Interaction of Singapore and Johor Bahru on Urban Climate during Monsoon Seasons

Jochen Kraus[1], Andhang Rakhmat Trihamdani[2], Tetsu Kubota[2], Han Soo Lee[3], Kensuke Kawamura[2]

[1]Institute for System Science, Innovation and Sustainability Research, University of Graz, Austria
[2]Graduate School for International Development and Cooperation, Hiroshima University, Japan
[3] Graduate School of Science and Engineering, Saitama University, Japan

Introduction

Background

Urban development in rapidly urbanizing regions, such as Southeast Asia, requires comprehensive planning and consideration of local characteristics. Tropical and subtropical cities, with their high temperatures and humidity, are particularly affected by increasing air temperature in relatively densely built-up areas. Increase in air temperature is in turn associated with higher cooling loads and hence higher energy consumption. Many major cities developed therefore strategies to ensure sustainable urban development. However, in regard to urban climate, proposed development strategies are limited to the borders of the city or the country. A comprehensive understanding of interactions between two major cities on their urban climate needs further investigation.

Objective

- Assess the interaction between the development in Singapore and Johor Bahru on the urban climate and the formation of Urban Heat Island
- Consideration of characteristic wind flow pattern in the research region during monsoon seasons
- Provide some understanding on cross-boundary mitigation strategies in tropical cities

Monsoon Characteristics

Southwest (SW) Monsoon:
- From June to September
- Prevailing wind direction from southwest

Northeast (NE) Monsoon:
- From November to March
- Prevailing wind direction from northeast

Intermonsoon:
- Variable direction
- Light wind flow

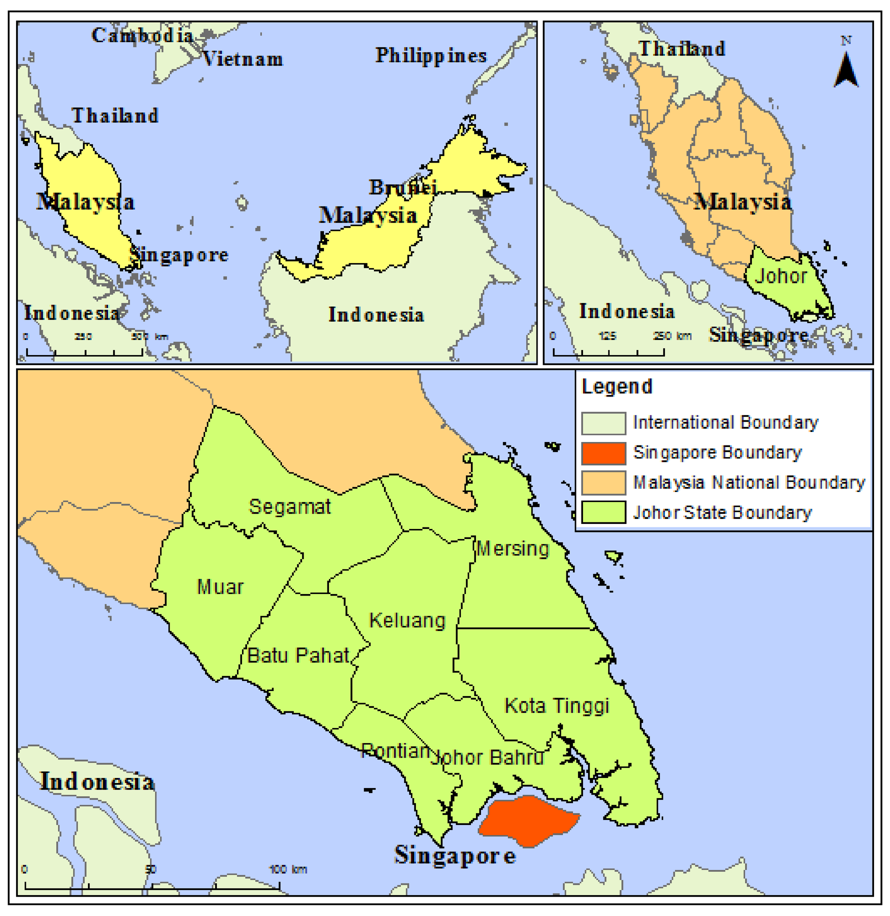

Figure 1: Geographic location of the research area

Methodology

Methodological Framework

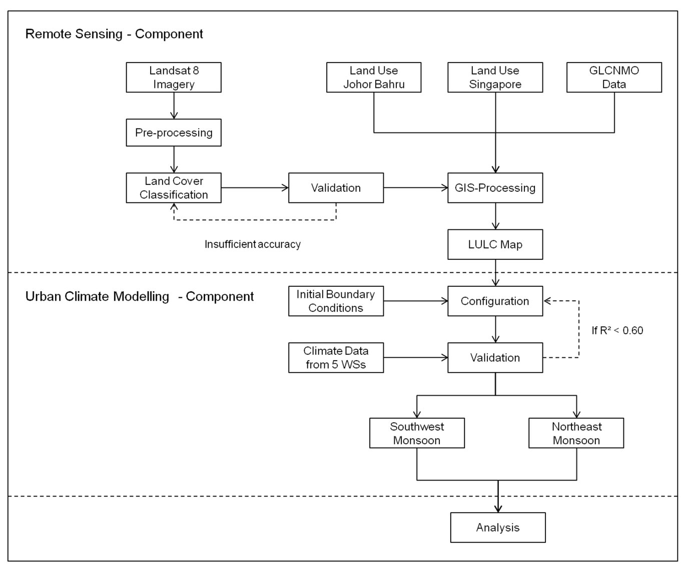

Figure 2: Methodological approach

Urban Climate Model

- Weather Research and Forecasting (WRF) model (version 3.6.1) with integrated Advanced Research WRF (ARW) dynamics solver
- Grid cell resolution = 0.5 km, vertical resolution = 30 layers

Table 1: WRF parameters and configuration for domain 1 to 4

	Domain 1	Domain 2	Domain 3	Domain 4
Resolution	13.5 km	4.5 km	1.5 km	0.5 km
Domain Size	204×204×30	204×204×30	198×198×30	204×204×30
WRF Version	WRF ARW v. 3.6.1			
Land use/cover Data	GLCC	GLCC	GLCNMO	Landsat 8
Initial Boundary Condition	GRIB1 NCEP FNL			
Longwave Radiation	RRTM Scheme			
Shortwave Radiation	Dudhia Scheme			
Surface Layer	Monin-Obukhov Similarity Scheme			
Land-Surface	Noah LSM			
Center Point	103.749997°E 1.527785°N			
PBL Type	YSU Scheme			
Microphysics	WRF SM 3-class Scheme			
Cumulus Scheme	Kain-Fritsch Scheme			
Period for Simulation Validation	00:00 UTC 12 to 00:00 UTC 18 June 2013			

LULC Map and Model Validation

Accuracy Assessment for Land Cover Data

- Supervised Classification (Maximum Likelihood Classification Algorithm) resulted in overall accuracy of 83.33 % (for scene 1) and 87.40 % (for scene 2)
- Produced land cover data for domain 4 accurately represented the actual land cover conditions

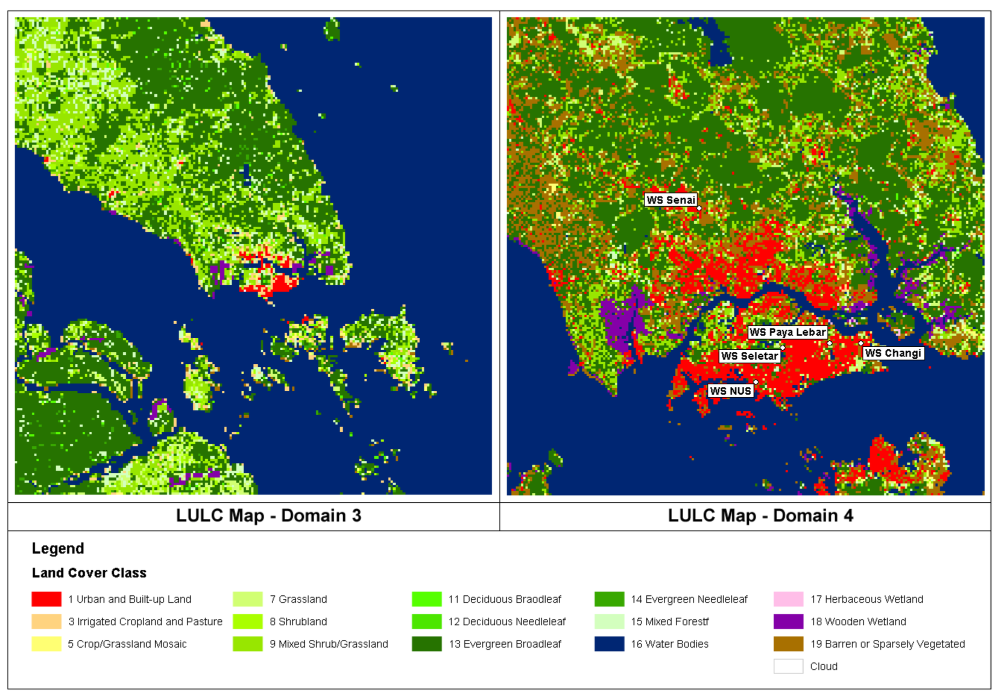

Figure 3: Land use and land cover mal for domain 3 and 4

Model Validation

- Validation period: 08:00 MYT (00:00 UTC) 12 to 08:00 MYT (00:00 UTC) 19 June, 2013

Table 2: WRF model validation for 5 weather stations

		Senai	Changi	Seletar	Paya Lebar	NUS
Temperature	R^2	0.892	0.734	0.863	0.821	0.570
	RMSE	1.274	1.143	1.561	3.032	0.599
	Bias	-0.189	-0.324	-0.878	-1.524	0.136
Wind Speed	R^2	0.643	0.483	0.542	0.548	0.540
	RMSE	2.482	1.775	1.731	1.390	1.007
	Bias	1.303	0.824	0.857	0.489	-0.062

- Simulation results for air temperature, wind speed, and wind direction show sufficient correlation with observed climate data from 5 weather station in Singapore and Johor Bahru

(a)

(b)

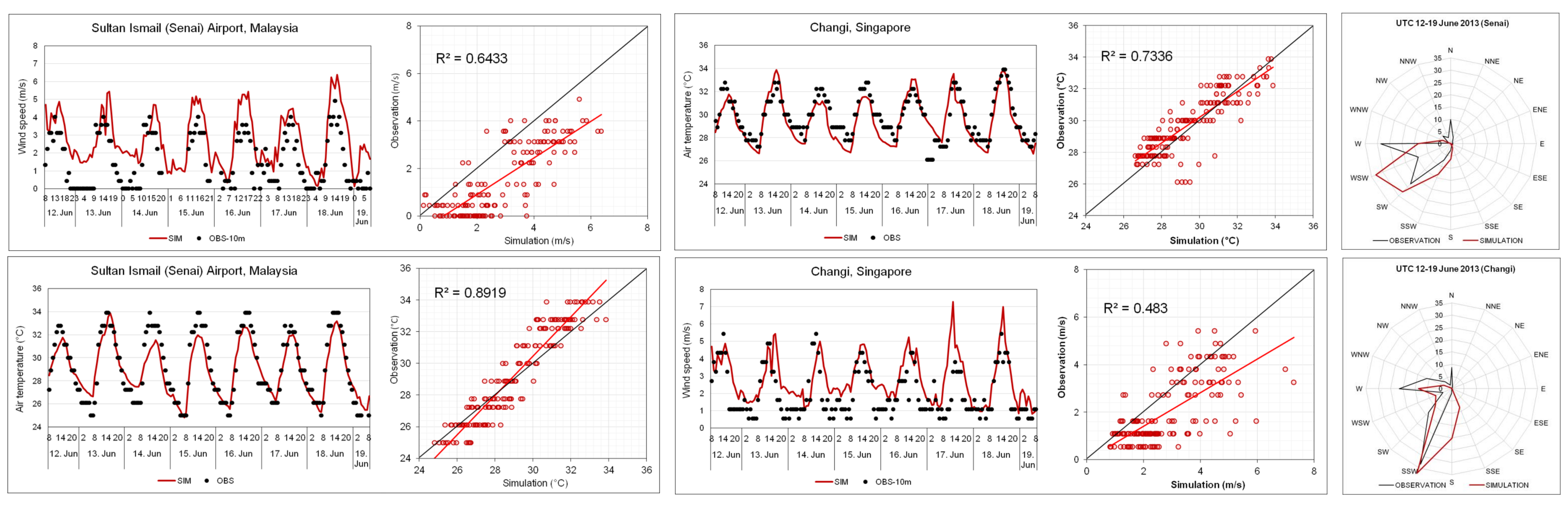

Figure 4: Validation results for air temperature, wind speed and direction: (a) WS Senai; (b) WS Changi

Simulation Results

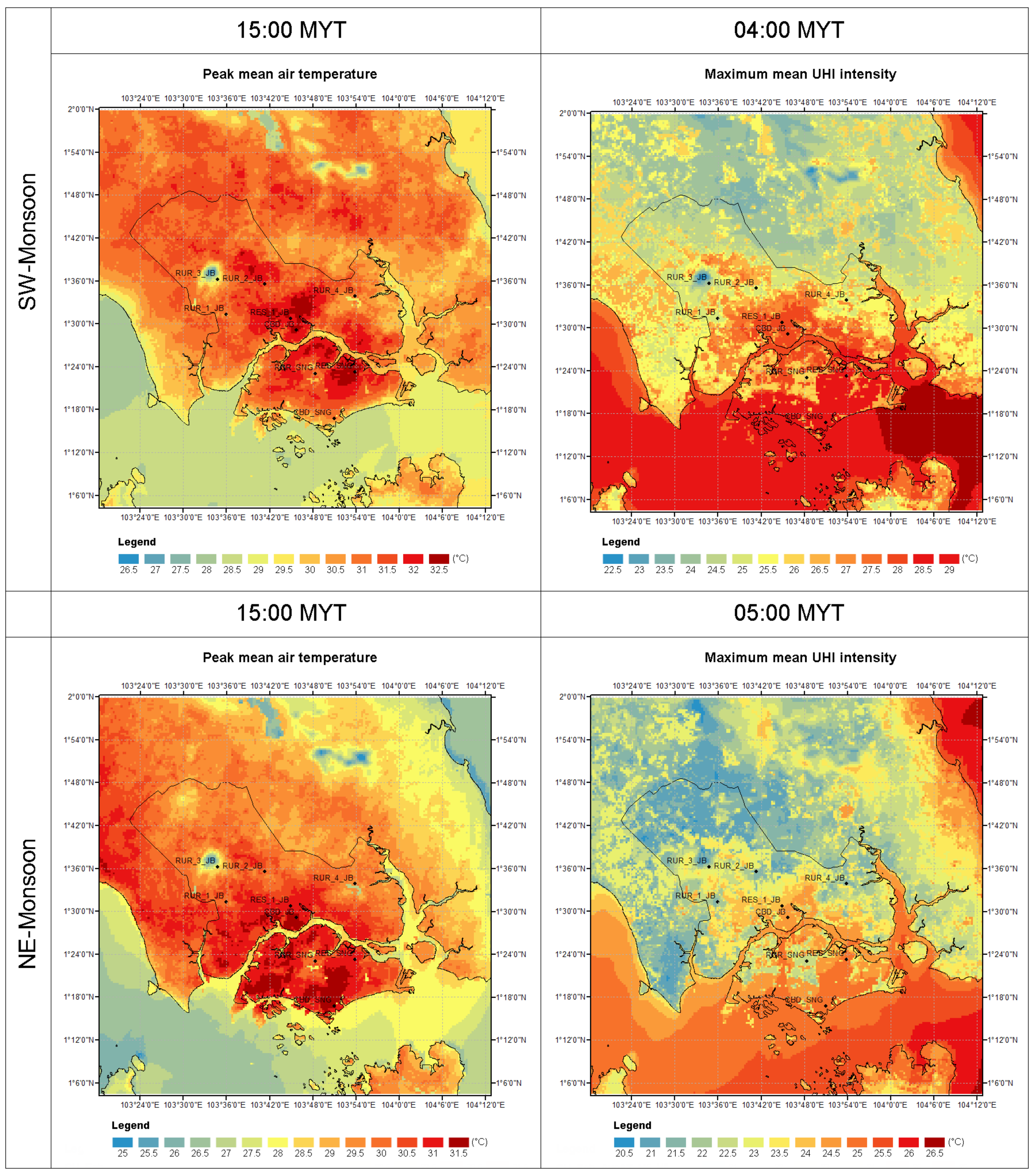

Figure 5: Spatial distribution of air temperature during monsoon seasons

Main findings:

- sea breeze effect during SW-monsoon results in lower air temperature (AT) in the CBD of Singapore (CBD_SNG) as compared to the CBD of Johor Bahru (CBD_JB)

  Daily mean AT CBD_SNG = 29.90 °C
  Nocturnal mean AT CBD_SNG = 28.69 °C
  Daily mean AT CBD_JB = 30.31 °C
  Nocturnal mean AT CBD_JB = 28.63 °C

- At night, the wind direction changes by 180° and leads to higher nocturnal AT in the CBD_SNG
- Mean UHI intensity during SW-monsoon is lower in Singapore due to sea breeze effect (SW-monsoon = 0.75 °C vs. NE-monsoon = 0.95 °C)
- During the day, the UHI dissolves over CBD_SNG

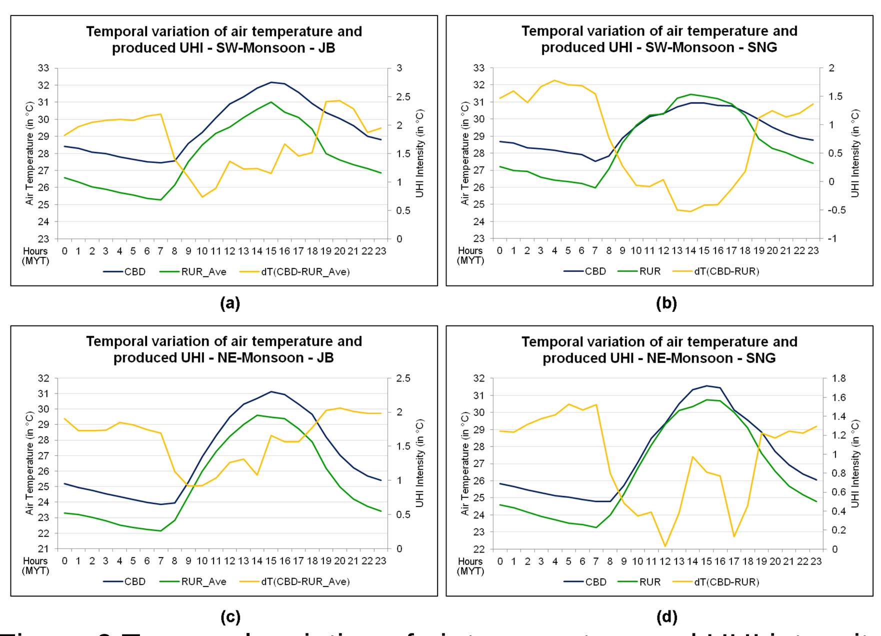

Figure 6:Temporal variation of air temperature and UHI intensity