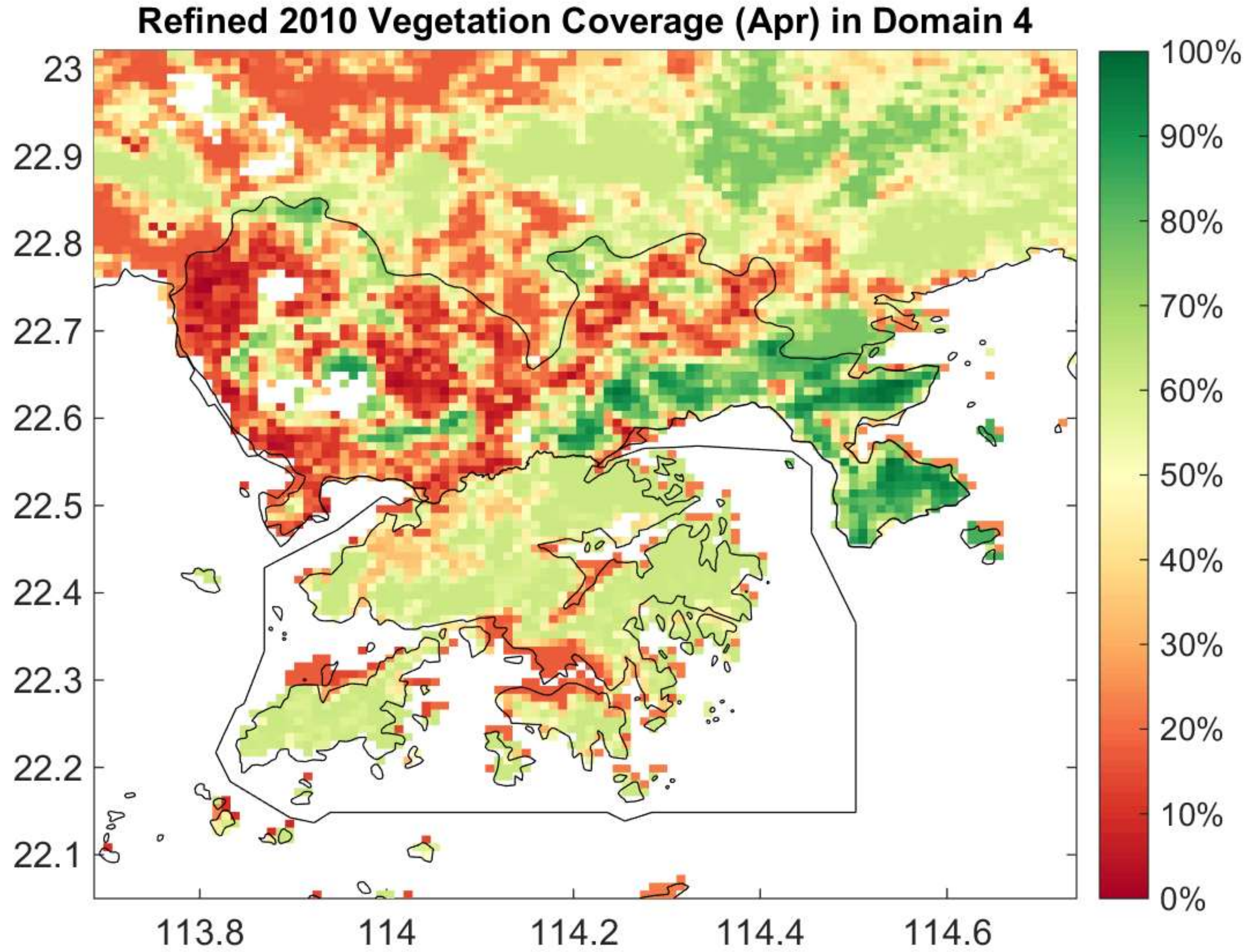
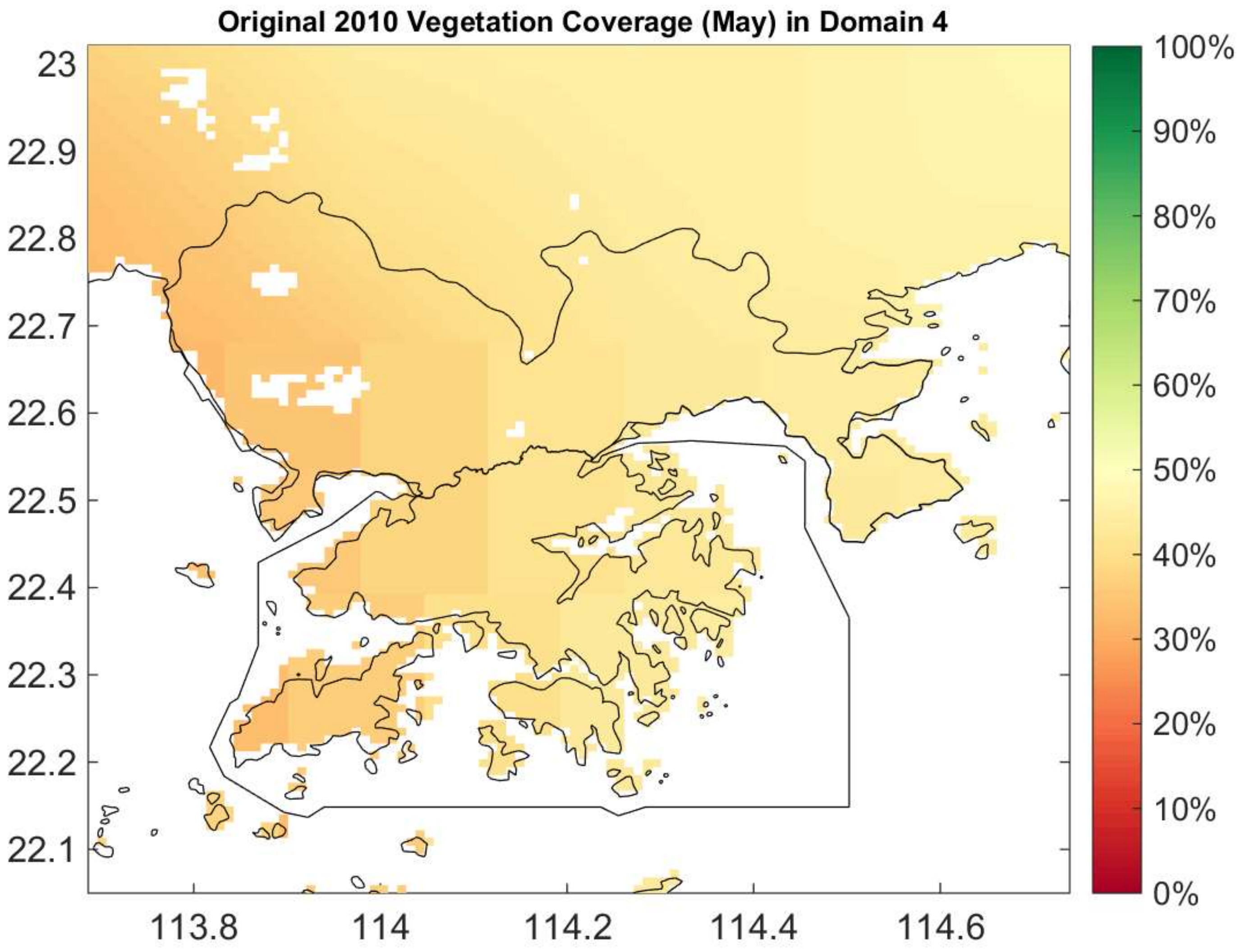
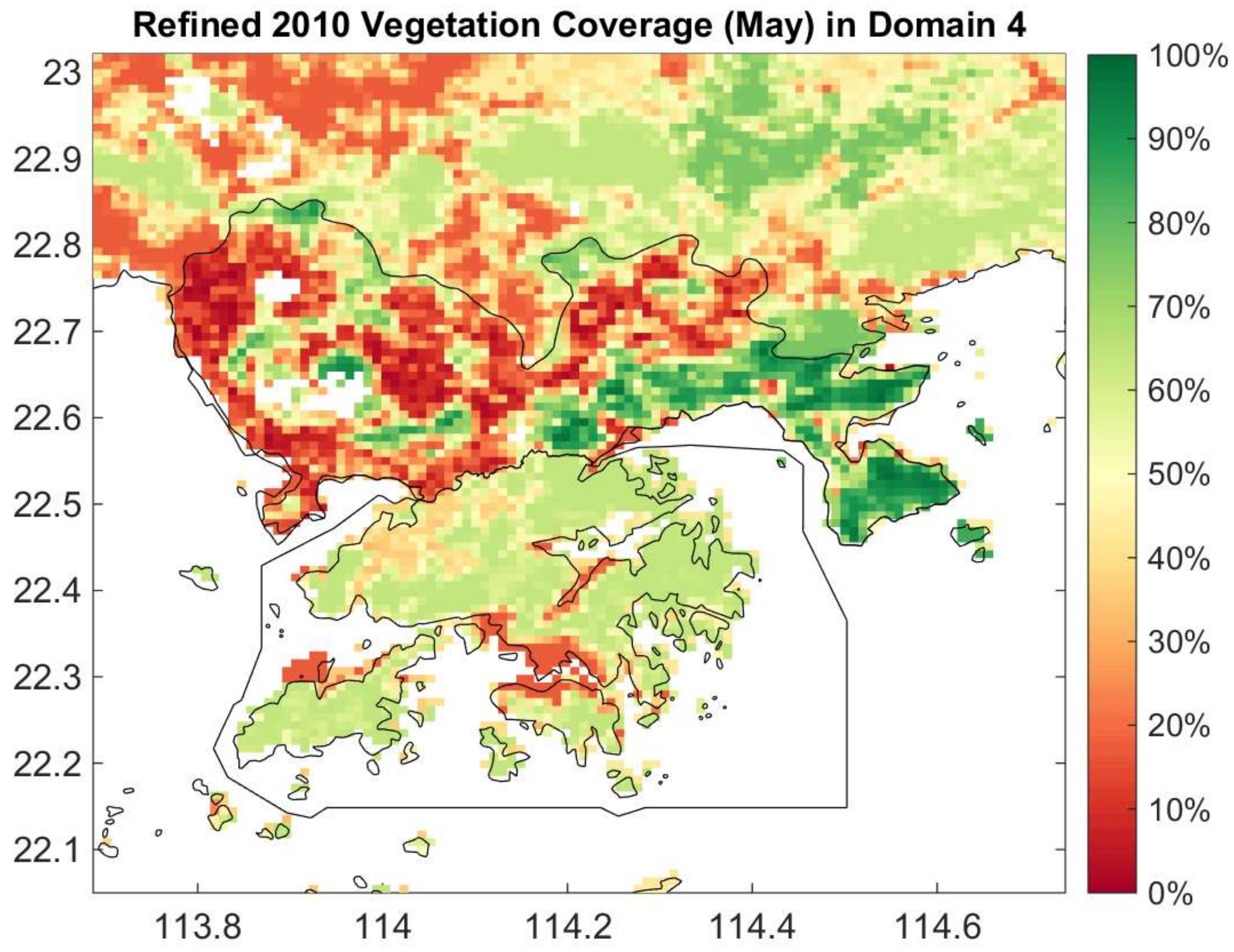




geo_data_refinement **Processing Package**

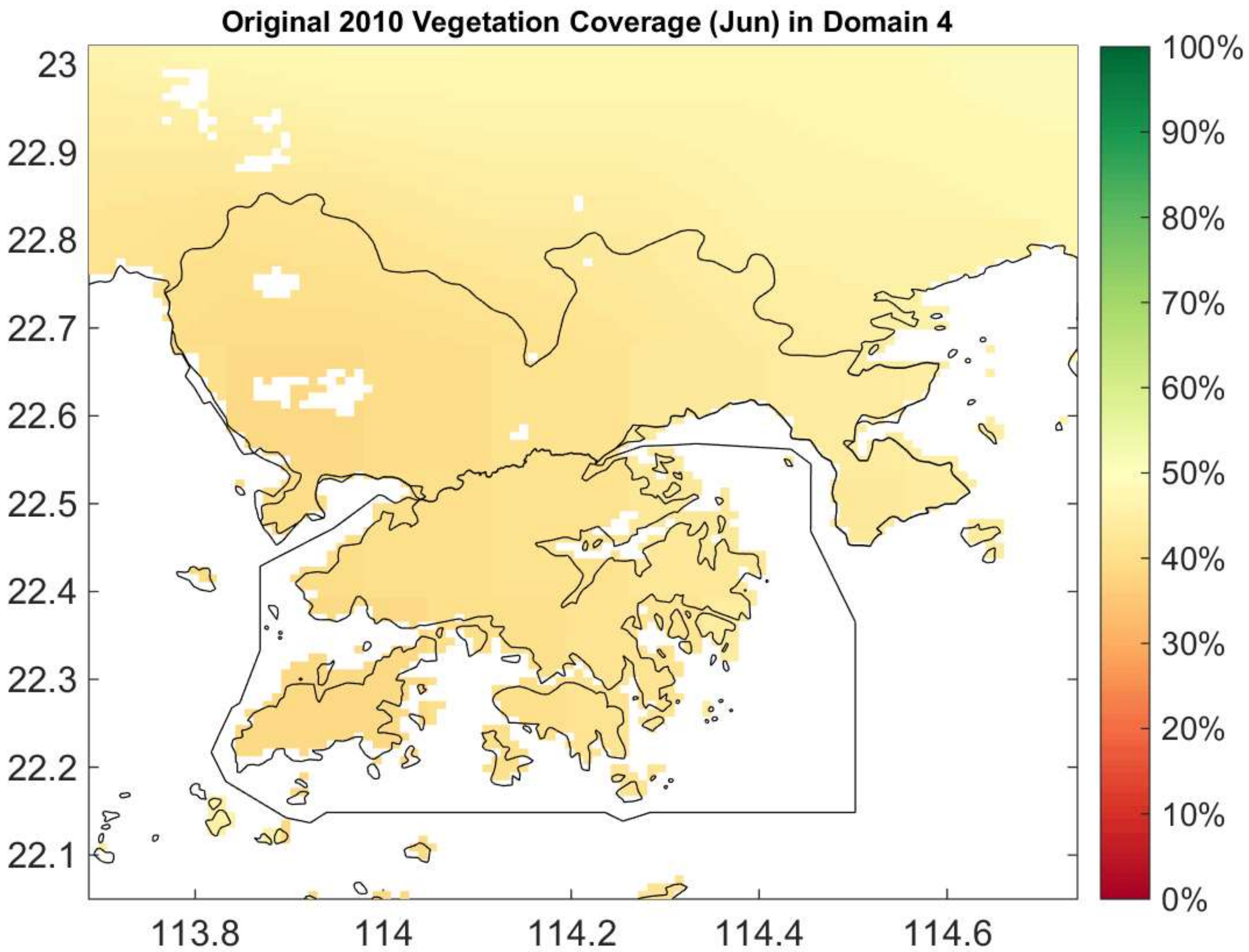
Technical Preparation – Data Preparation – Primary Data Processing

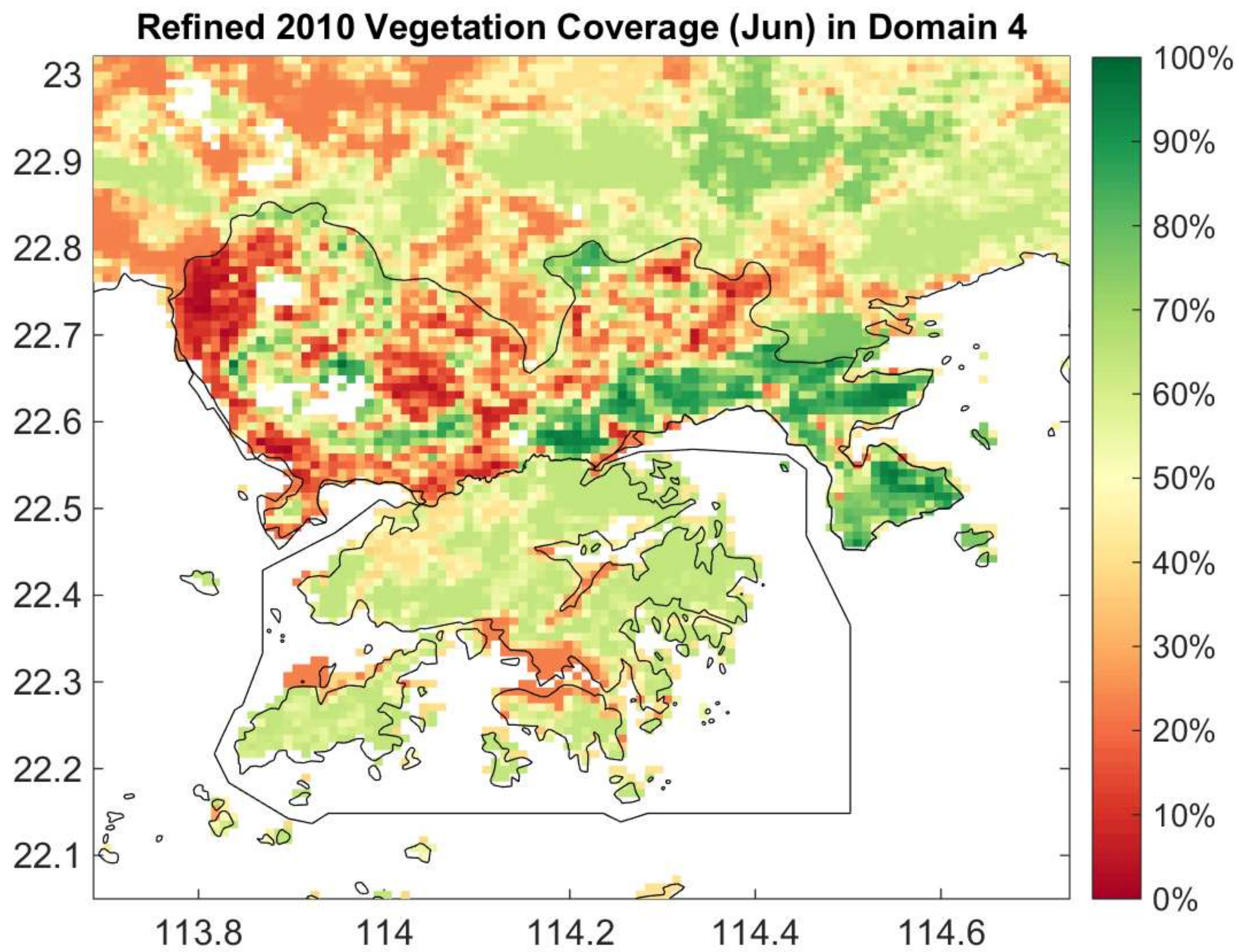




***geo_data_refinement* Processing Package**

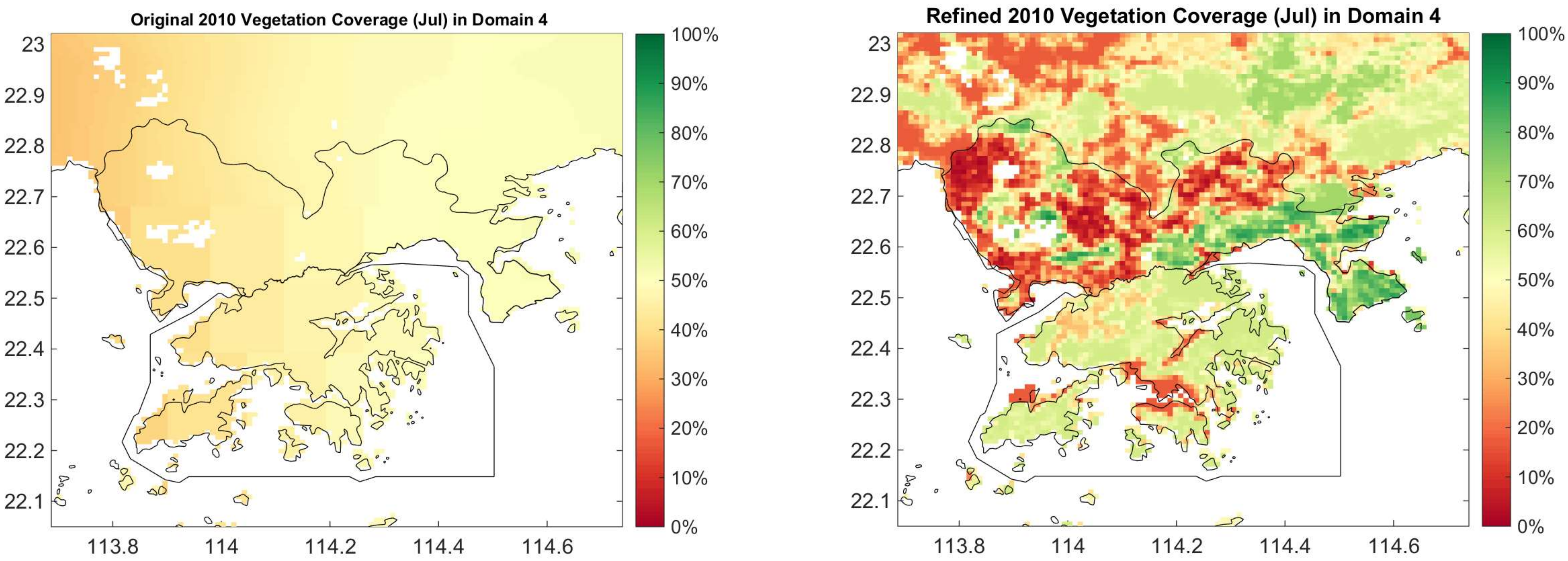
Technical Preparation – Data Preparation – Primary Data Processing





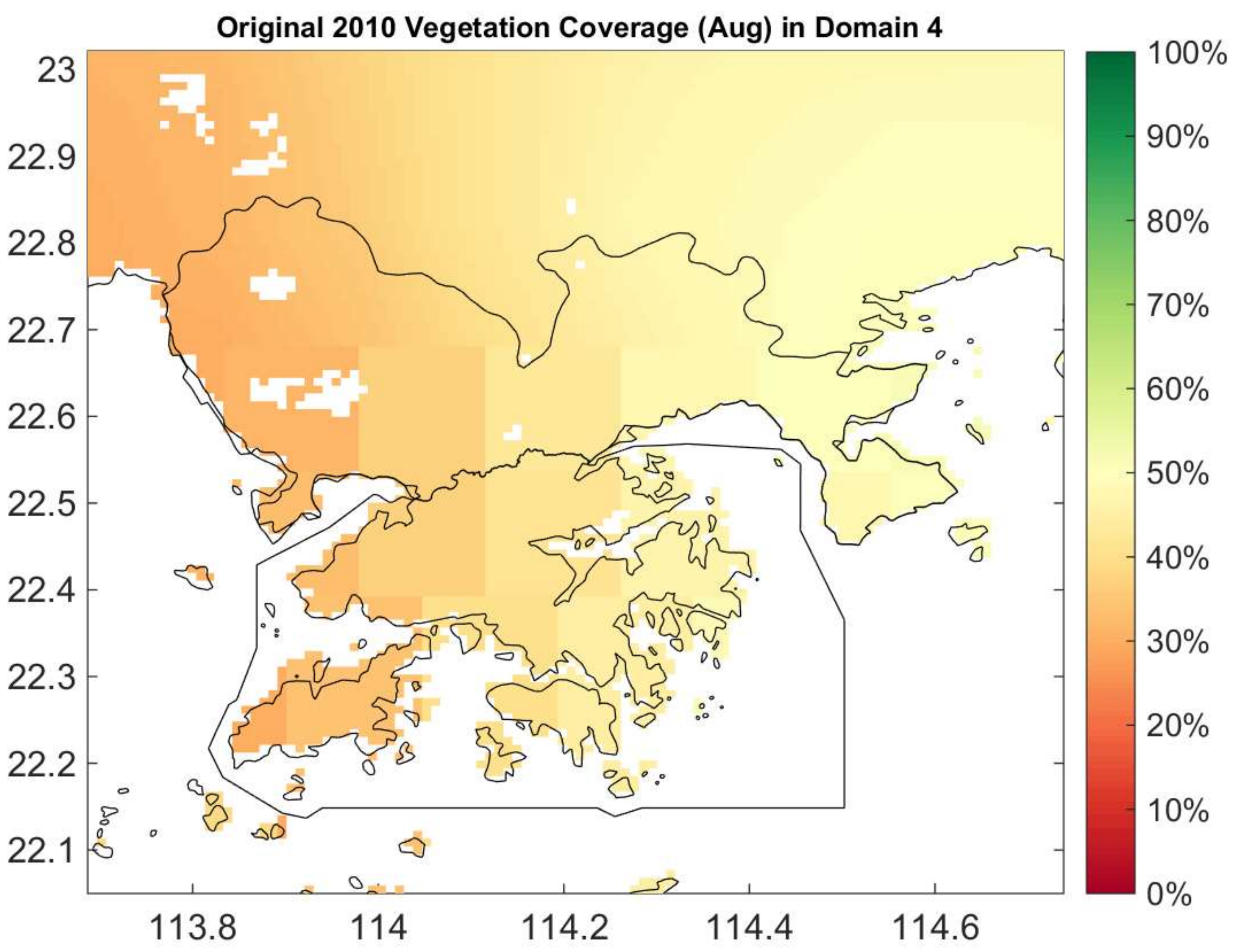
geo_data_refinement **Processing Package**

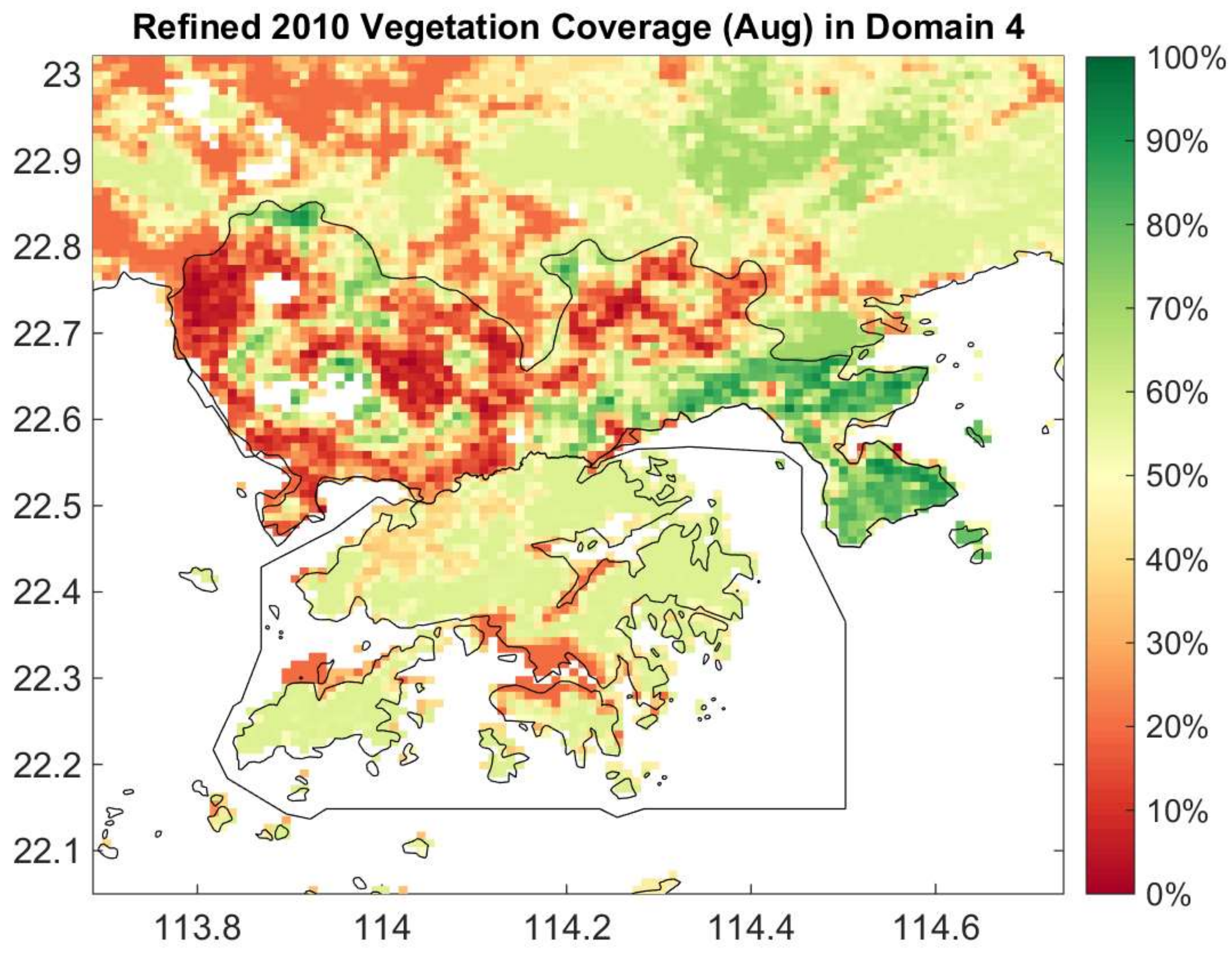
Technical Preparation – Data Preparation – Primary Data Processing



geo_data_refinement **Processing Package**

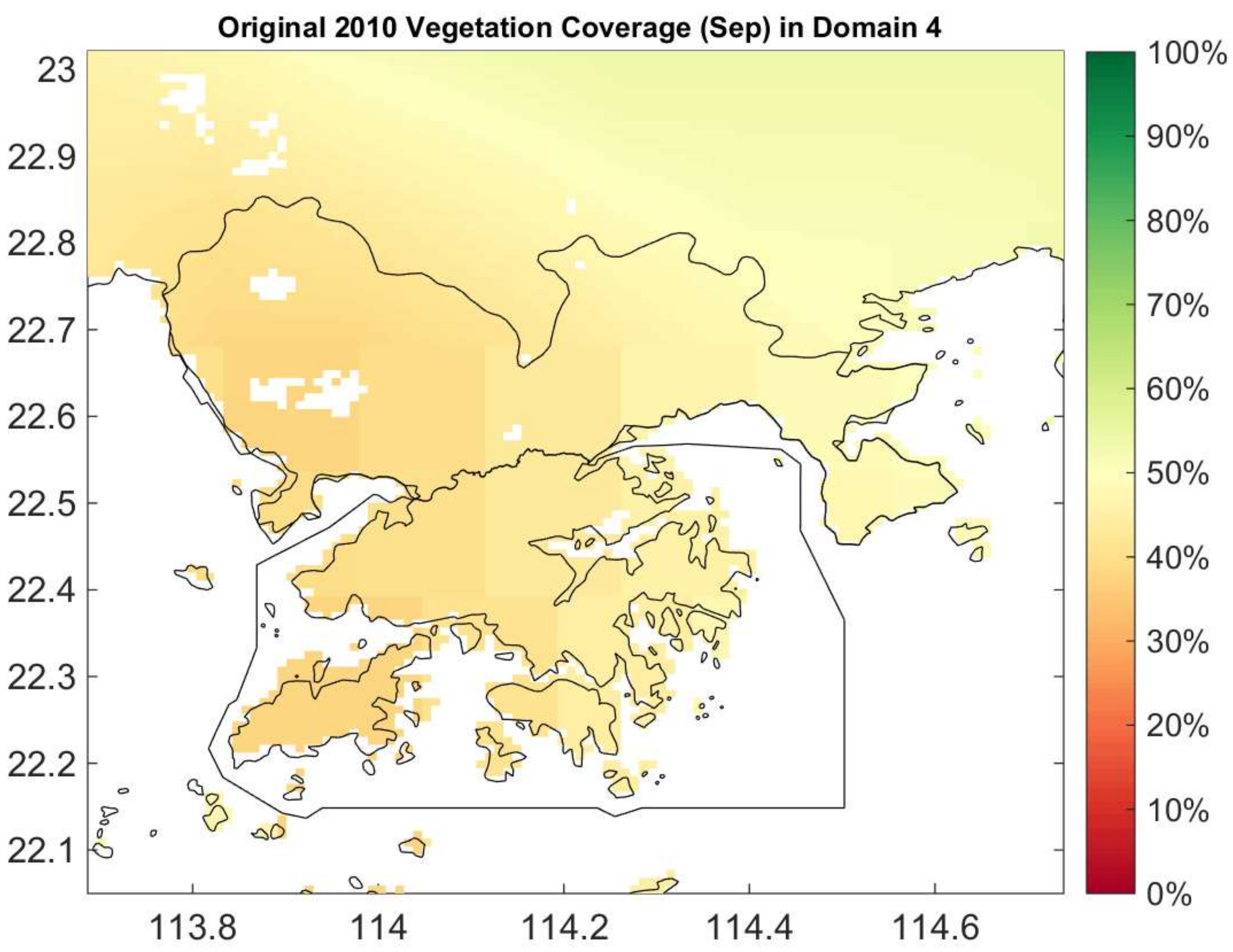
Technical Preparation – Data Preparation – Primary Data Processing

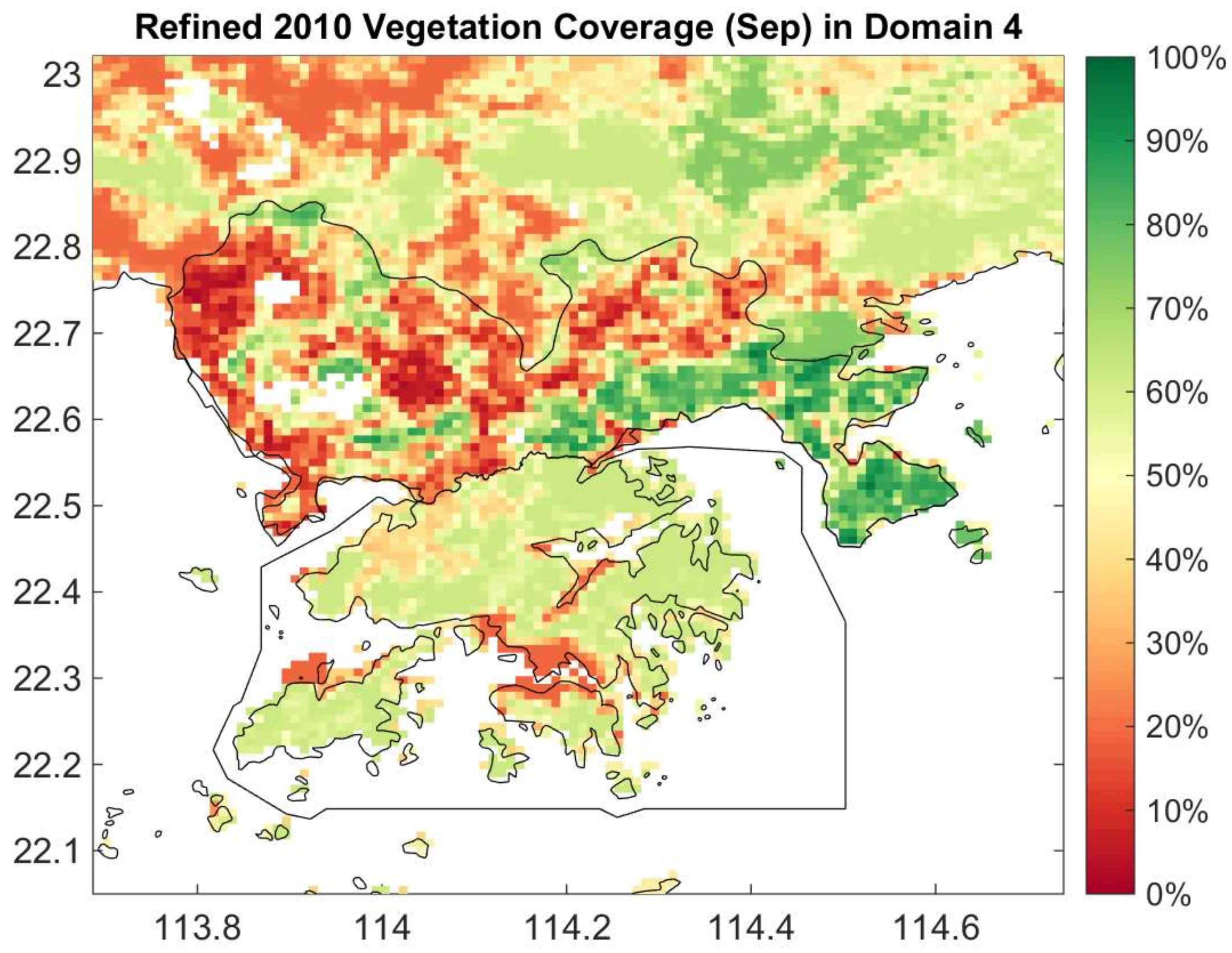




geo_data_refinement **Processing Package**

Technical Preparation – Data Preparation – Primary Data Processing





geo_data_refinement **Processing Package**

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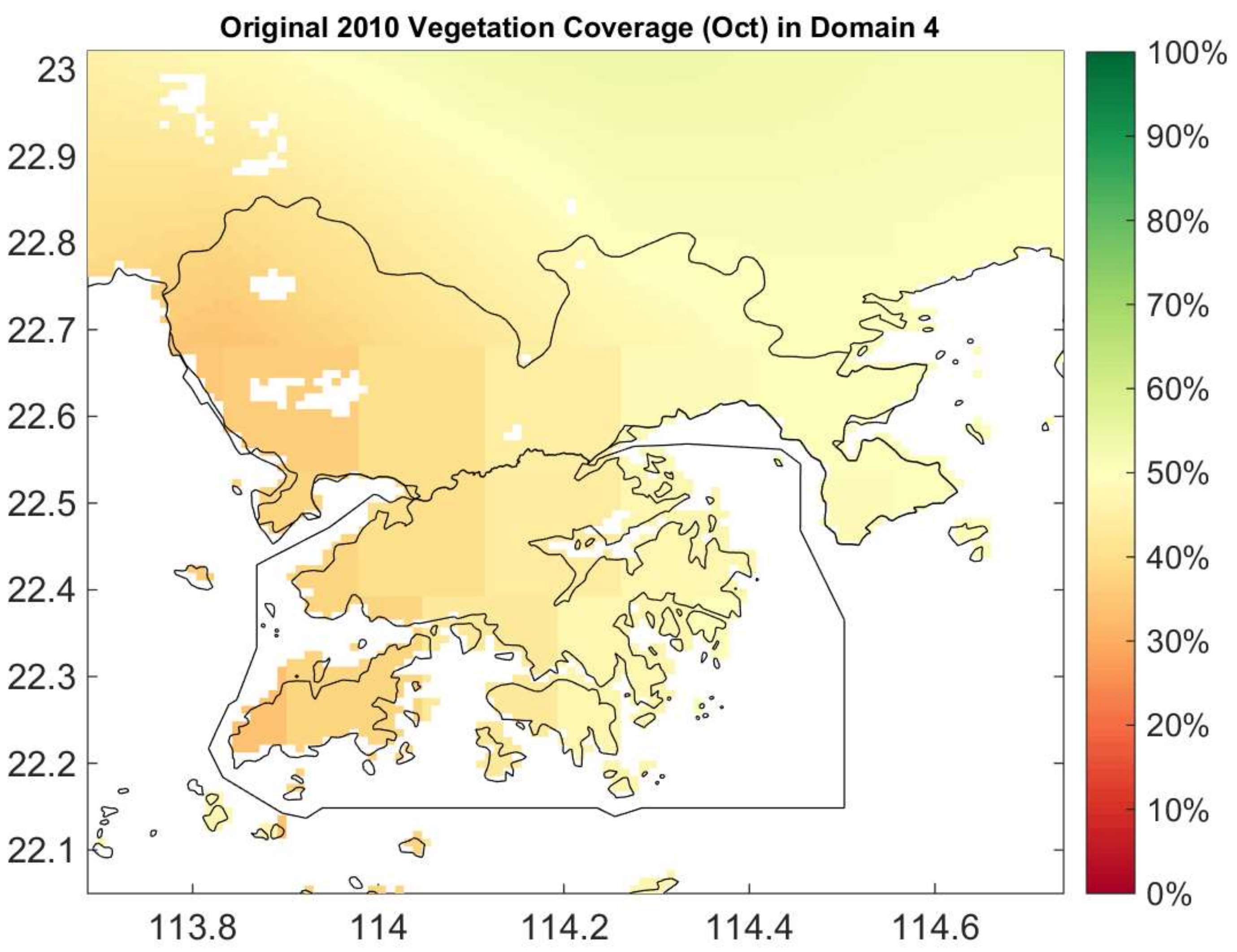

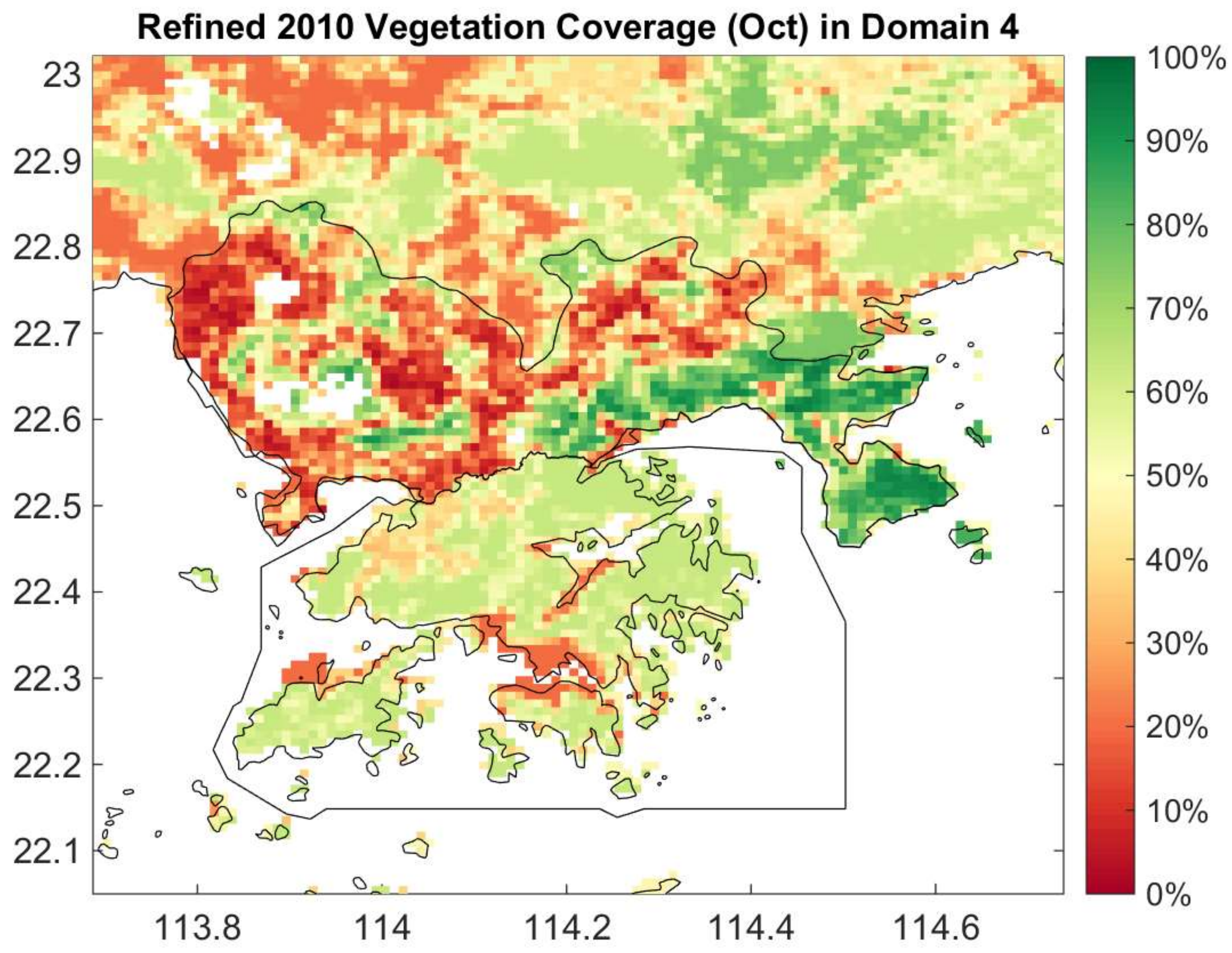

geo_data_refinement **Processing Package**

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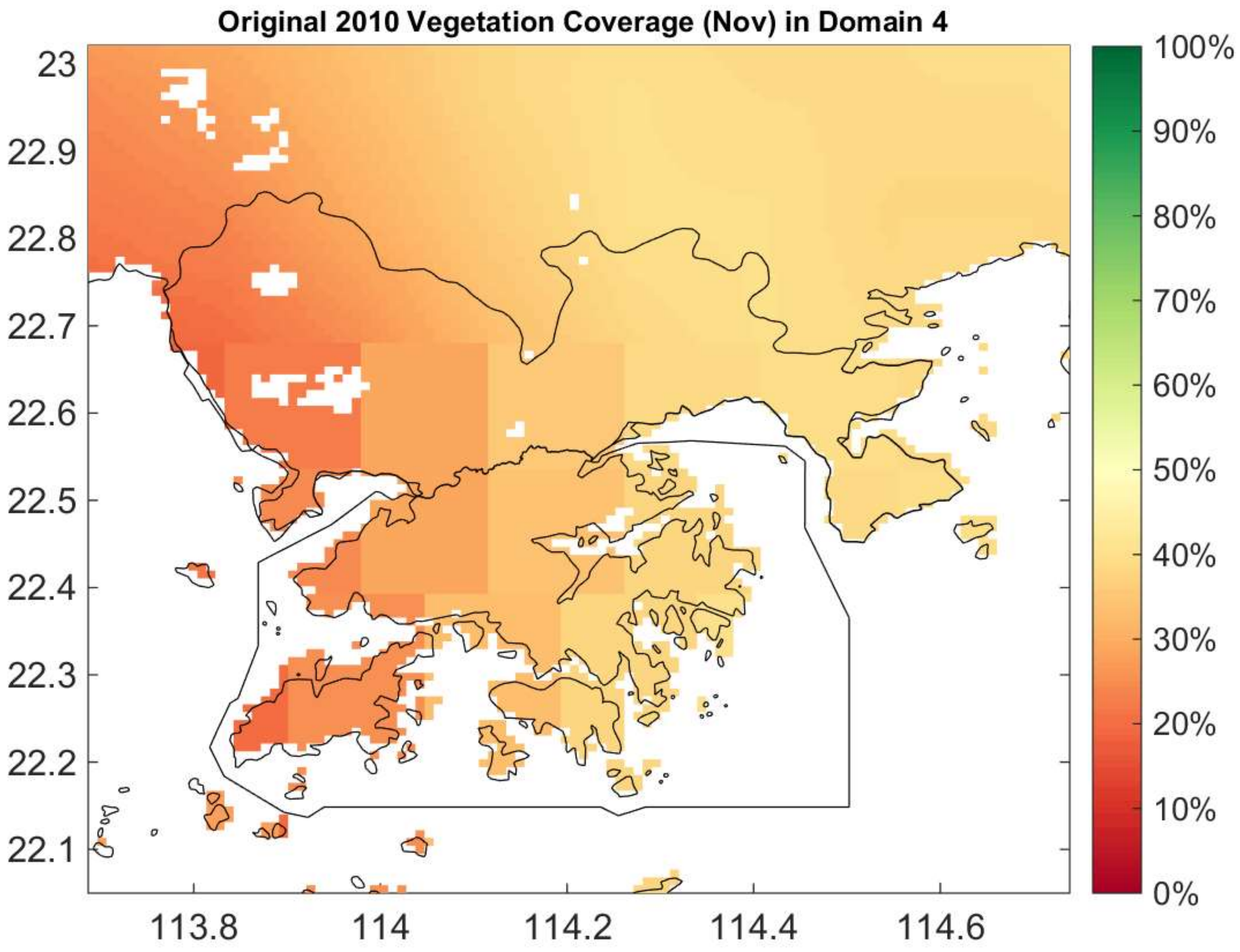
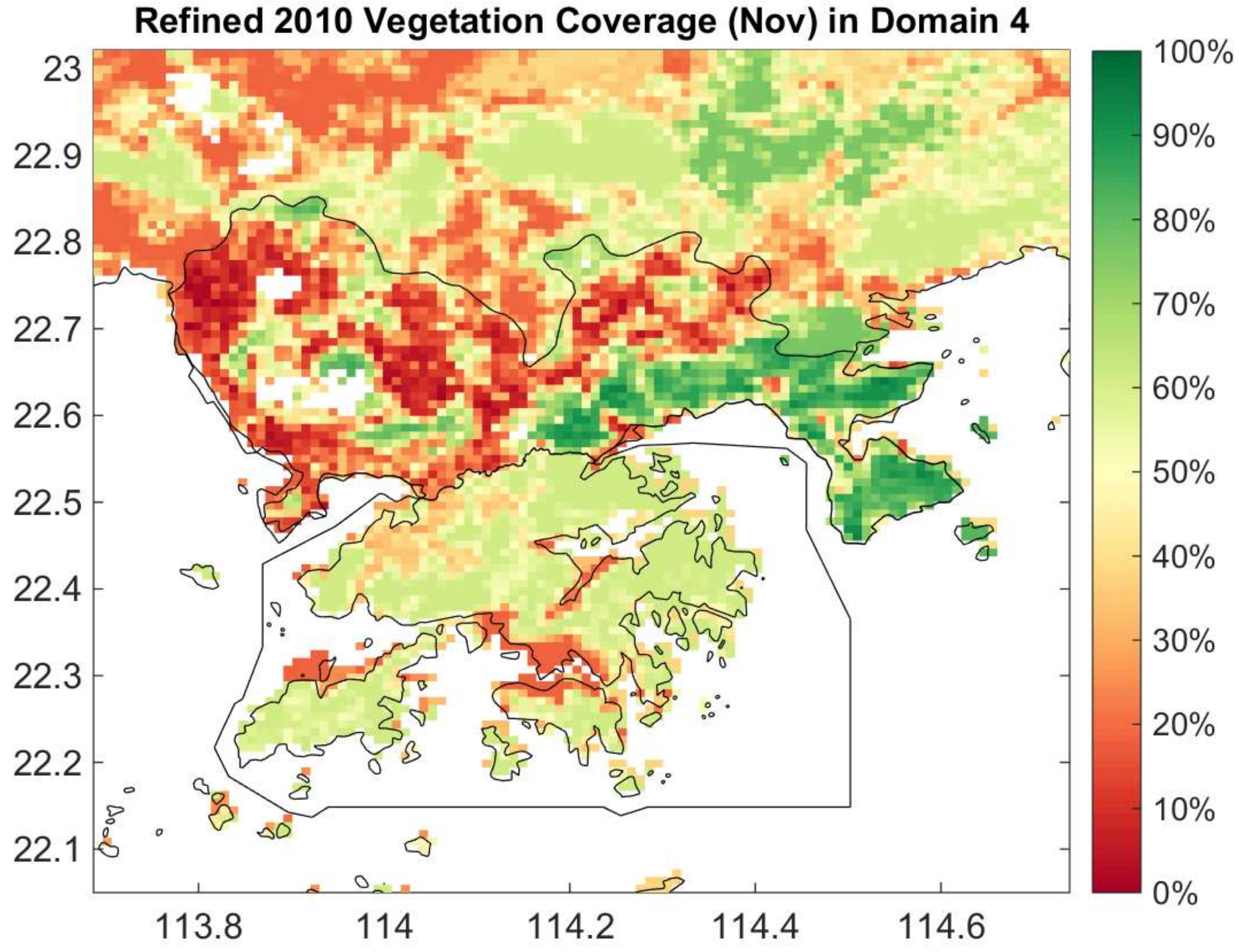
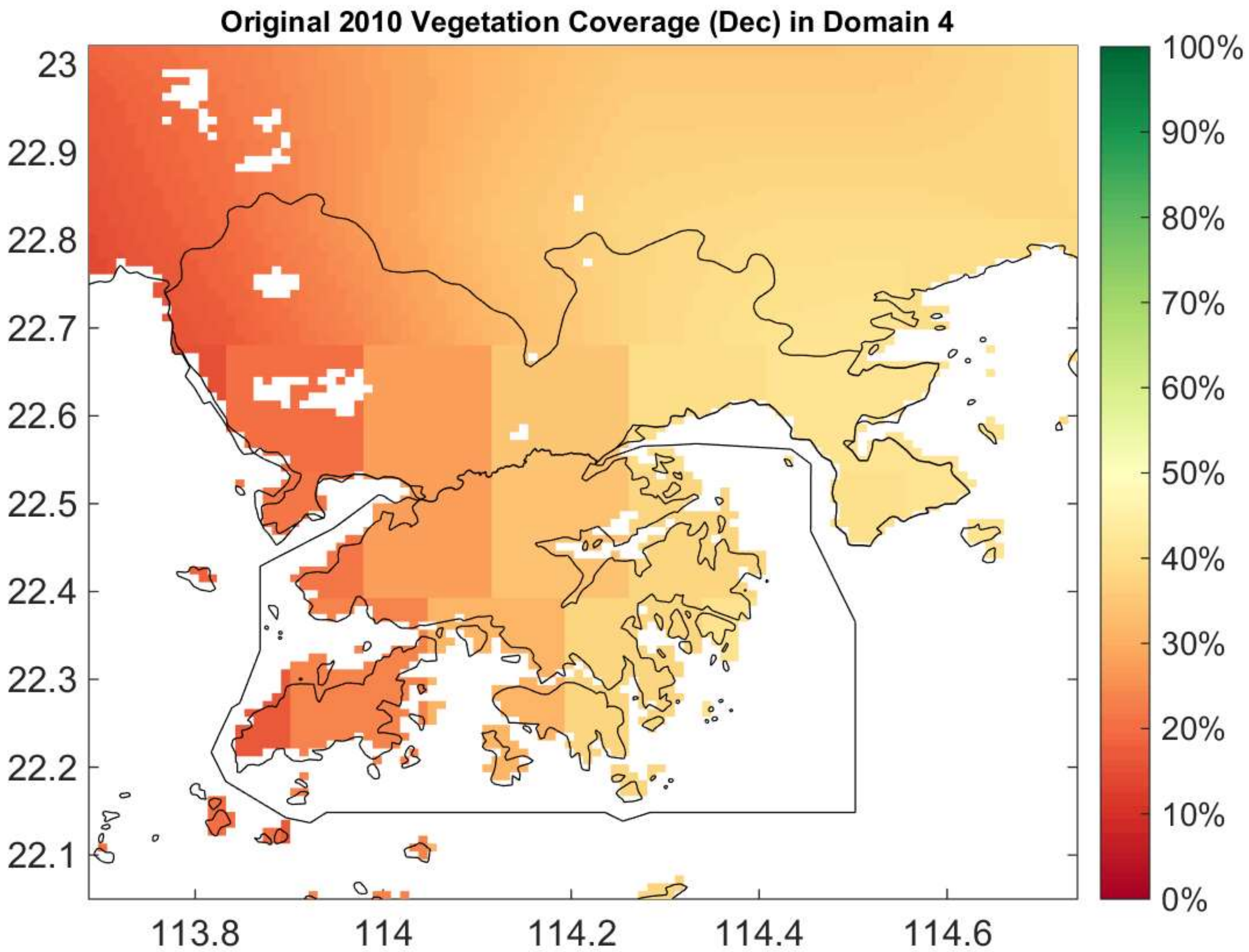
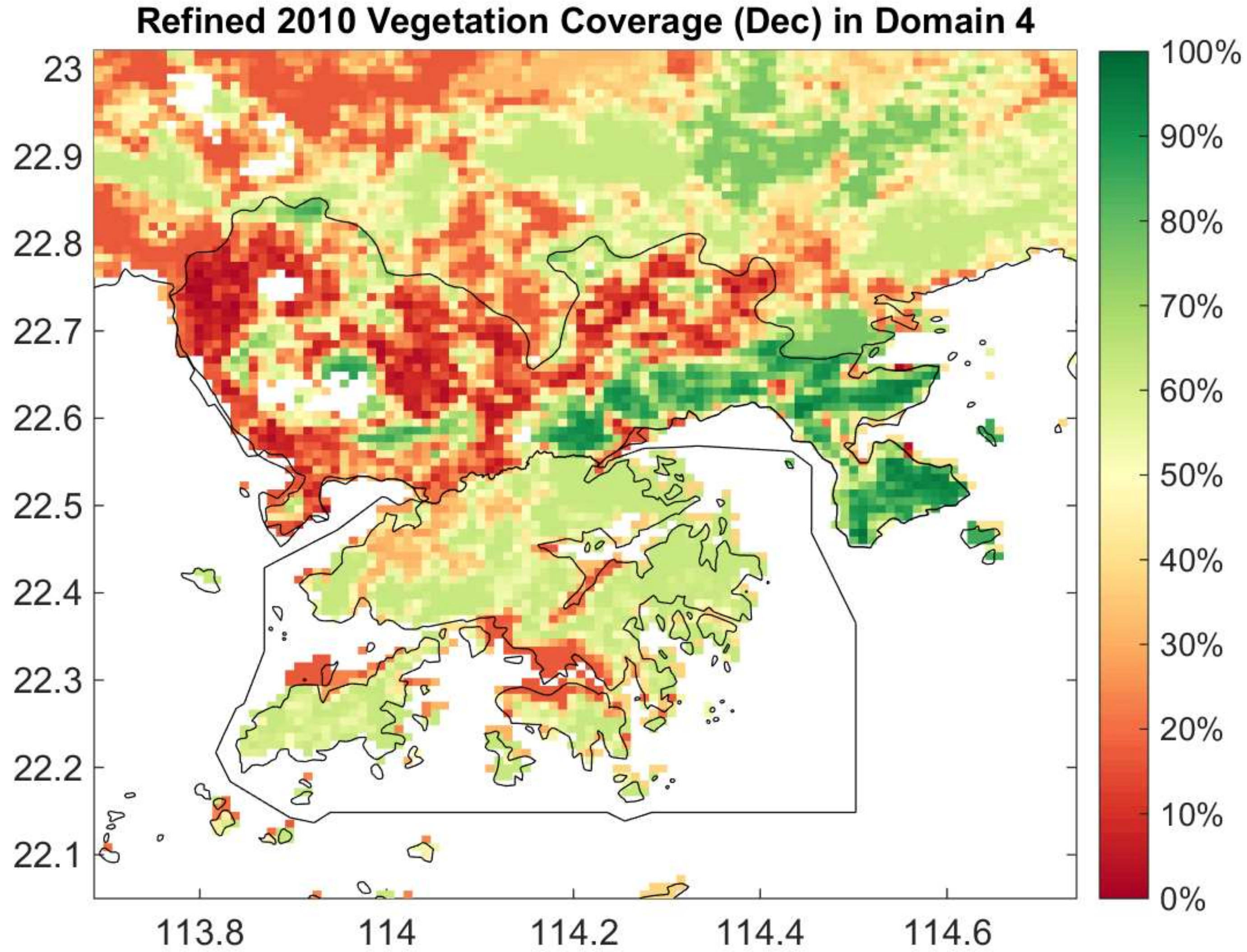




geo_data_refinement **Processing Package**

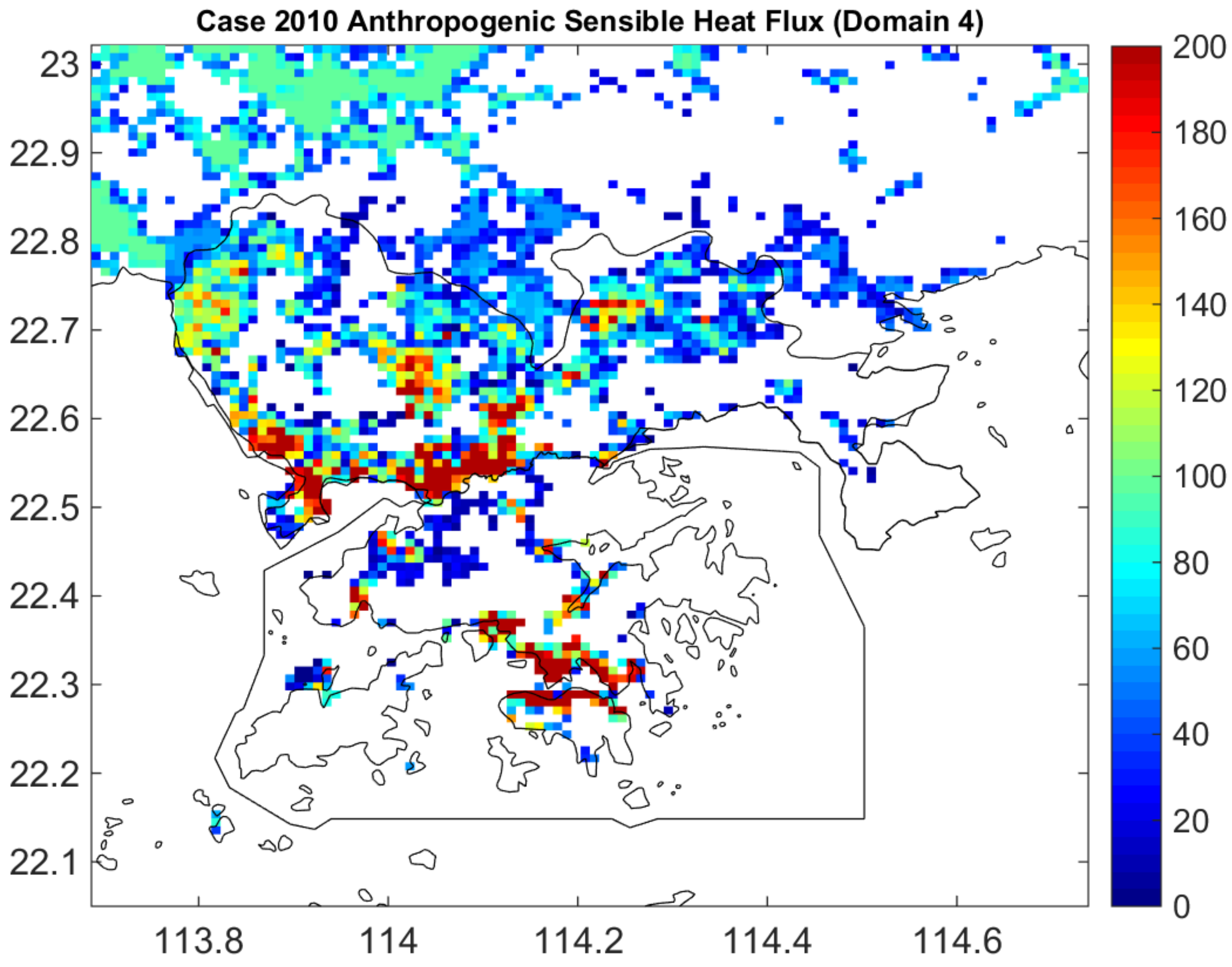
Technical Preparation – Data Preparation – Primary Data Processing

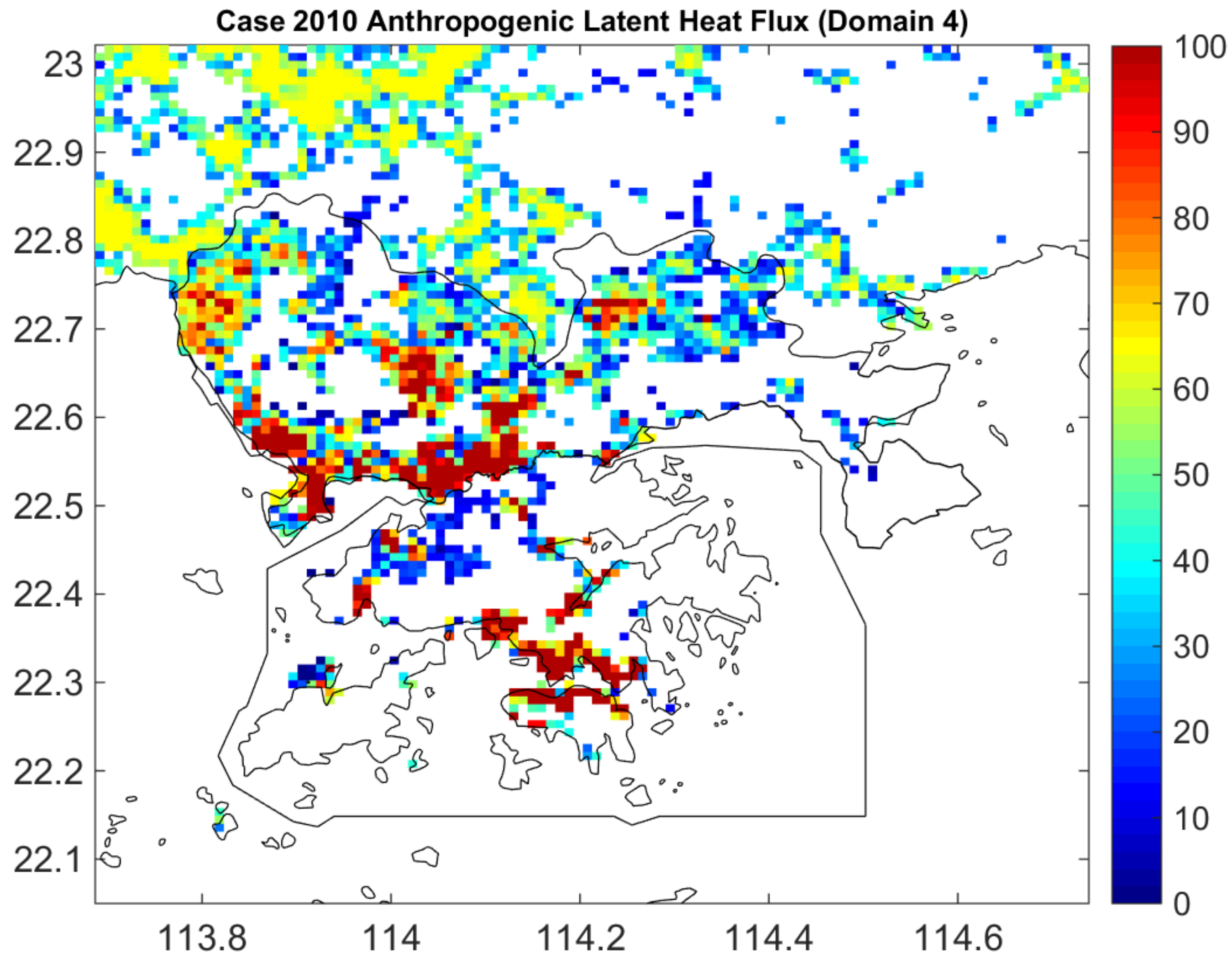




geo_data_refinement **Processing Package**

Technical Preparation – Data Preparation – Primary Data Processing





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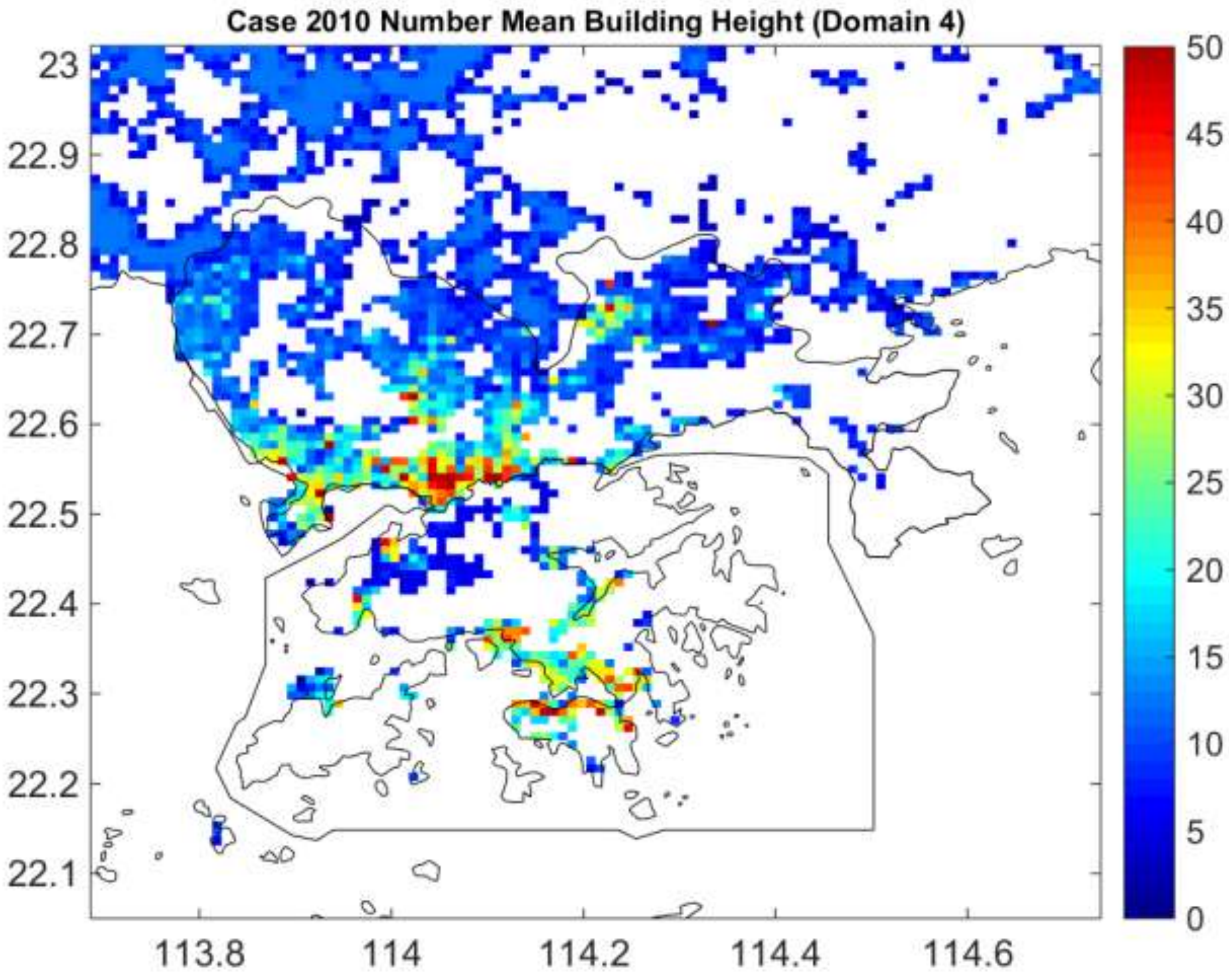

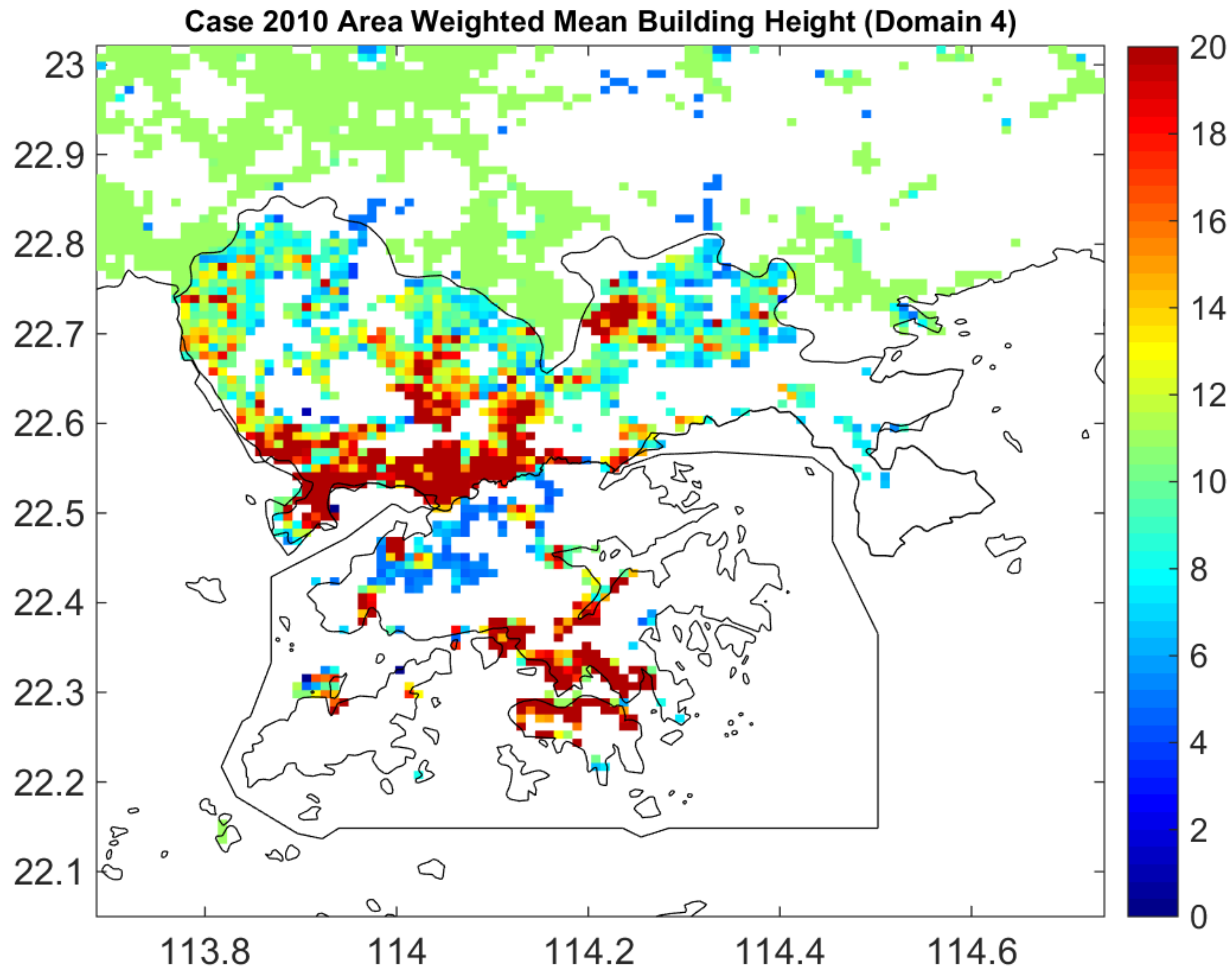

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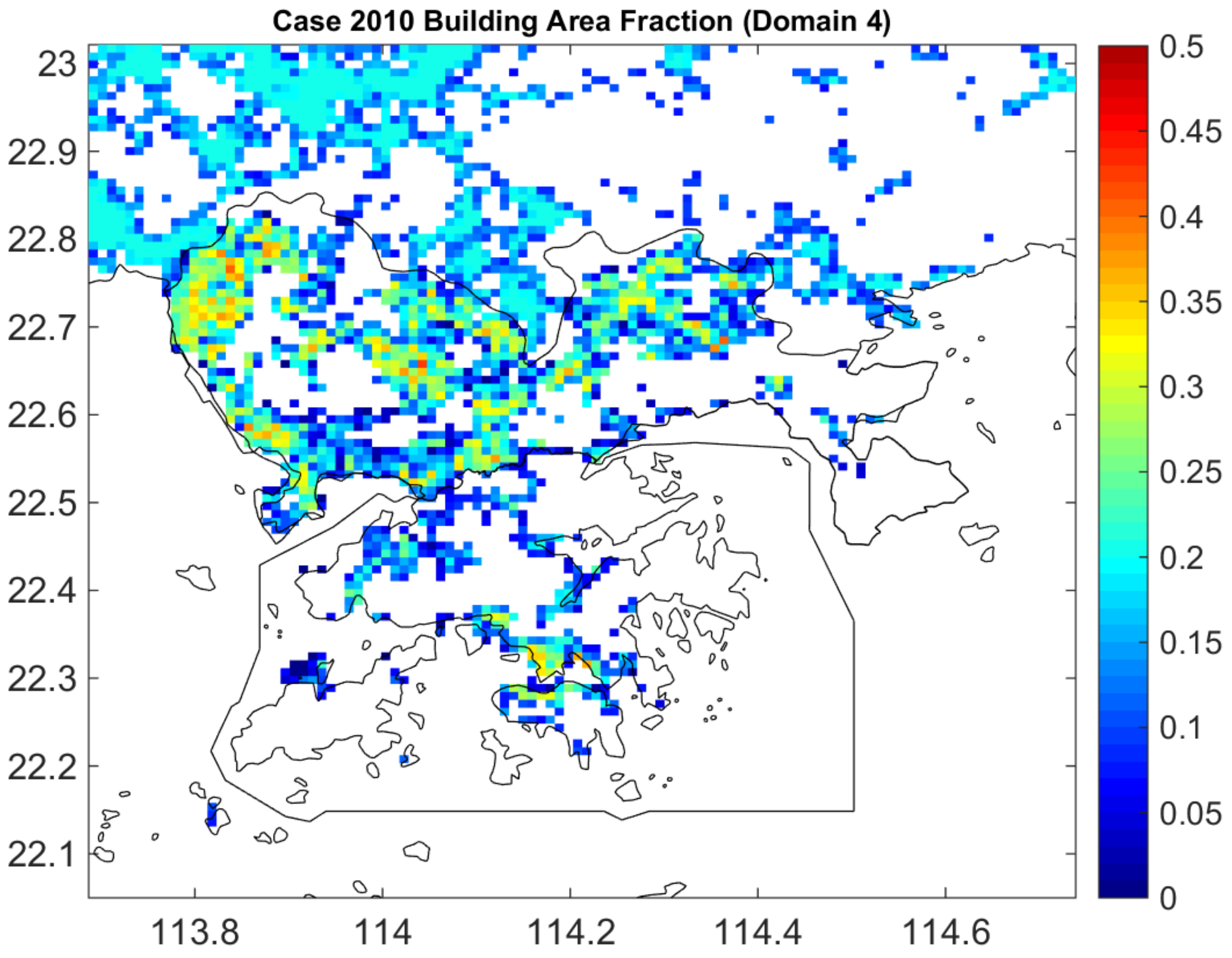

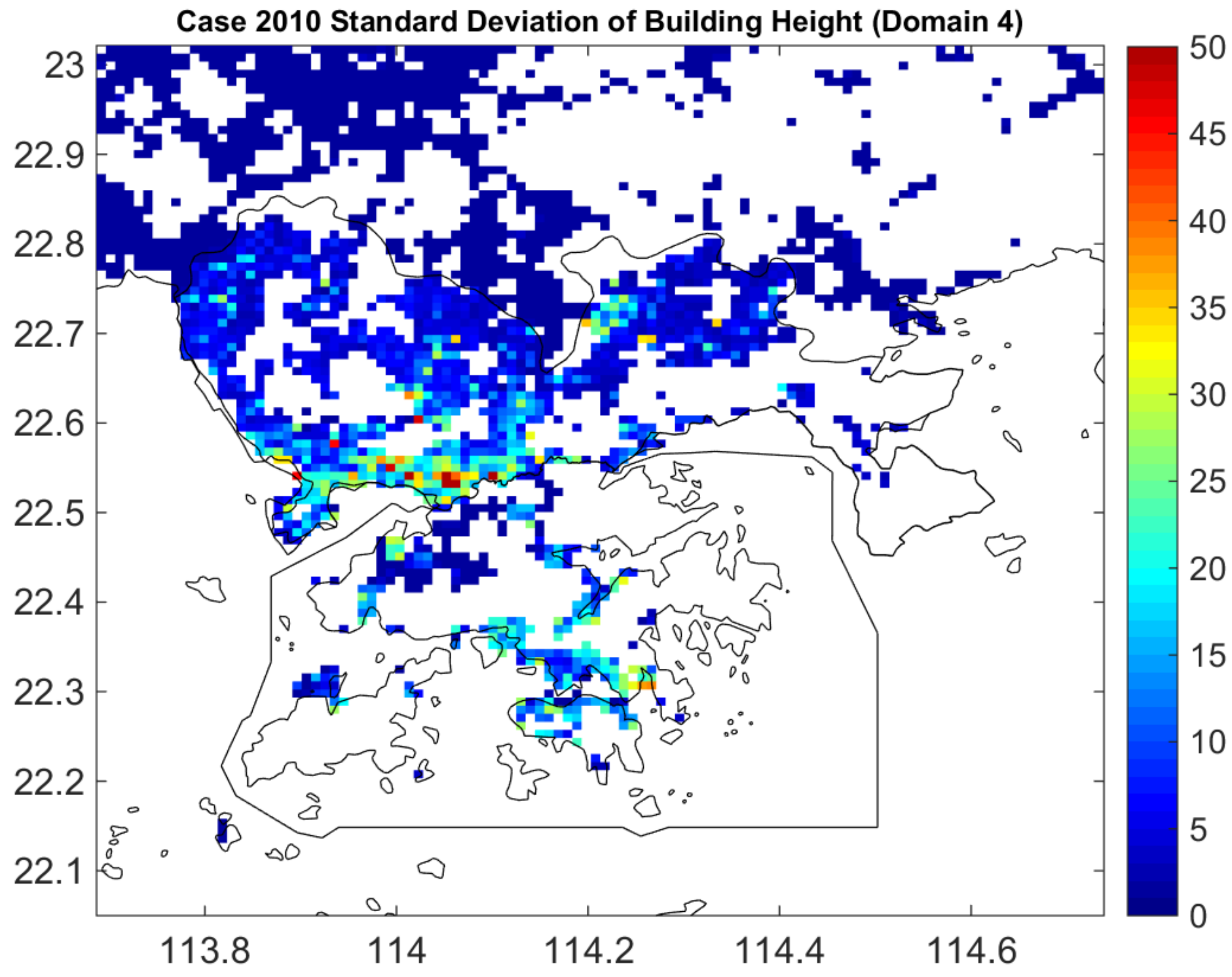

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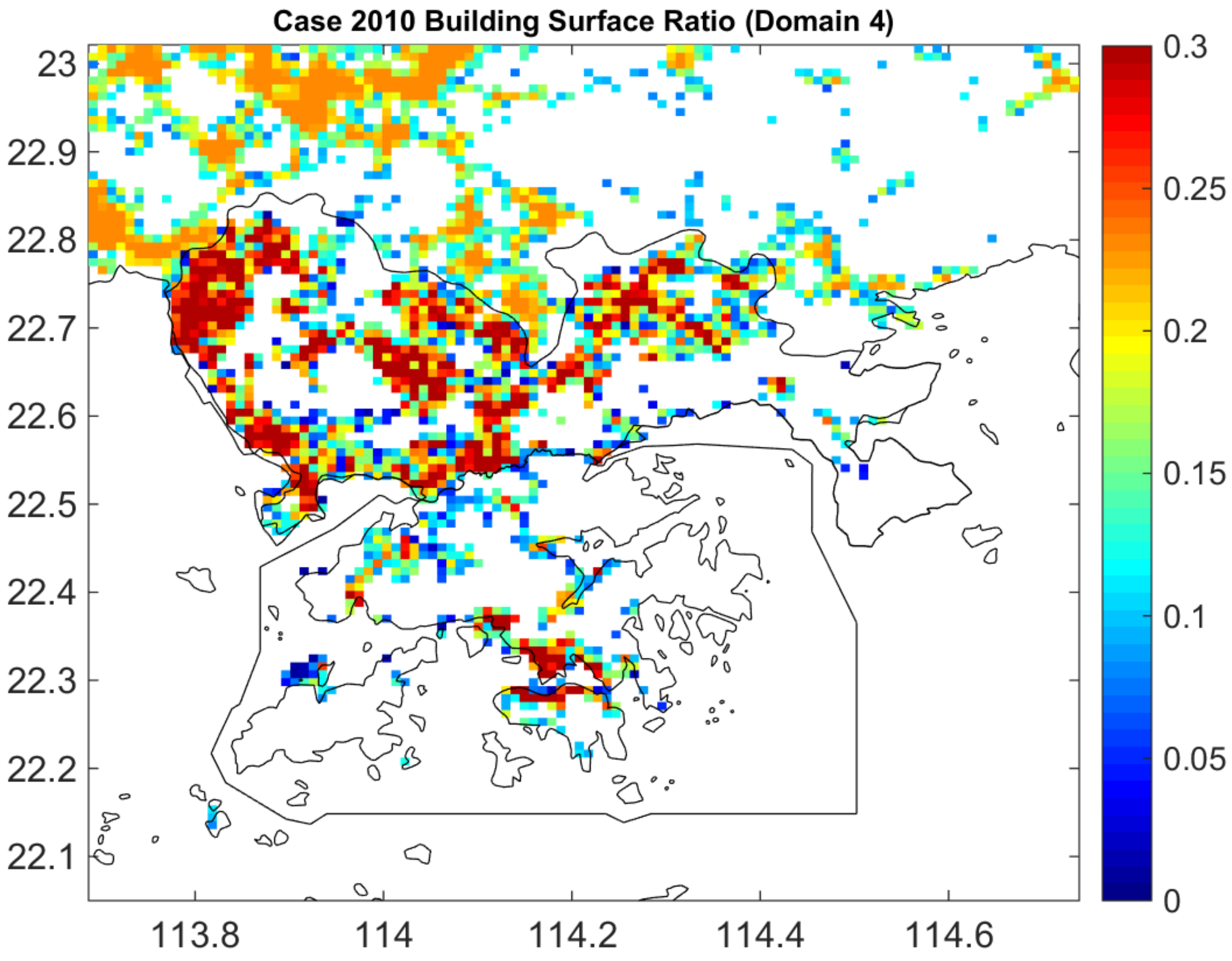
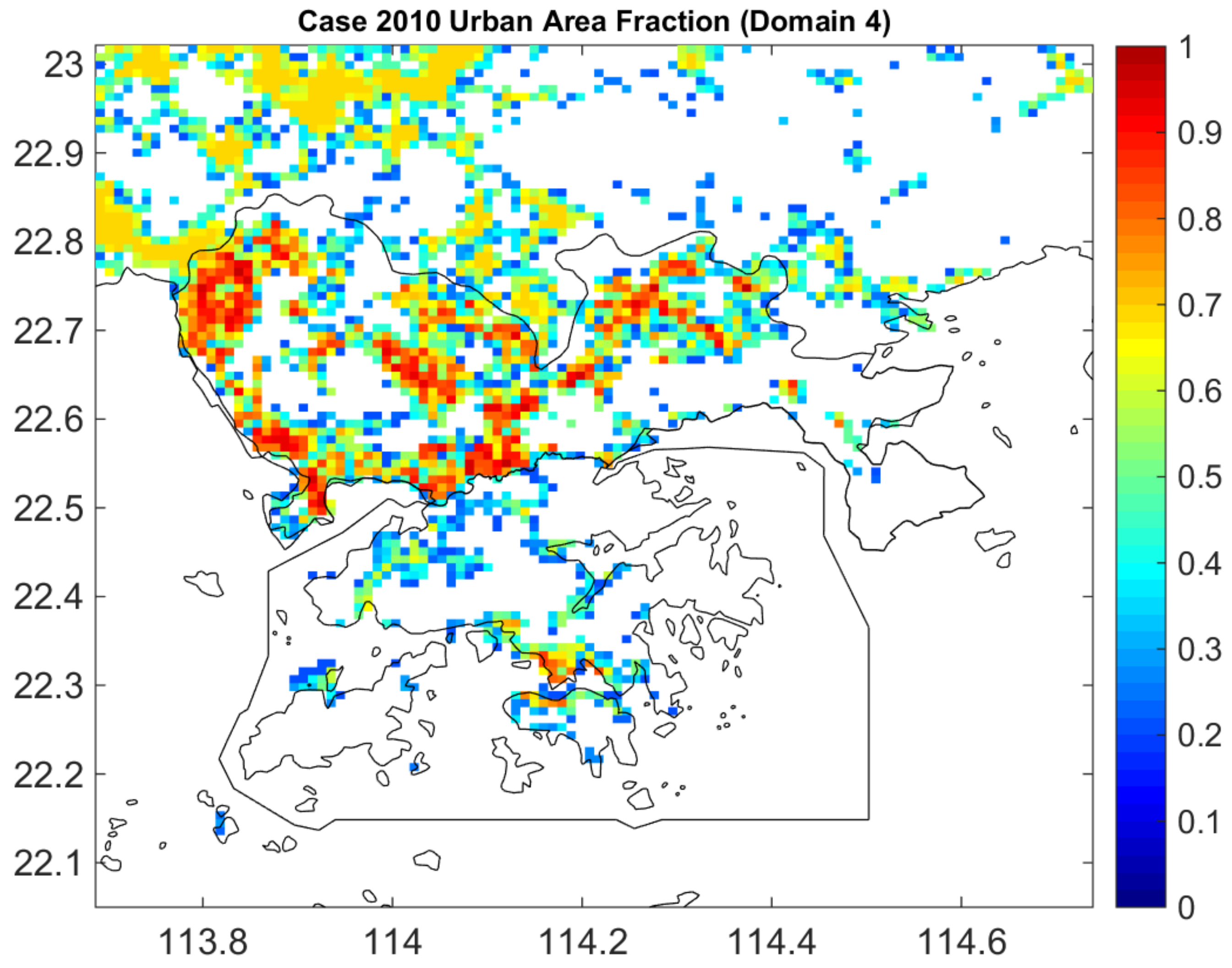
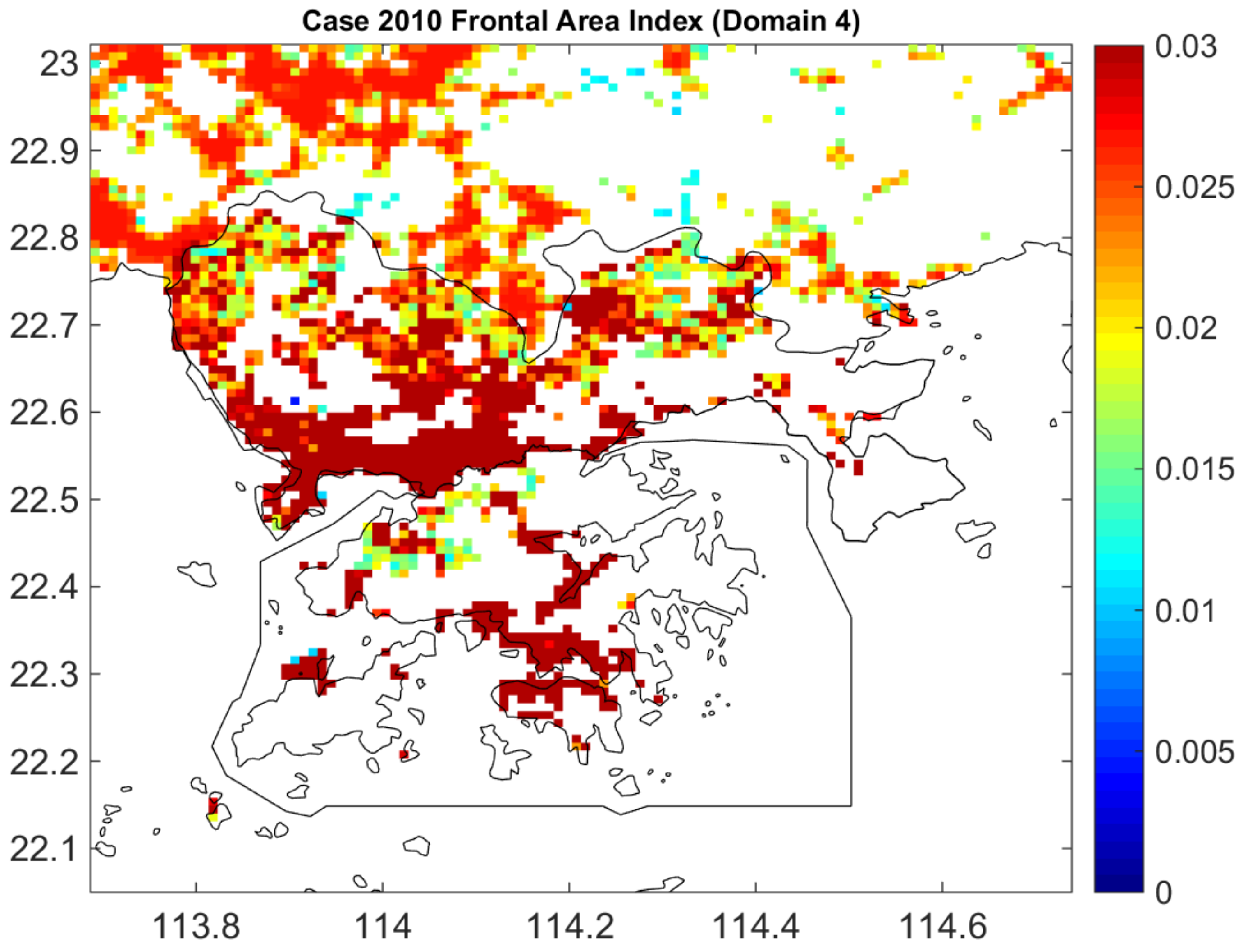




Technical Preparation – Data Preparation – Primary Data Processing



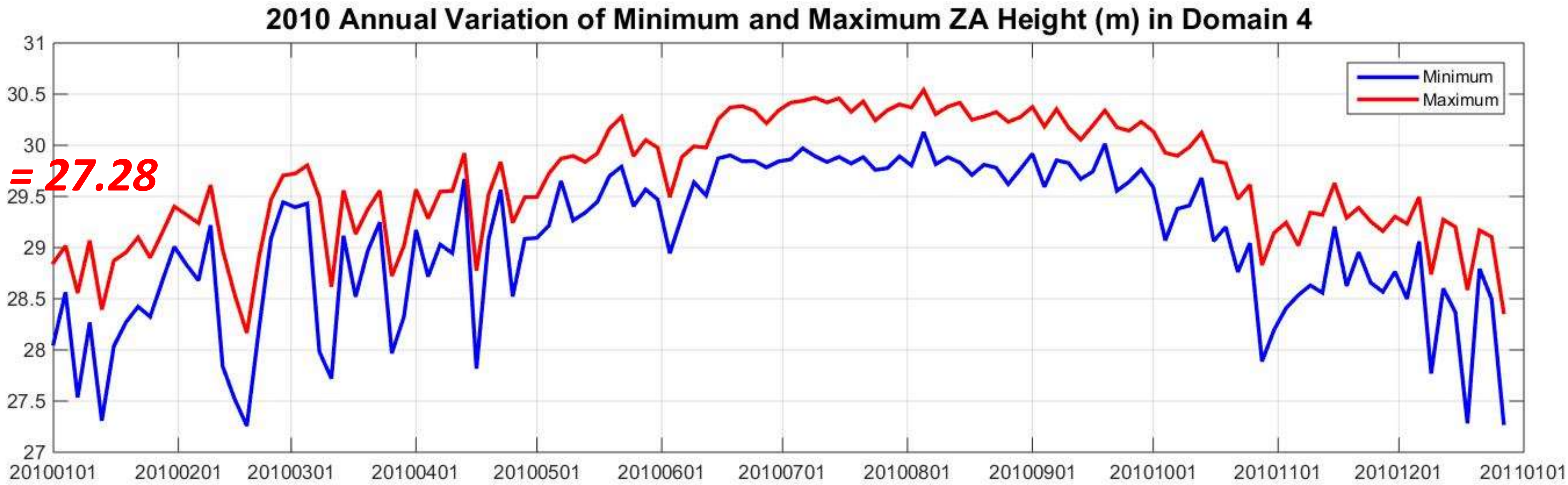
ZDC + *Z0C* + 2 >= *ZA*

The first atmospheric level height of WRF model

Roughness length above canyon for momentum

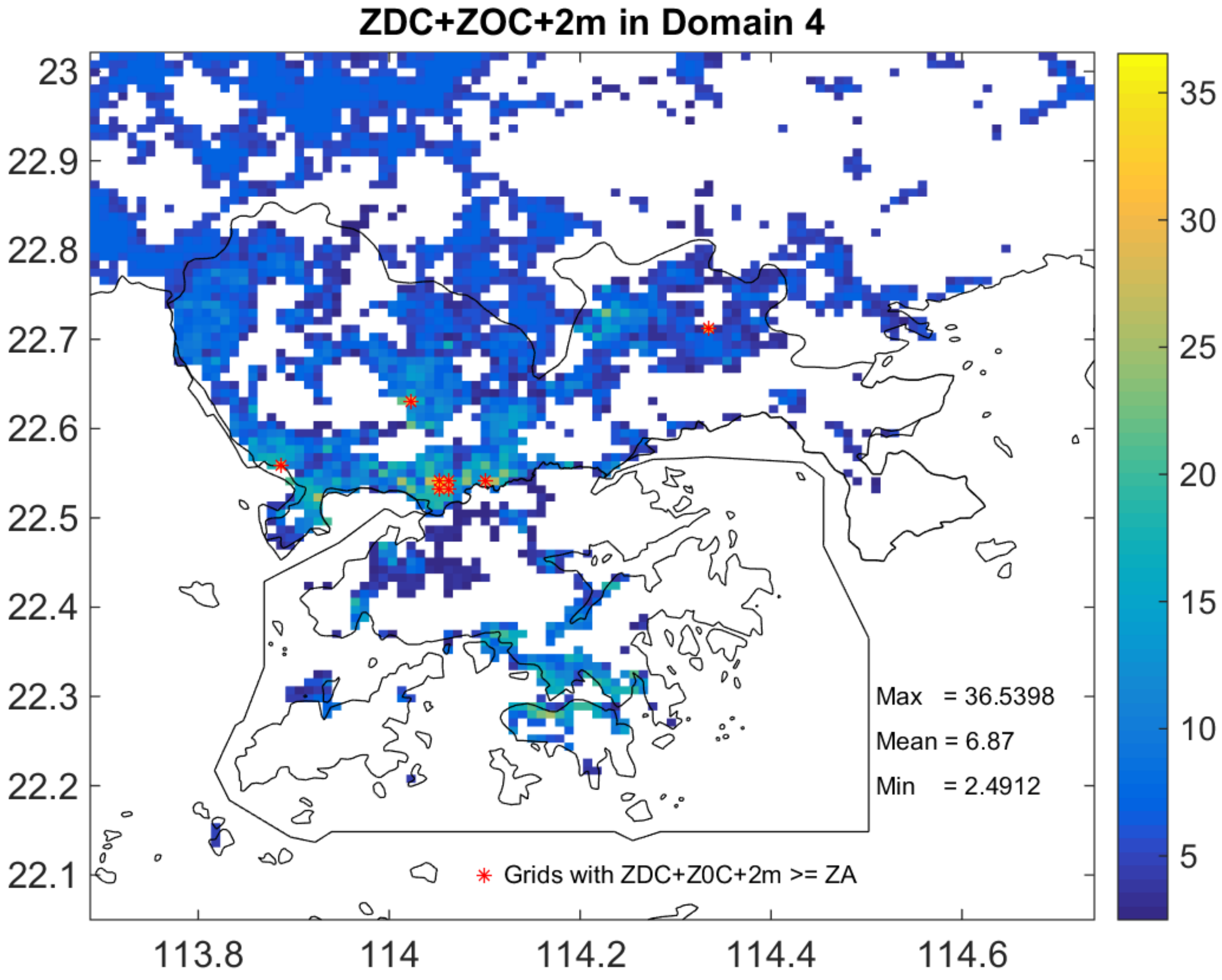
Zero plane displacement height

ZAmin = 27.28



ZDC + *Z0C* + 2 >= 27.28

Technical Preparation – Data Preparation – ZA Problems Processing



lon	lat	*MH_URB2D* (m)			*BUILD_HEIGT* (m)		*ZDC* (m)		*Z0C* (m)		*ZDC+Z0C+2m*		*ZA*	*ZA - (ZDC+Z0C+2m)*	
		orginal	cut %	new	original	new	original	new	original	new	original	new		original	new
114.05	22.53	44.21	**88%**	**38.91**	53.78	**47.32**	26.84	23.62	1.18	0.87	30.03	26.49	27.28	**-2.75**	**0.79**
114.06	22.53	51.31	**95%**	**48.75**	62.34	**59.22**	20.59	19.56	5.29	4.80	27.89	26.37	27.28	**-0.61**	**0.91**
114.05	22.54	66.89	**77%**	**51.50**	81.21	**62.53**	23.09	17.78	10.72	6.78	35.81	26.56	27.28	**-8.53**	**0.72**
114.06	22.54	51.86	**95%**	**49.27**	59.02	**56.07**	20.90	19.85	5.06	4.58	27.95	26.43	27.28	**-0.67**	**0.85**
114.10	22.54	47.26	**95%**	**44.89**	59.23	**56.27**	22.84	21.70	3.11	2.80	27.95	26.50	27.28	**-0.67**	**0.78**
113.89	22.56	53.83	**91%**	**48.98**	51.36	**46.73**	23.36	21.25	3.95	3.26	29.31	26.51	27.28	**-2.03**	**0.77**
114.02	22.63	60.48	**90%**	**54.43**	57.65	**51.88**	20.34	18.31	7.74	6.37	30.08	26.68	27.28	**-2.80**	**0.60**
114.33	22.71	65.92	**87%**	**57.35**	69.56	**60.51**	10.00	8.70	19.37	15.61	31.36	26.30	27.28	**-4.08**	**0.98**

Observation Datasets	Sources
2010 PRD Precipitation	Department of Geography & Resource Management, The Chinese University of Hong Kong
2010 PRD 10 m Wind Speed	
2010 PRD Relative Humidity	
2010 PRD Short Wave Radiation	
2010 PRD 2 m Air Temperature	
MODIS/Aqua Land Surface Temperature and Emissivity (LST/E) product	NASA EOSDIS Land Processes DAAC, USGS Earth Resources Observation and Science (EROS) Center

Modeling Variables for Model Evaluation		Corresponding Observation Datasets
Name	Description	
RAINC	Accumulated Total Cumulus Precipitation	2010 PRD Precipitation
RAINNC	Accumulated Total Grid Scale Precipitation	
U10	U at 10 M	2010 PRD 10 m Wind Speed
V10	V at 10 M	
RH2	2 m Relative Humidity	2010 PRD Relative Humidity
SWDOWN	Downward Shortwave Flux at Ground Surface	2010 PRD Short Wave Radiation
T2	TEMP at 2 M	2010 PRD 2 m Air Temperature
TSK	Surface Skin Temperature	2010 Surface Temperature

Perkins Skill Score (PSS)

This is used for revealing quantifiably the extent of overlap between the observed and modeled variables' Probability Density Function (PDF). 1 : a perfect simulation 0 : a worst simulation.

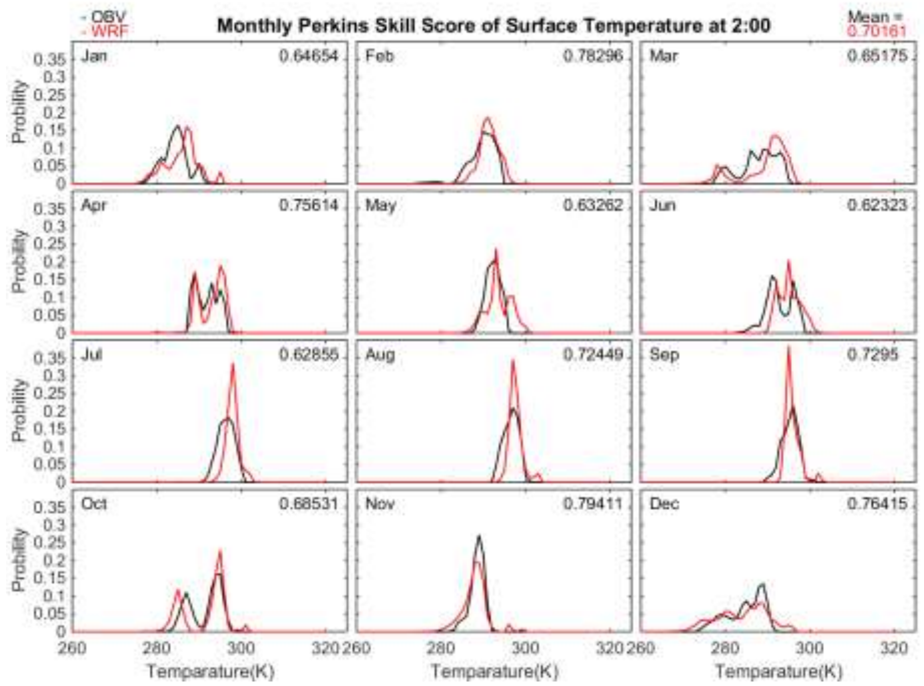
Temporal Comparison of Spatial Variation

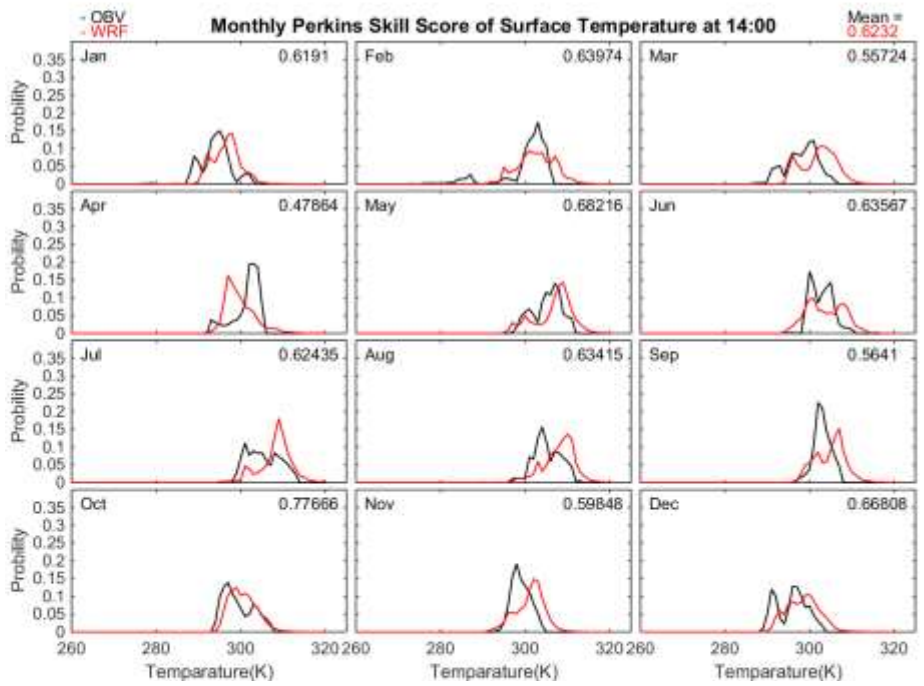
This compares the modeled and observed variables' spatial variation ranges and median at the temporal dimension.

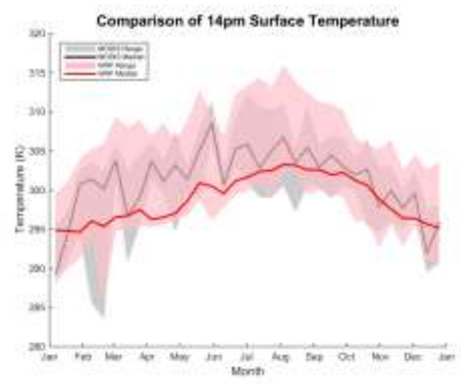
Difference Probability Density Function (PDF)

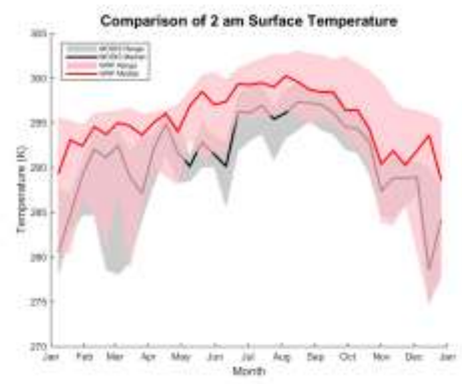
This shows the probability density to the extent to which modeled variable diverges from the corresponding observed one.

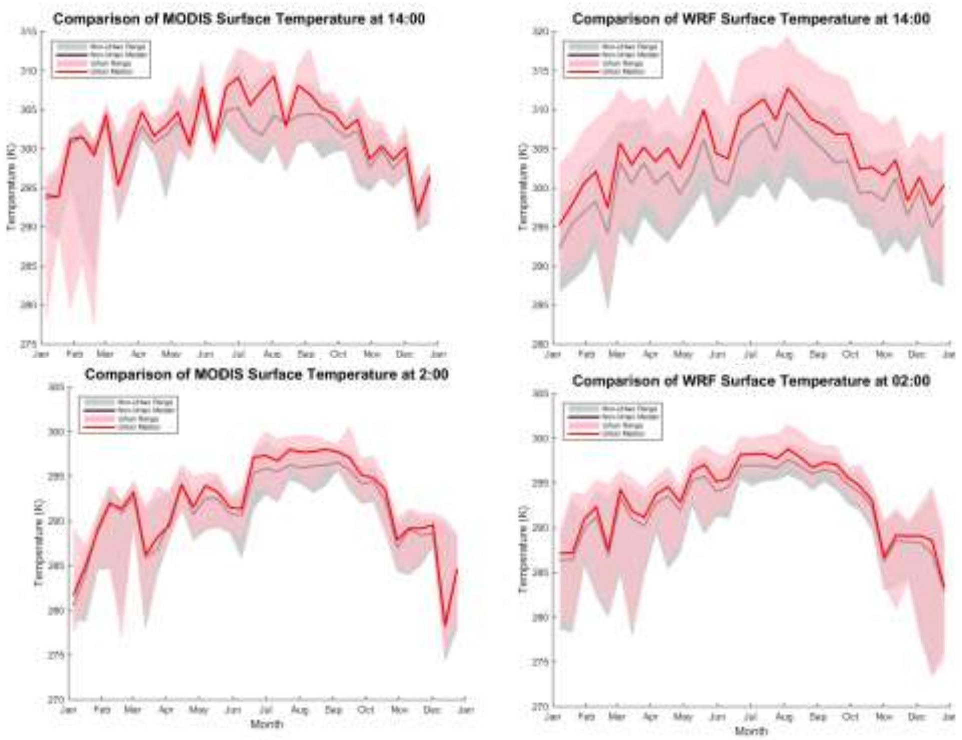
Model Evaluation and Conclusions – Model Evaluation – Surface Temperature

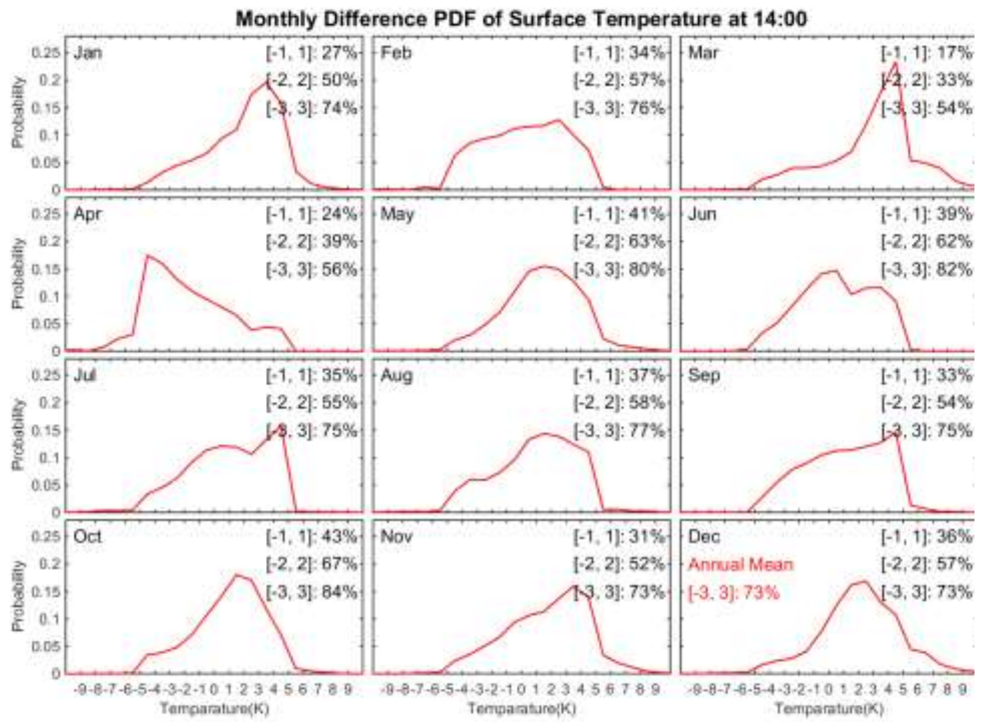


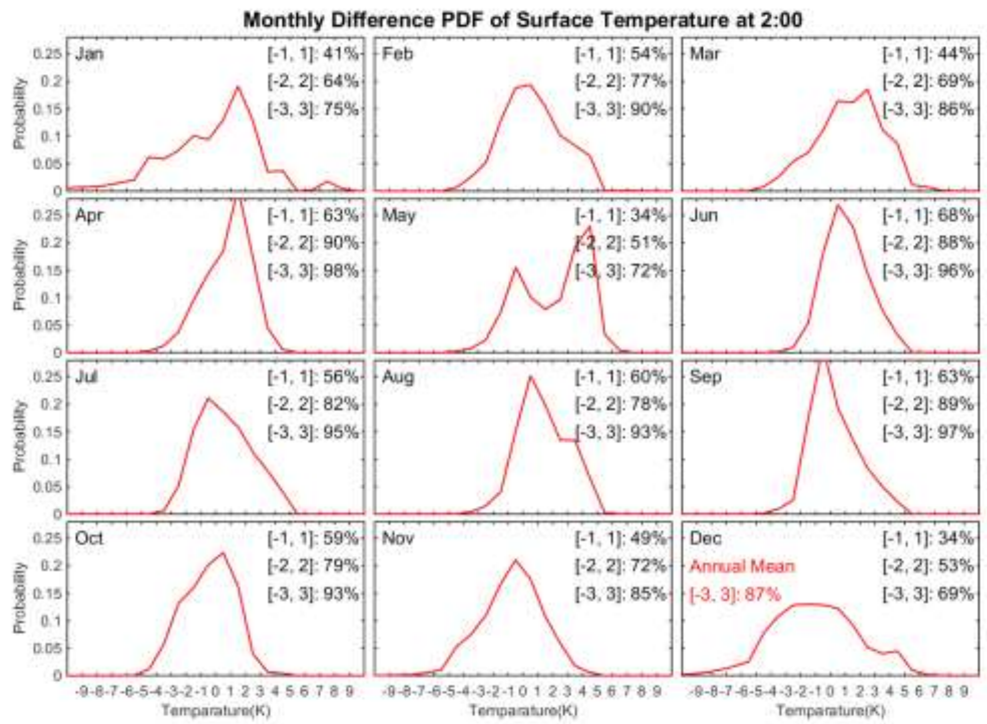






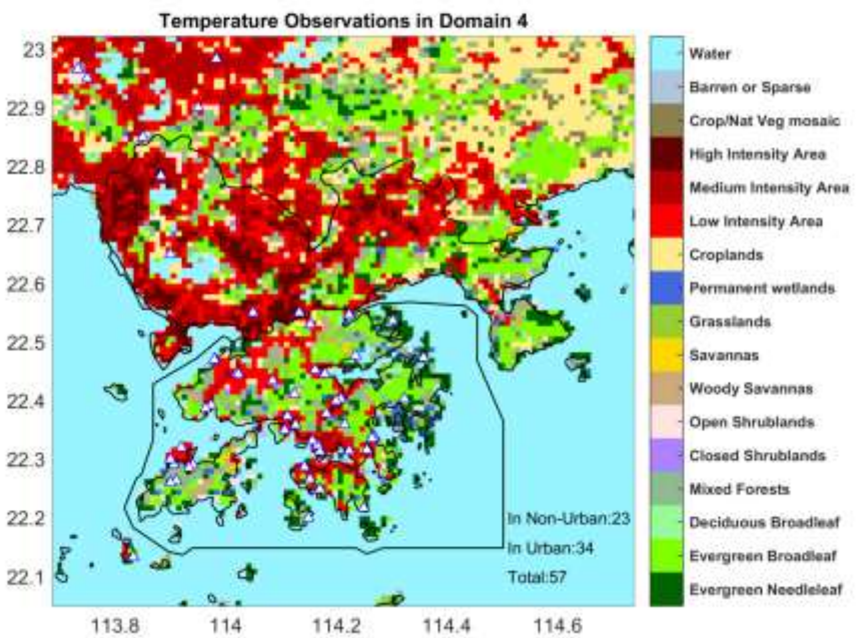


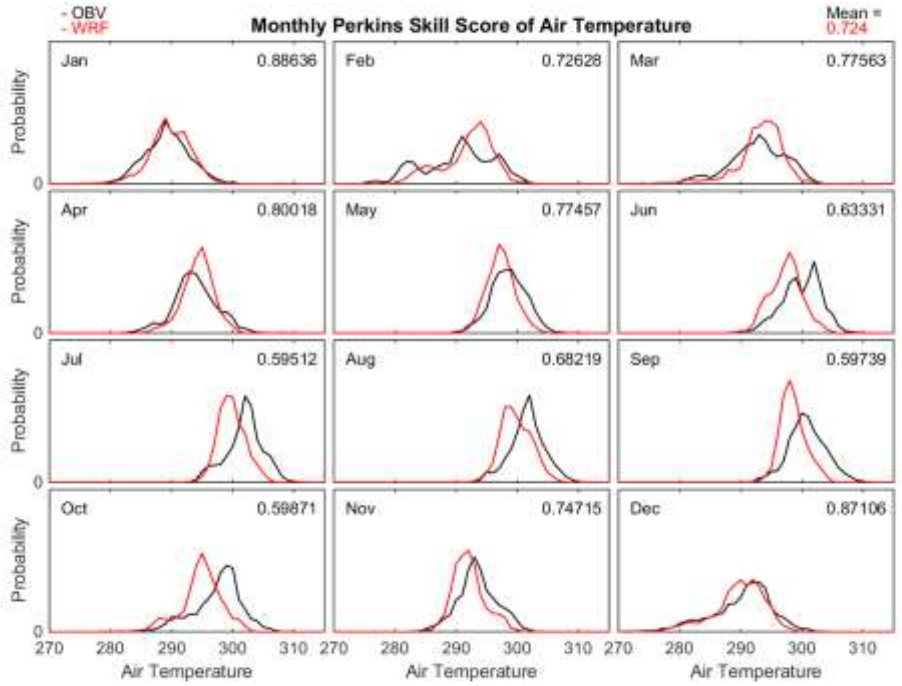


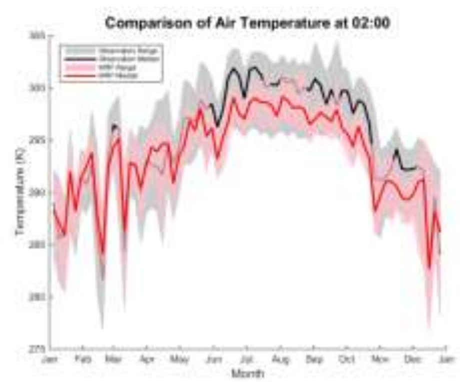


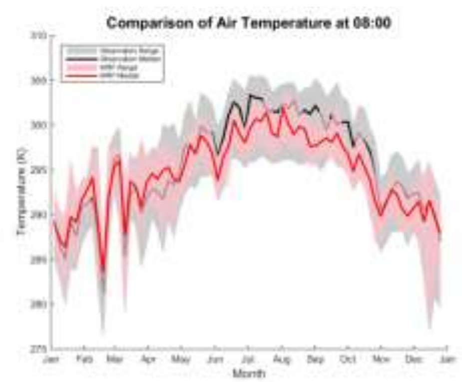
The modeled surface temperatures represent the corresponding MODIS ones with an acceptable Perkins Skill Score and also have the same annual variation and the same urban climatological spatial patterns as that of the MODIS ones.

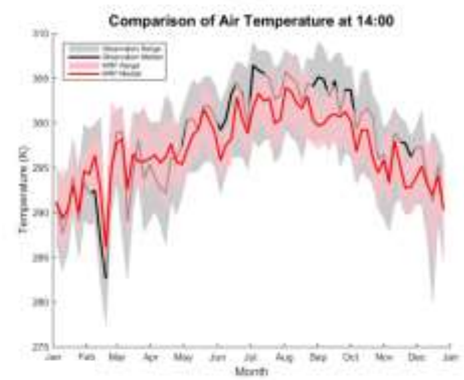
Model Evaluation and Conclusions – Model Evaluation – 2m Air Temperature

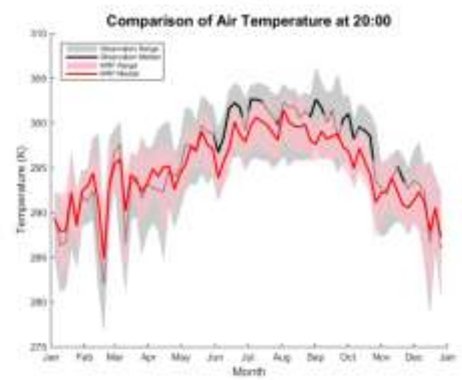


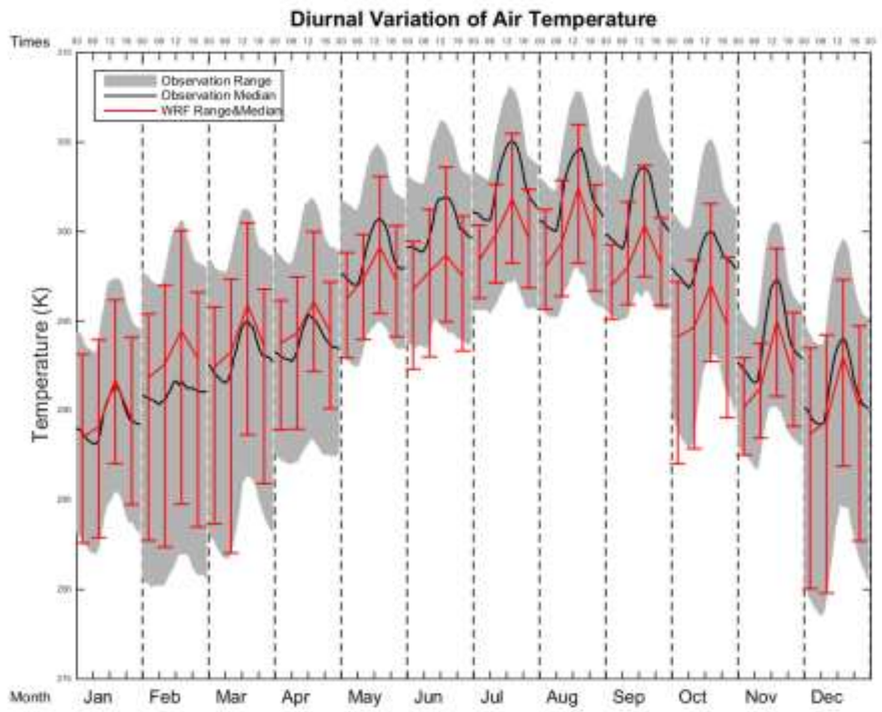


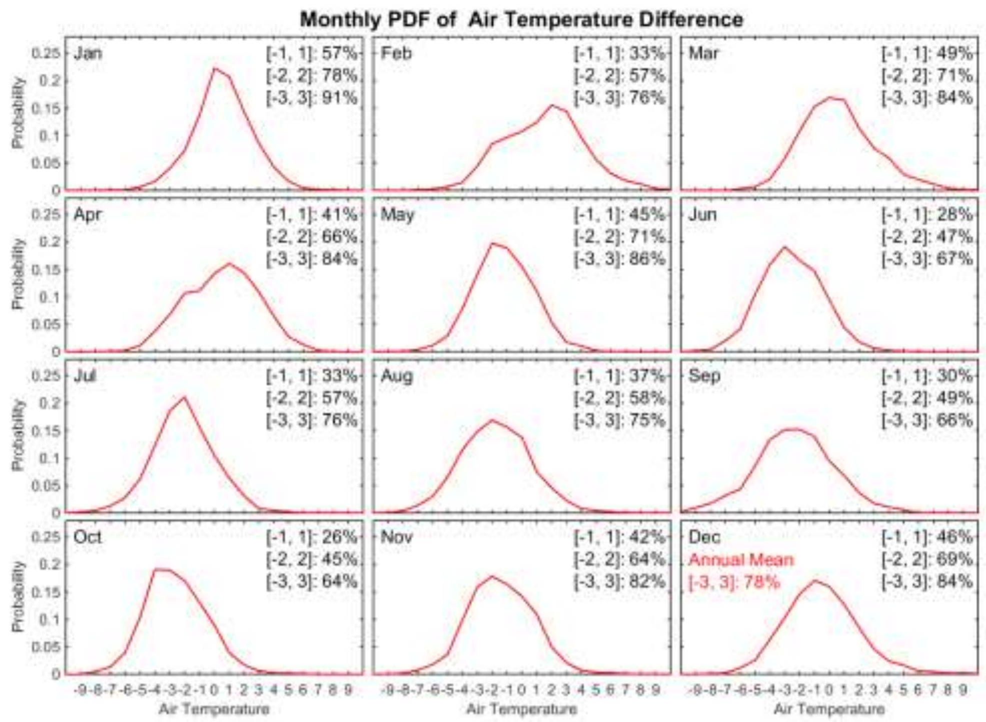






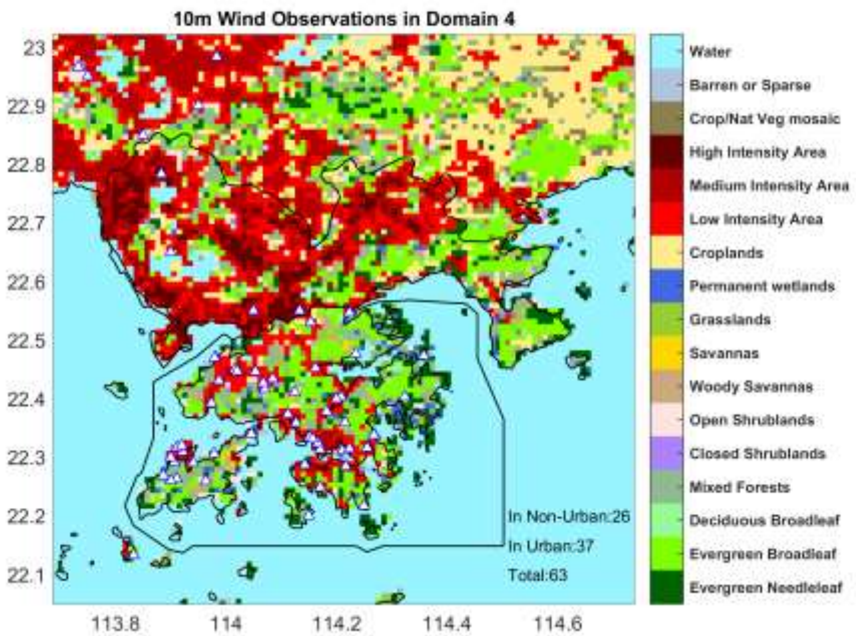


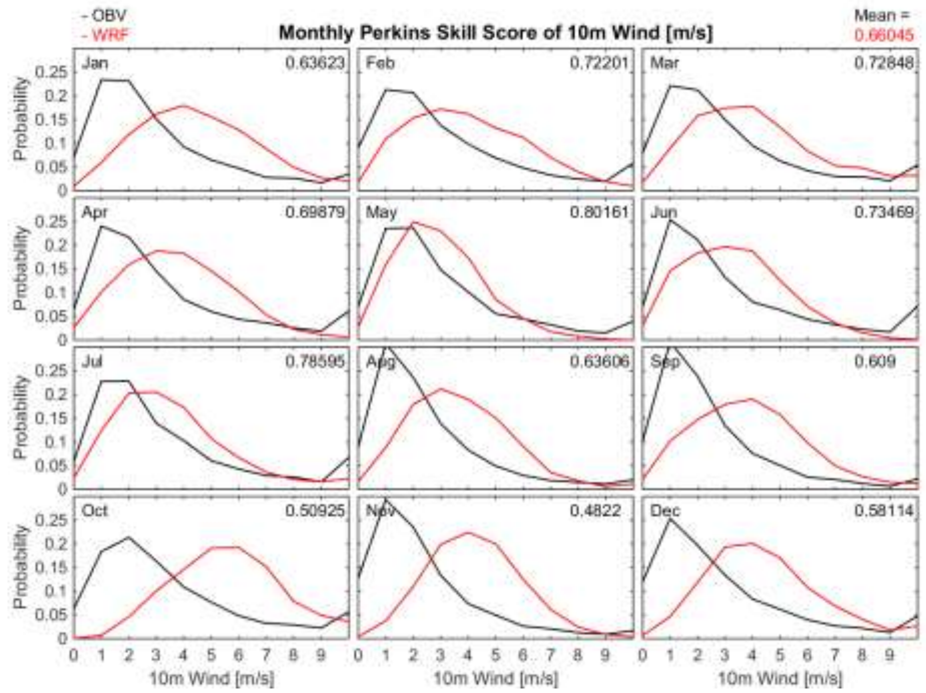


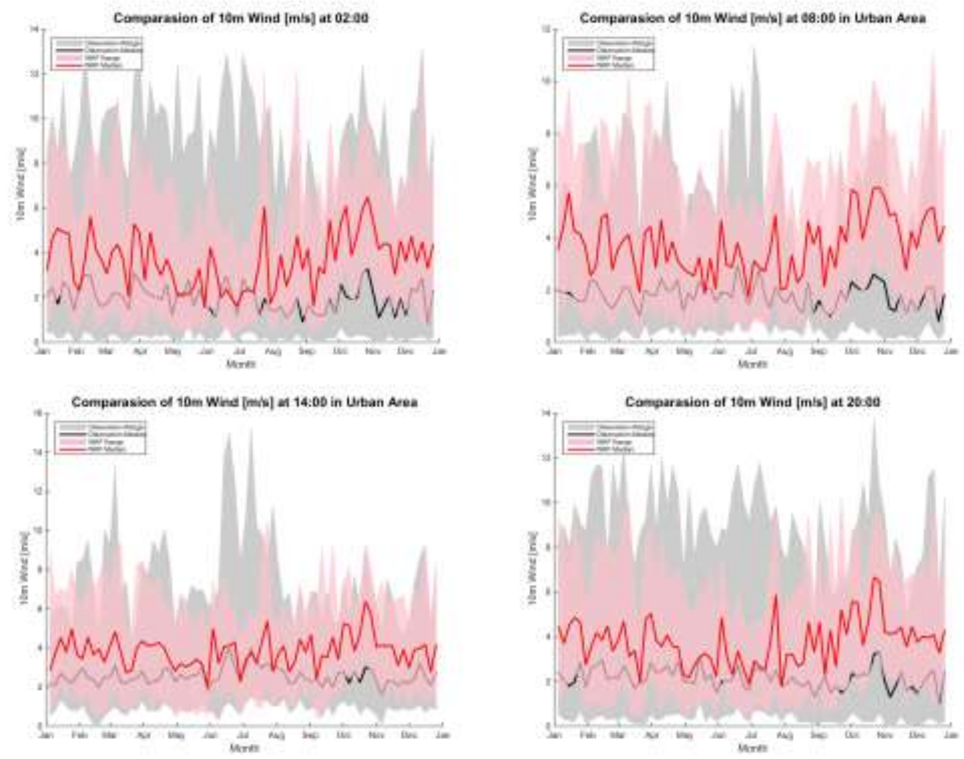


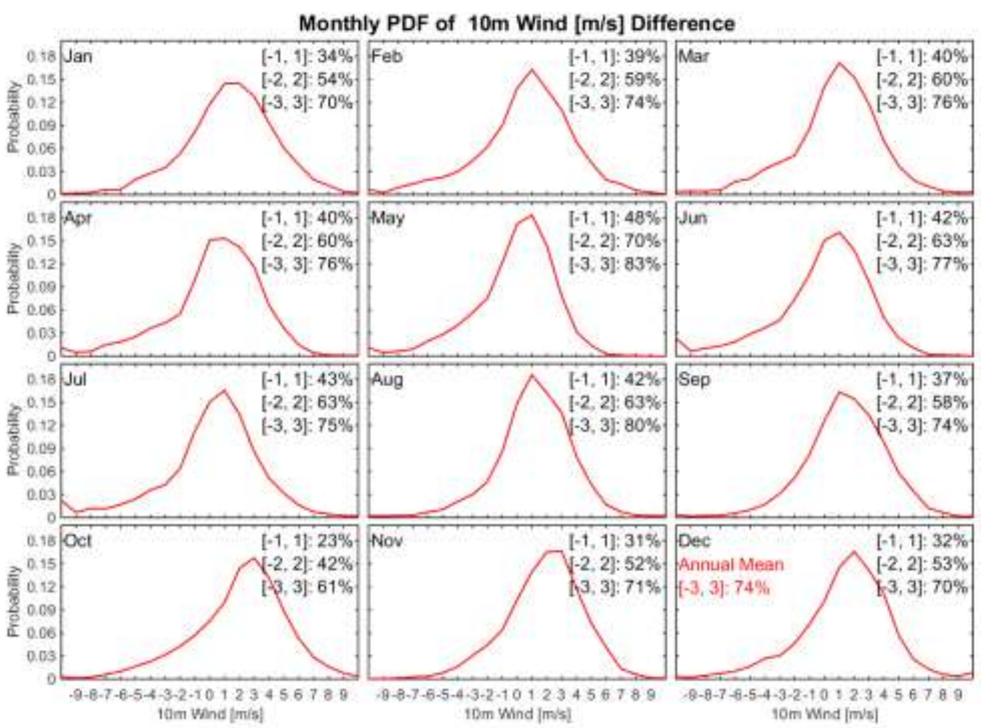
The model produced quite a good simulation of 2-meters air temperature with annual mean Perkins Skill Score of 0.724. It also captured the behaviors of monthly and diurnal variation of observed 2-meters air temperatures.

Model Evaluation and Conclusions – Model Evaluation – 10m Wind Speed



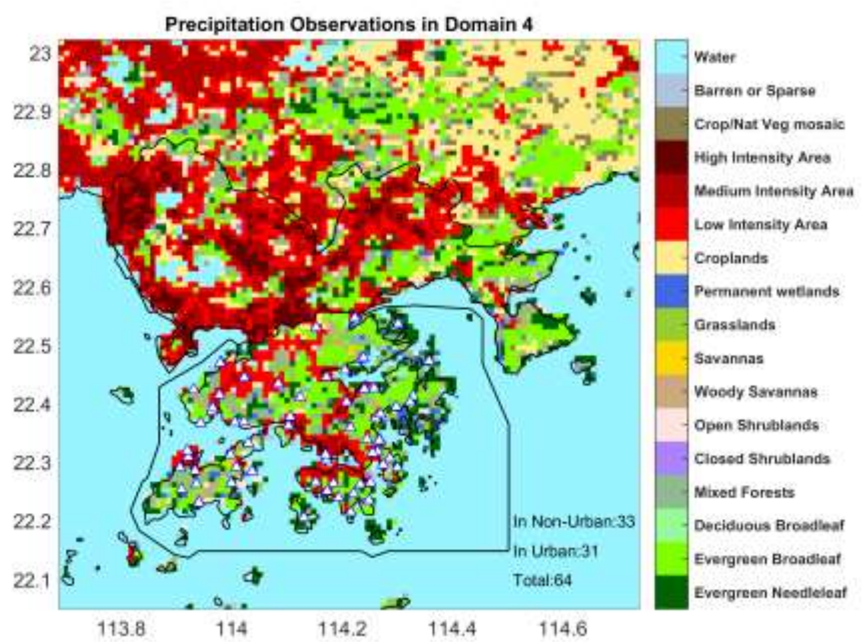


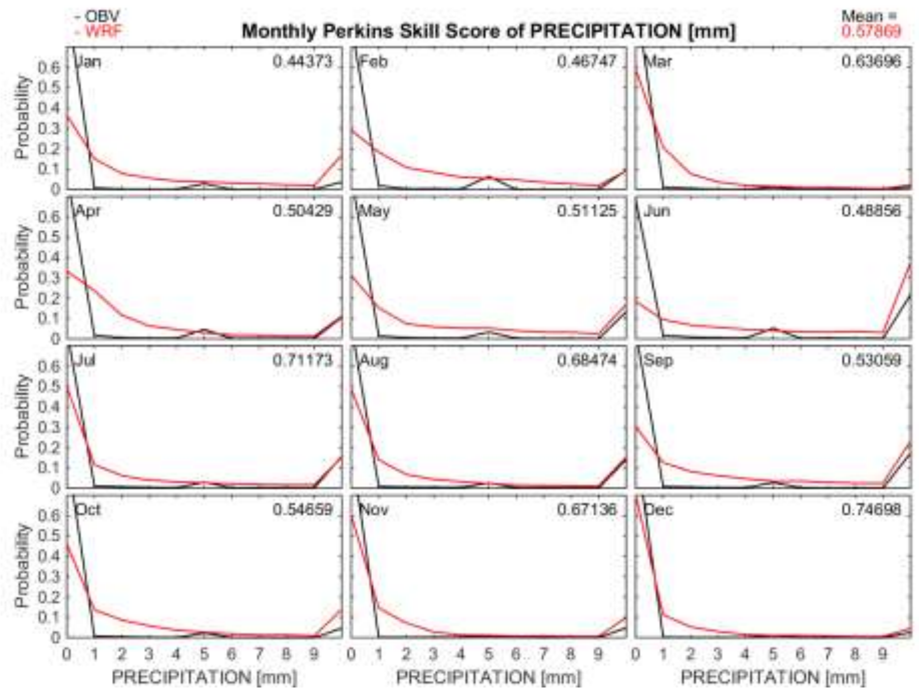


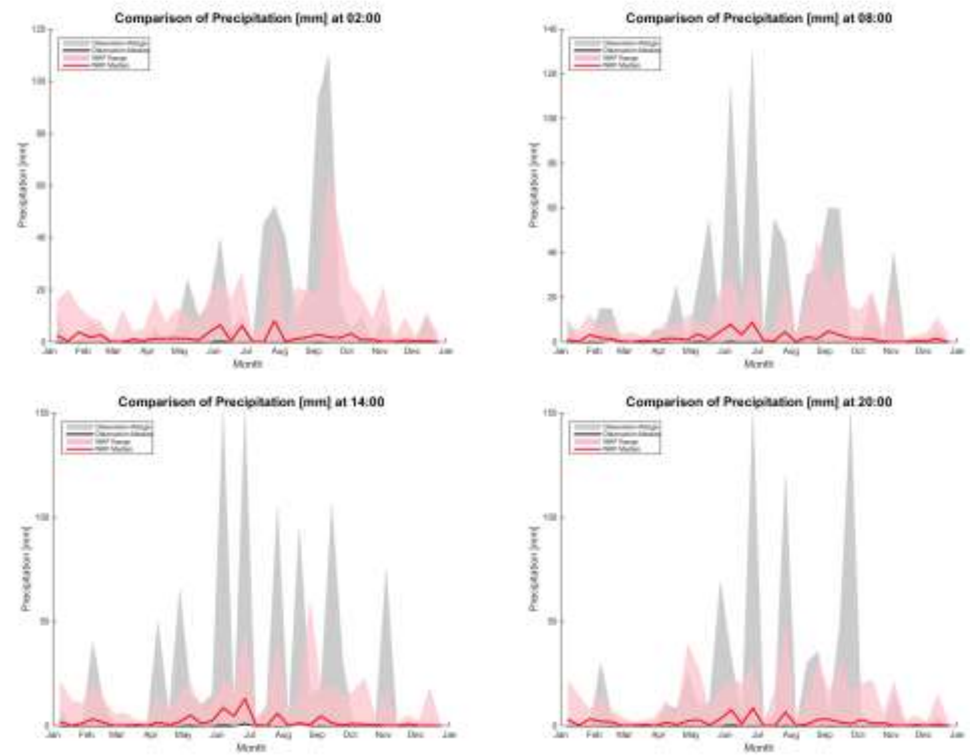


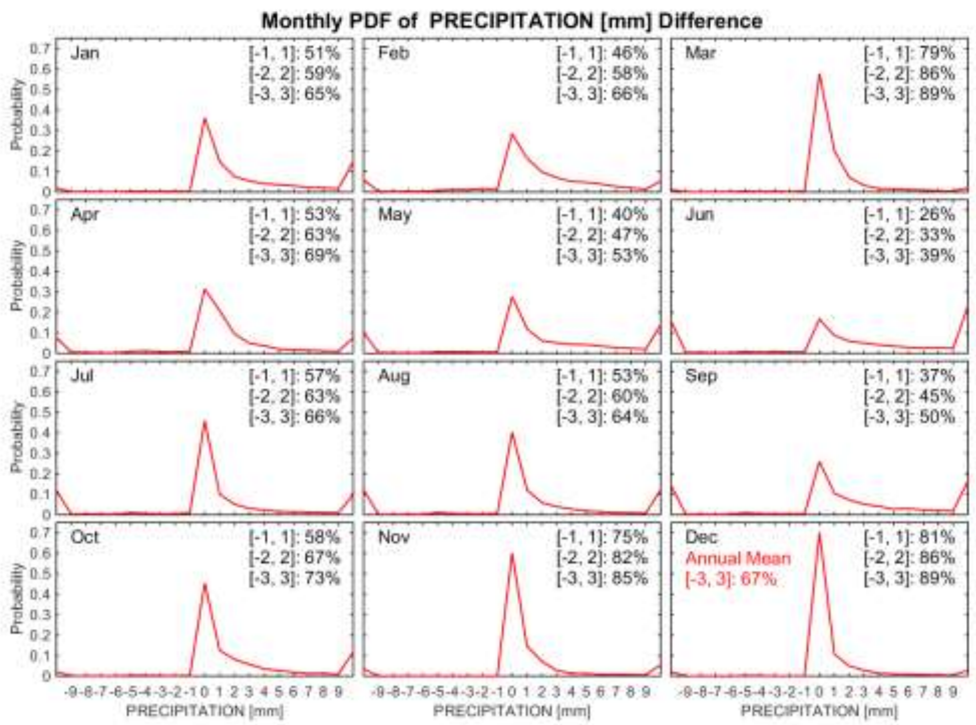
The model simulated the 10-meters wind speed with acceptable Perkins Skill Score. The modelled ones of 10-meters wind speed also have the same annual variation as that of the observed ones.

Model Evaluation and Conclusions – Model Evaluation – Precipitation



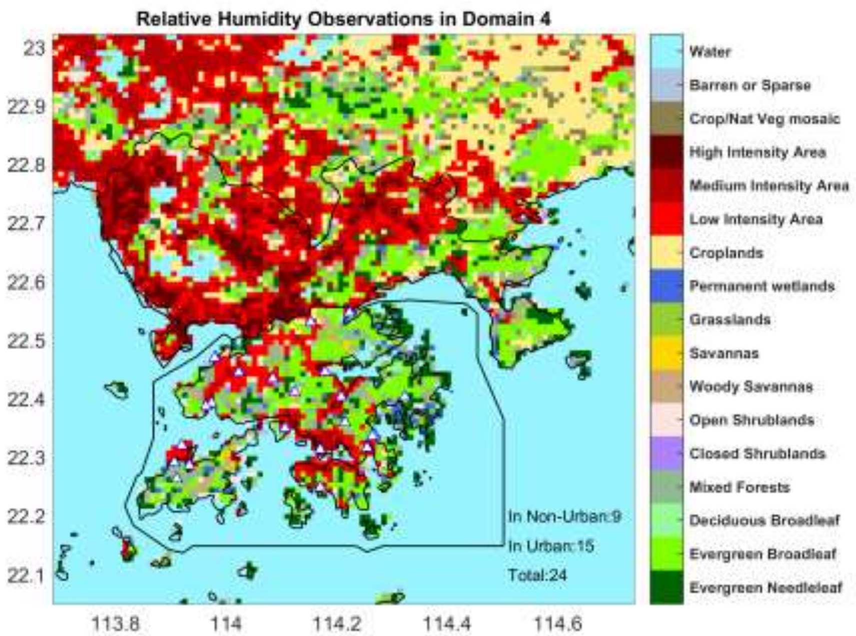


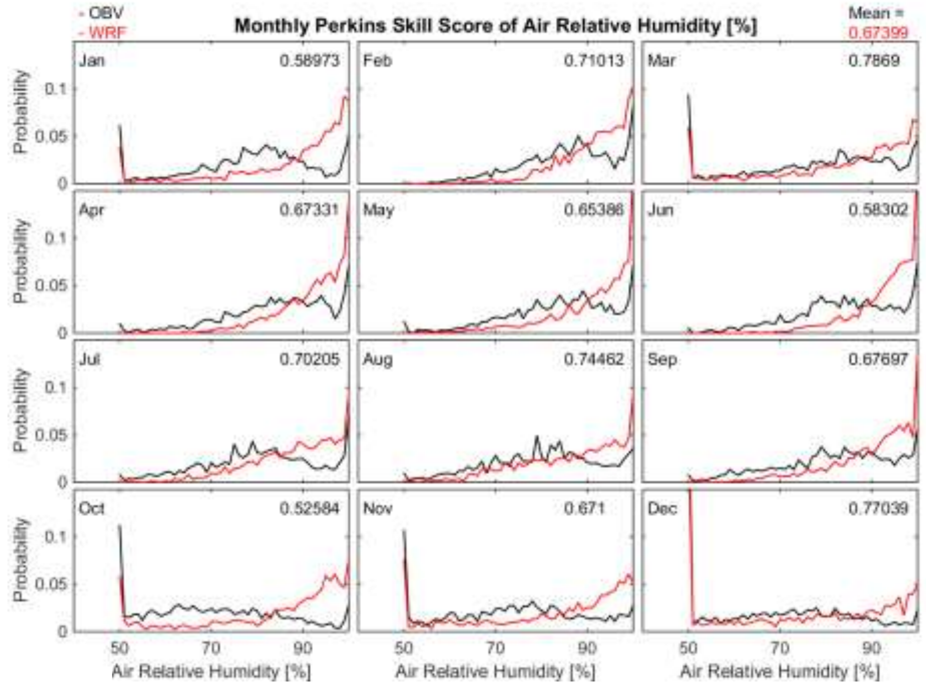


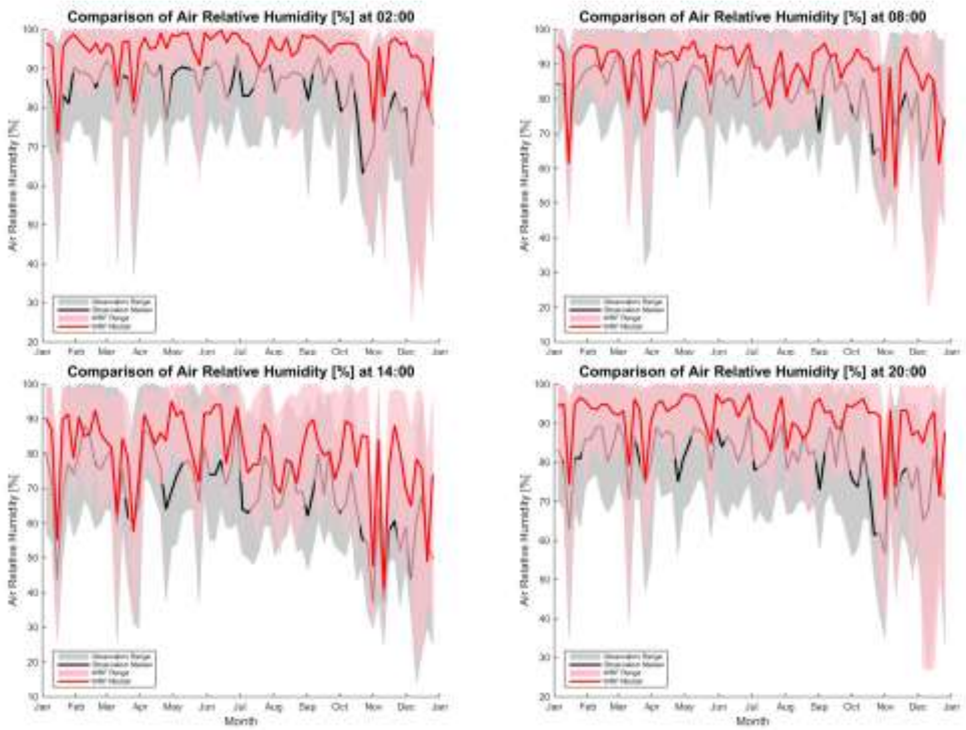


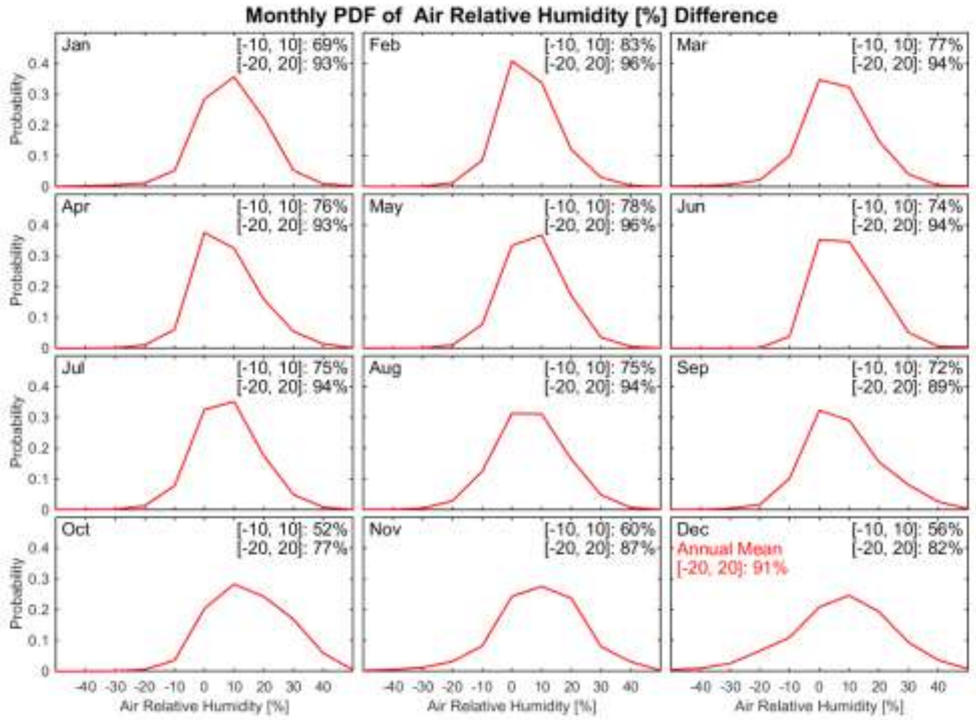
Based on the comparison of experiments and observations with respect to the modelled and observed measurements of precipitation, a well-grounded conclusion is provided that the model simulated the precipitation with an acceptable Perkins Skill Score. Moreover, the modelled precipitations also have the same annual variation as that of the observed ones.

Model Evaluation and Conclusions – Model Evaluation – Relative Humidity



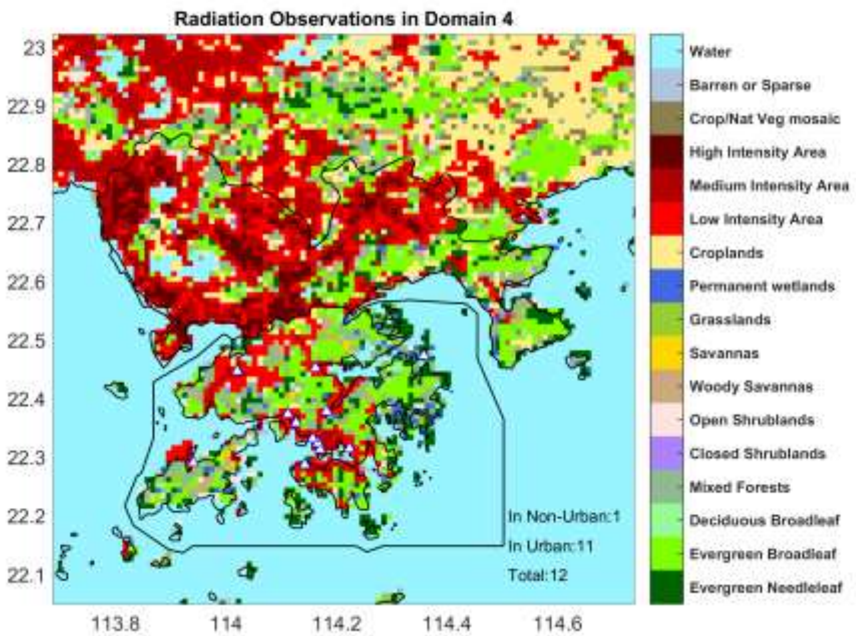


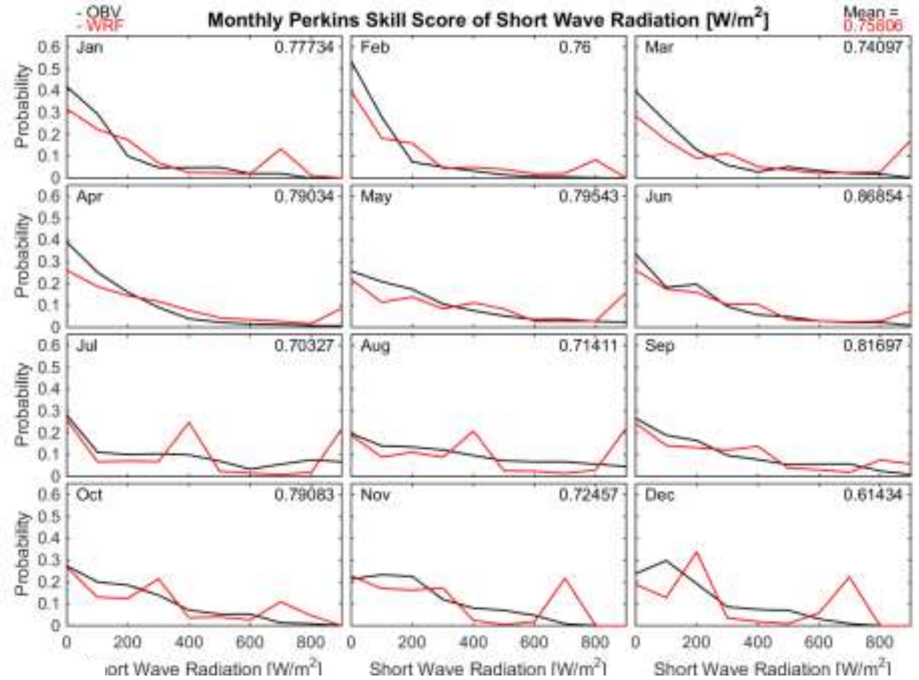


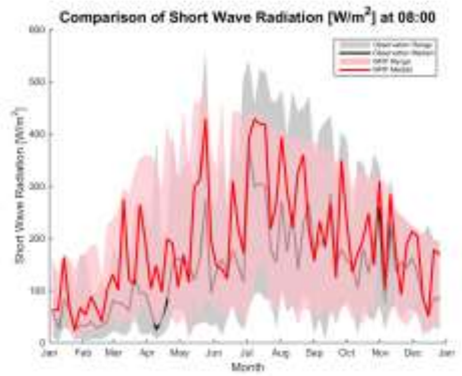


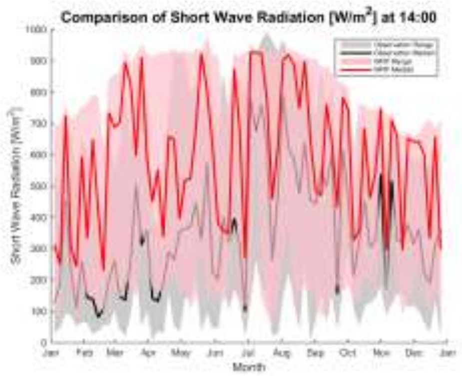
The model can simulate the relative humidity with an acceptable Perkins Skill Score and accuracy and also appropriately simulate the monthly variation pattern of relative humidity.

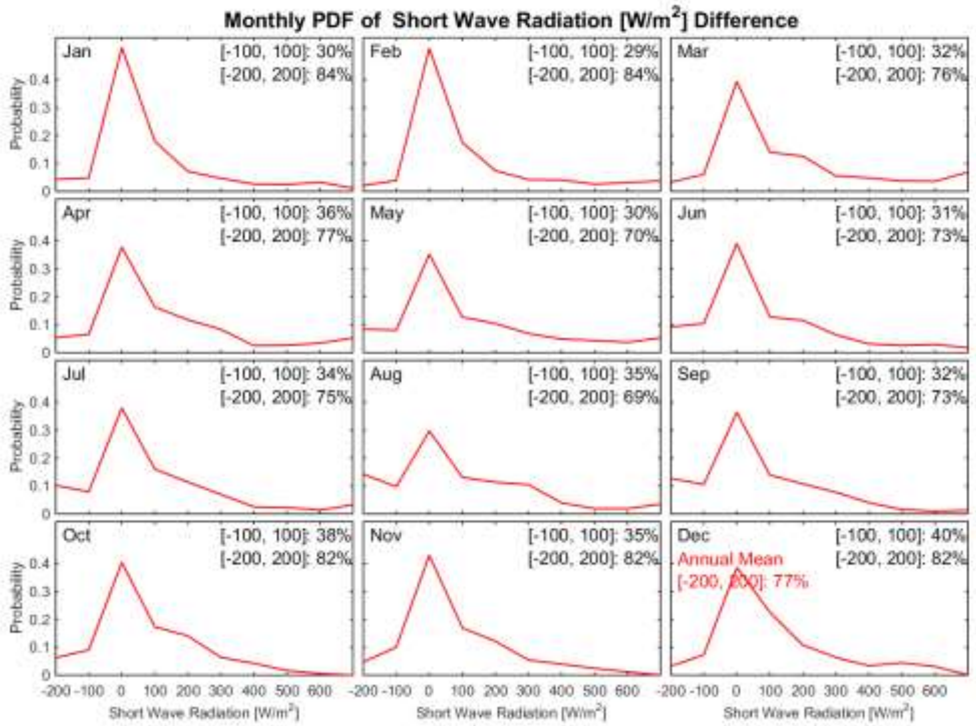
Model Evaluation and Conclusions – Model Evaluation – Downward Shortwave











The model can simulate the downward shortwave radiation with an acceptable Perkins Skill Score and accuracy and also appropriately simulate the monthly variation pattern of downward shortwave radiation.

Meteorological Features

This atmospheric model appropriately portrayed the annual variations in climatological patterns of air temperature, surface temperature, 10 m wind speed, air relative humidity, and downward shortwave radiation shown by above its figures of temporal comparison of spatial variation, and accordingly there is a similarity of temporal and spatial features between the modelling results and observations. It means that the model captured the temporal and spatial meteorological features of urban climate.

Simulation Accuracy

The model also achieved at least an acceptable Perkins skill score and accuracy in the simulations of 2 m air temperature, surface temperature, 10 m wind speed, precipitation, air relative humidity, and downward shortwave radiation.

Model Evaluation and Conclusions – Conclusions

Simulation Accuracy

The model bias cannot be identified from the difference which includes the natural gap, observation bias and the model bias, and accordingly, the model accuracy cannot be assessed precisely.

Focus of Model Evaluation

A model can simulate a resonance with the natural system (Oreskes et al. 1994). Therefore, a model evaluation should aim at assessing the similarity of temporal and spatial features between the modelling results and observations.

Methodological Framework

(1) Two elements: observation datasets and its corresponding modelled variables.

(2) Two aspects: the similarity of temporal and spatial features between the modelling results and observations, and the degree of difference between the modelled variables and its corresponding observed ones.

(3) Three tools: Perkins Skill Score (PSS), Temporal Comparison of Spatial Variation, and Probability Density Function (PDF) of Difference.

The end

Research Background → Methodology → Technical Preparation → Model Evaluation and Conclusions

Thank you for listening, Any questions?

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