Climate Change Information System for UHI for Planning and Design
A Singapore Case Study

Tian Kuay LIM, Singapore

A Multi-agency Initiative (Urban Redevelopment Authority, National Parks Board, Housing Development Board, Building Control Authority, Singapore Land Authority, Land Transport Authority, Jurong Town Corporation, Information Development Agency and Ministry of National Development/Ministry of the Environment & Water Resources)

Singapore - City in a Garden

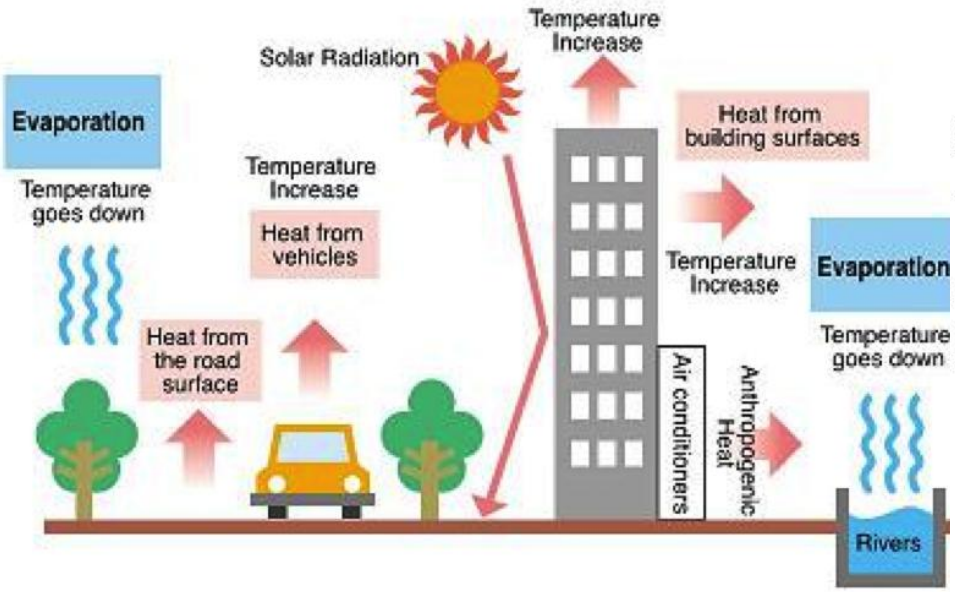
Highly urbanised city: Population: 5.2Million, Land Area: 714 sq km

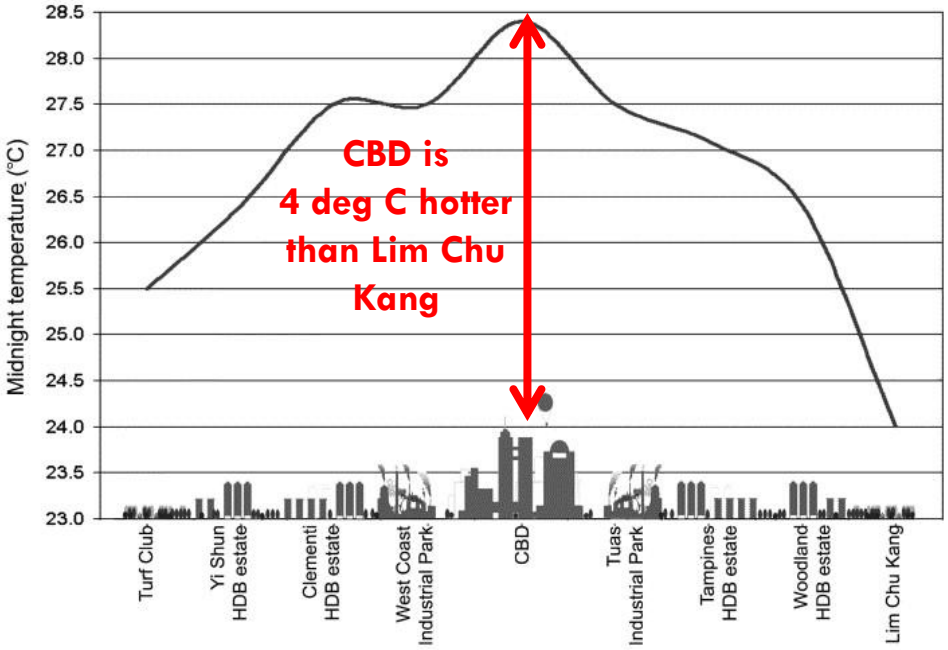
- Tropical weather, High-rise Buildings & Rich Urban Forestry

- Environmental Stresses & Climate Change Impacts, include:
Urban Wind Channels ► Urban Heat Island Effects (*Heat Ventilation)*

BACKGROUND: UHI- A CONSEQUENCE OF URBAN DEVELOPMENT

- Trapping of heat within urban canyons
- Increased heat storage from man-made materials
- Less vegetation and evapotranspiration
- Anthropogenic heat release
- Poor air movement and reduced heat transfer



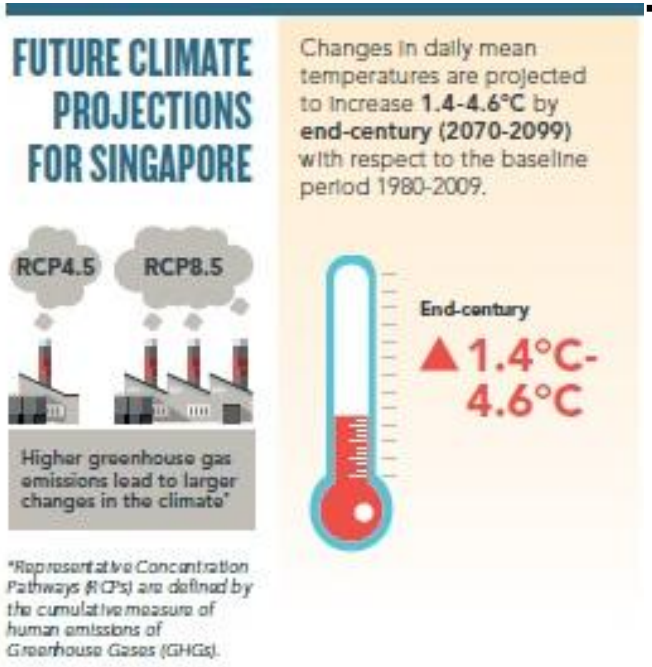


Source: Wong & Yu, 2005

BACKGROUND: UHI- A CONSEQUENCE OF URBAN DEVELOPMENT

- Due to combined effects of climate change (global warming) + further intensification of urban developments
- Negative impacts on thermal comfort, health and building energy use for cooling

Singapore's UHI could worsen in future

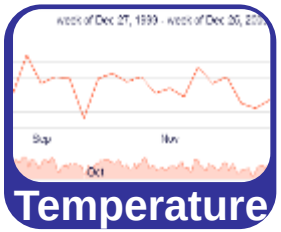


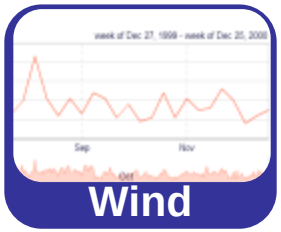
Integrated Adaptation Planning and Design
(Combined effects of UHI + global warming)


Map


Land Use


Terrain

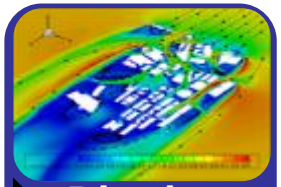

Temperature

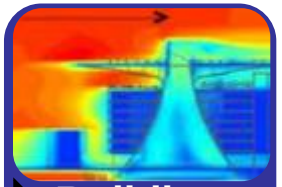

Wind

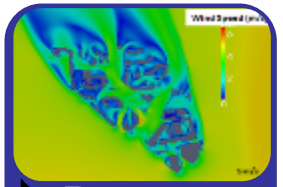

Sea Level

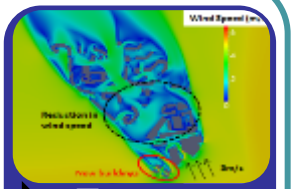
1. Geospatial and Environmental Data


Island

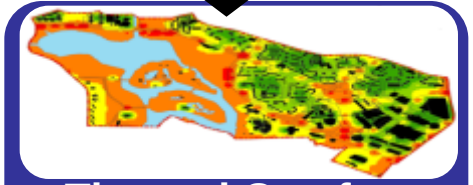

District


Building


Present


Future

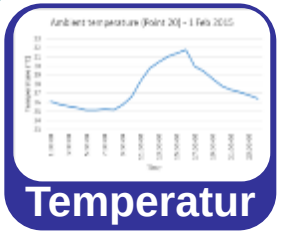
2. Integrated Urban Modelling & Simulation and & Sensing

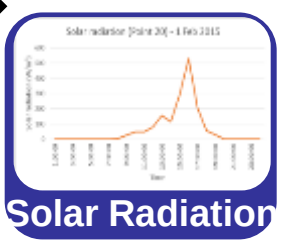

Thermal Comfort

3. User Interface and Data Analytics Platform

Adaptation & Mitigation Strategies

Calibrate and Validate


Temperatur


Solar Radiation

Sensing
Measuremen
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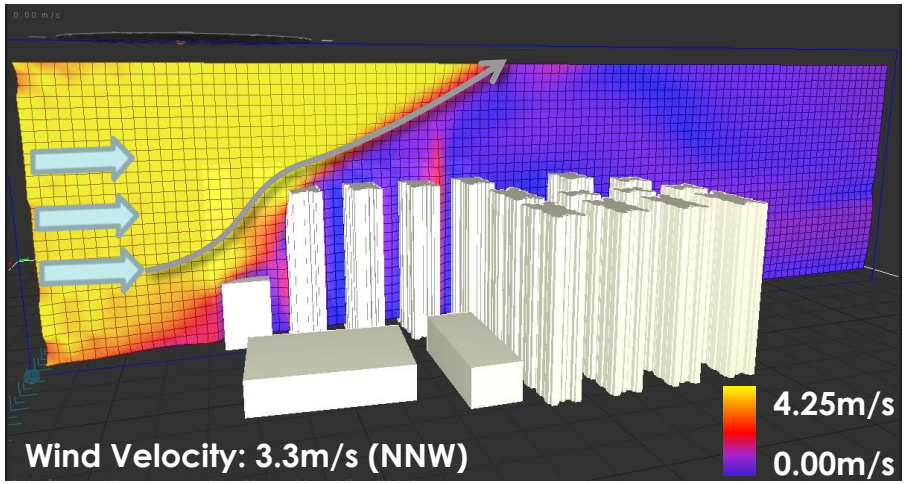
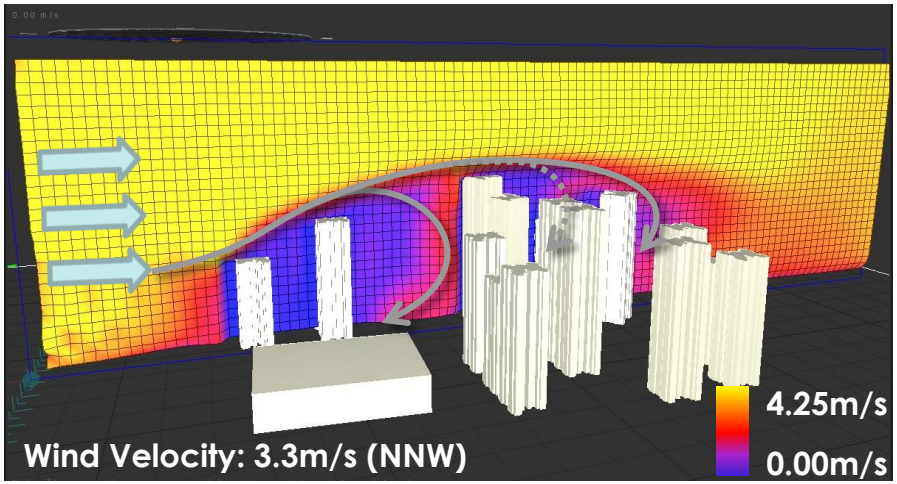
Urban Heat Island Effect Assessment

BAU: GPR 5.6
All 40 Storey HDB Blocks



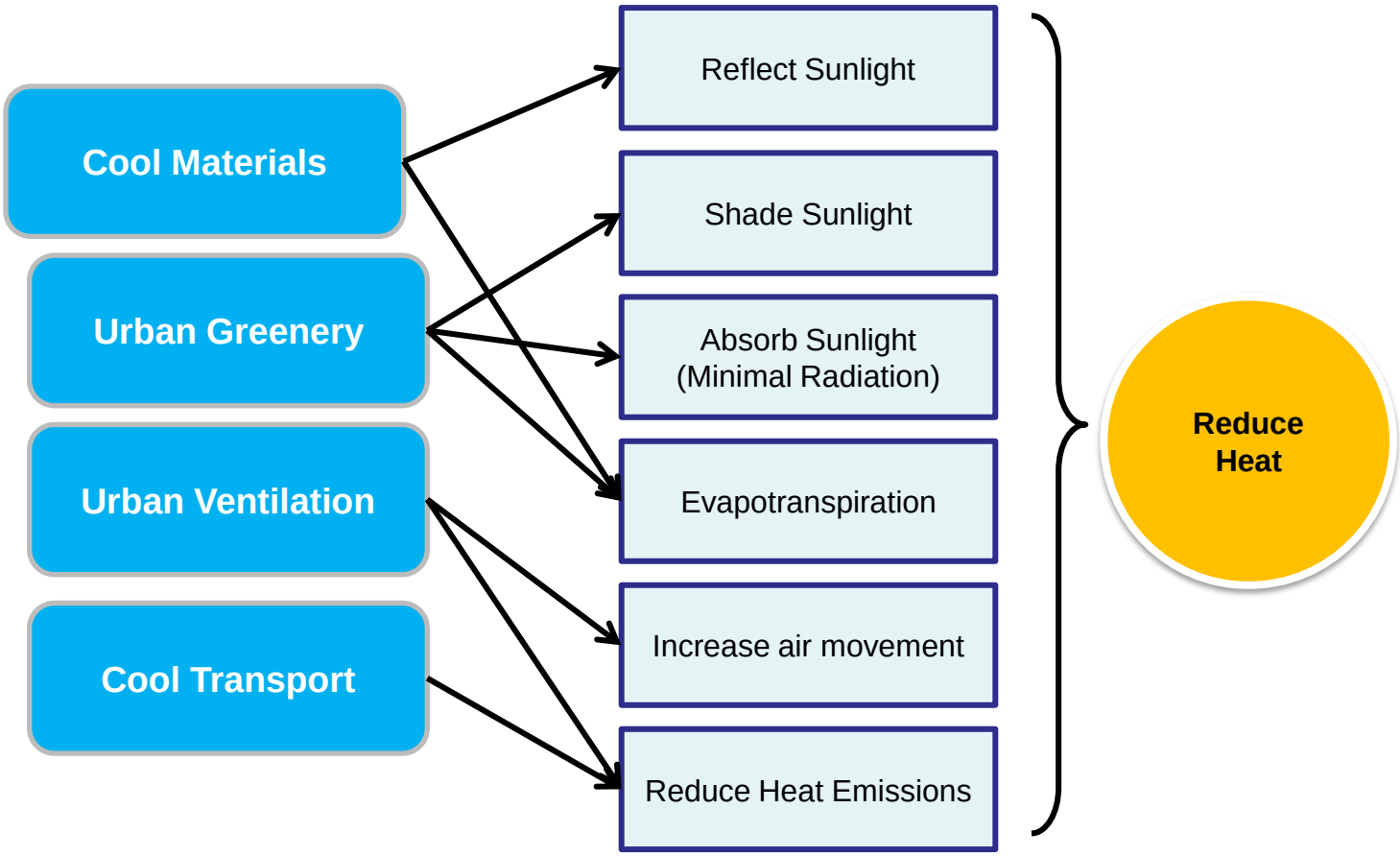
Improved scheme: GPR 4.2
Height differentiated HDB Blocks



How will the development of a new town affect the wind flow and comfort (thermal) in adjacent towns? Wind corridors; good ventilation; parks, open spaces and greenery?

Integrated Adaptation Planning and Design
(Combined effects of global warming + UHI)

- Need for climate-sensitive planning and design upfront
- UHI and global warming mitigation covers different aspects of our built environment, and involves different agencies.



Thermal Comfort Assessment Framework

(1) Integrated, Coupled Multi-scales Urban Model

Incorporates Location as an Element for Decision-making

Location-Specific Thermal Comfort Stress Assessment uses integrated, coupled multi-scales models:

(i) weather/climate & environment models (1~0.1 km resolution);

- **GSM/RSM/MSM**: Horizontal aspects 10km (regional domain) to (1~0.1 km resolution);
- Coupling of Land Surface Model (NOAH) to Urban Canopy Model – (Development)

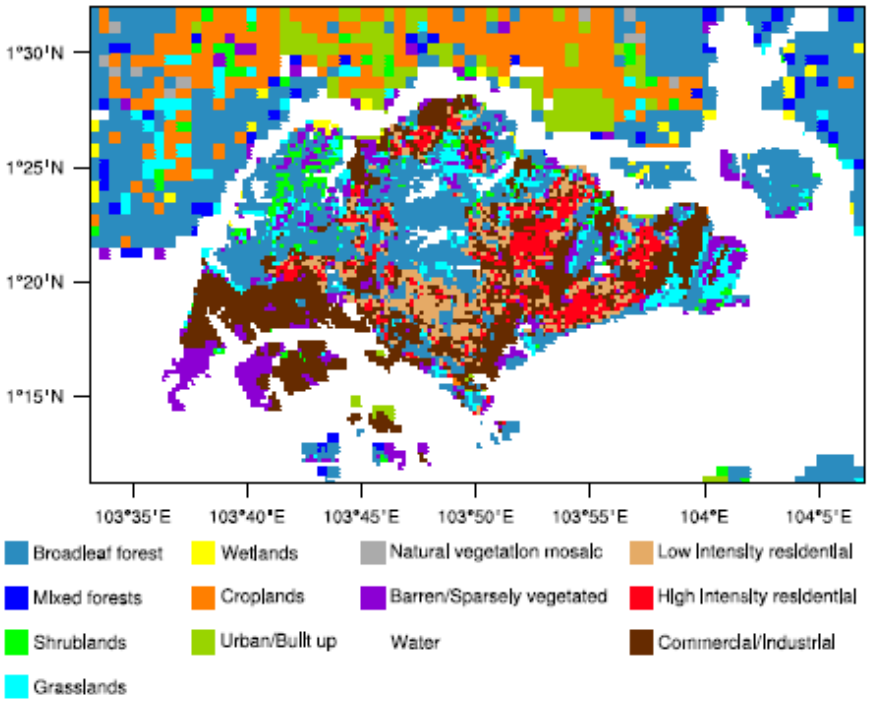
(ii) urban modeling (1~10 metre resolution)

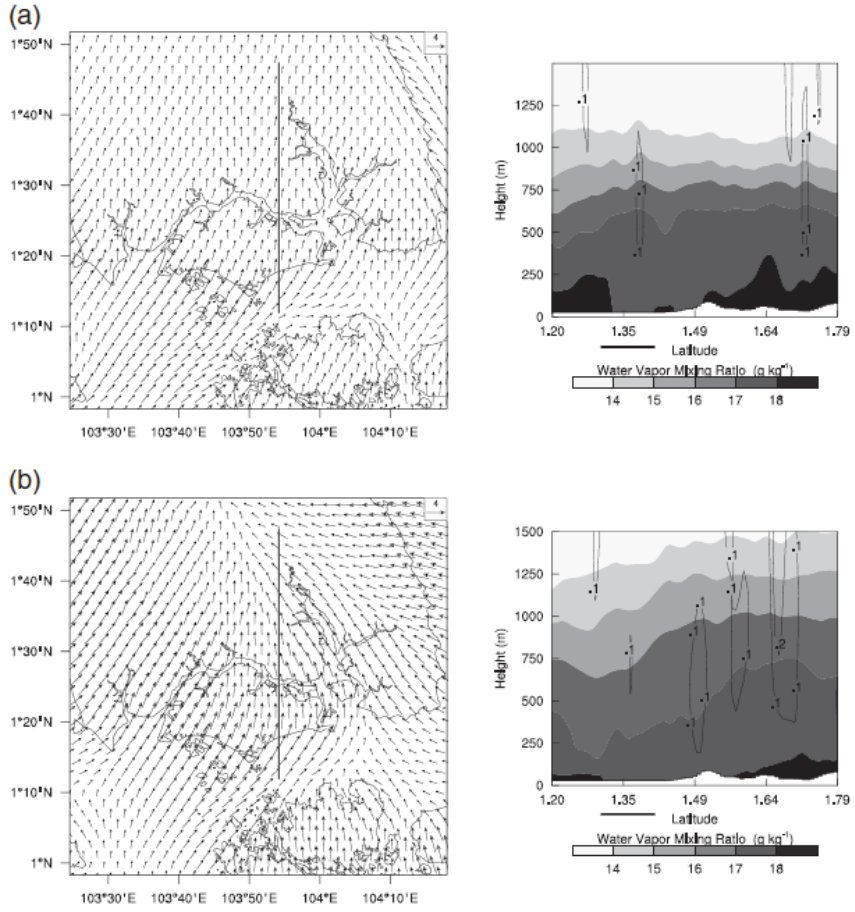
Based on OpenFoam and CFD code: Mass conservation and momentum equations were solved together with specific model equations, such as energy balance, turbulence such as Spalart Allmaras turbulence model, etc.

Coupling of Land Surface Model to Urban Canopy Model (Development- Preliminary Results)

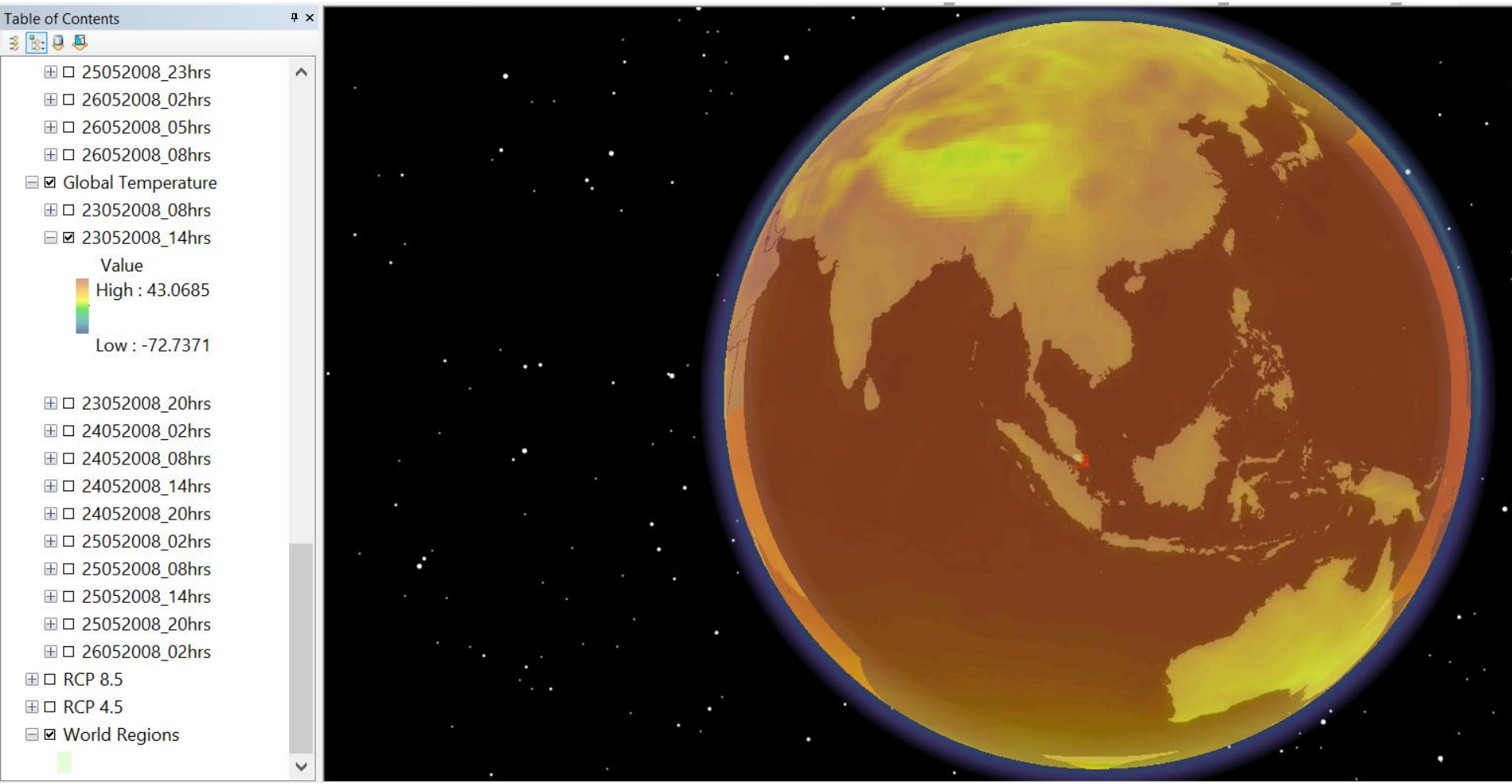
The effects of land use type and anthropogenic heat (AH) and its diurnal variation on the thermal and wind environment such as coupling the Noah Land Surface Model (*Chen and Dudhia, 2001) to the Single-Layer Urban* Canopy Model (*Kusaka et al., 2001; Kusaka and Kimura, 2004) using a tile-approach (Tewari et al., 2006).*

Land Use/Land Cover Map

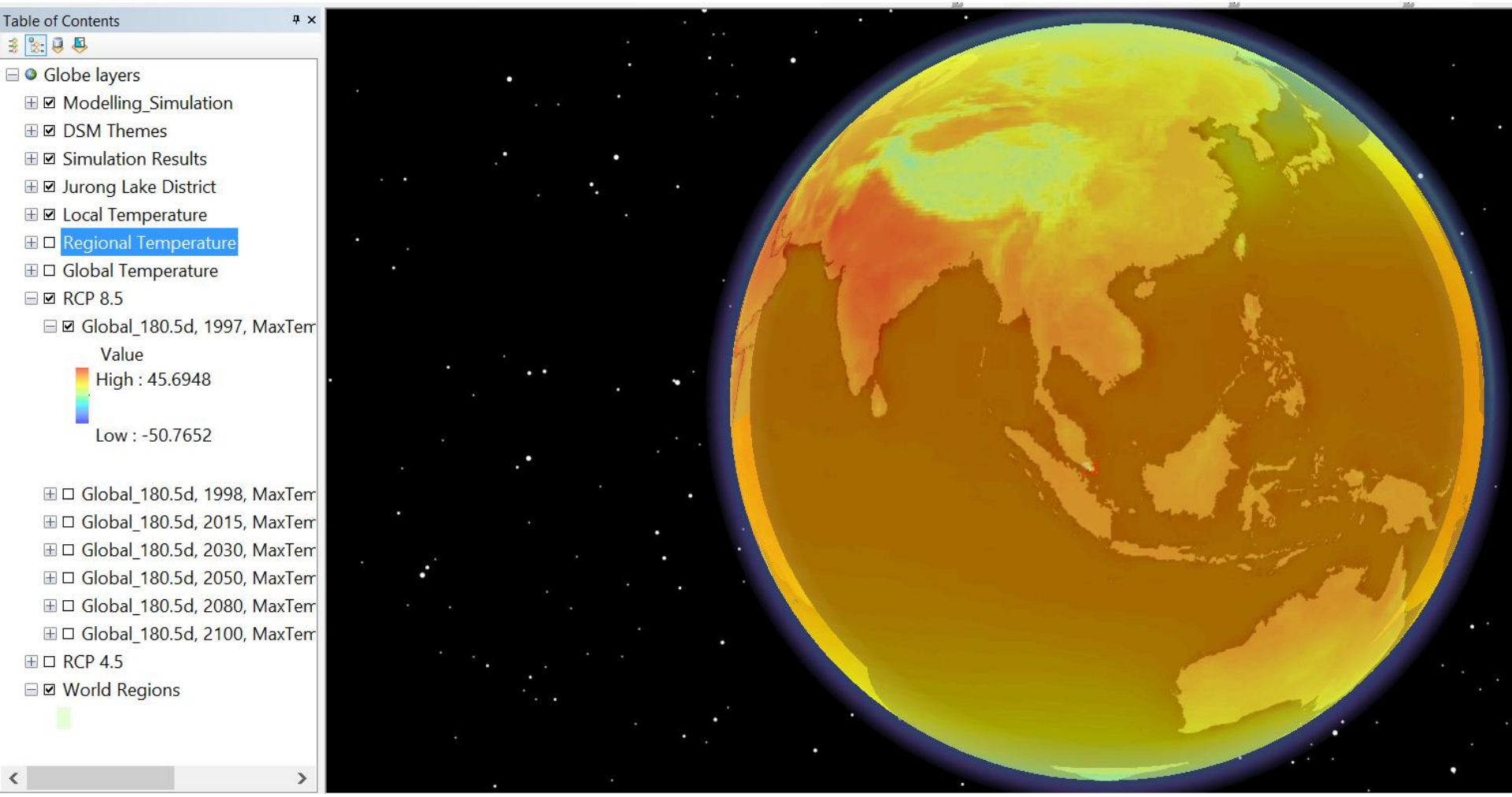




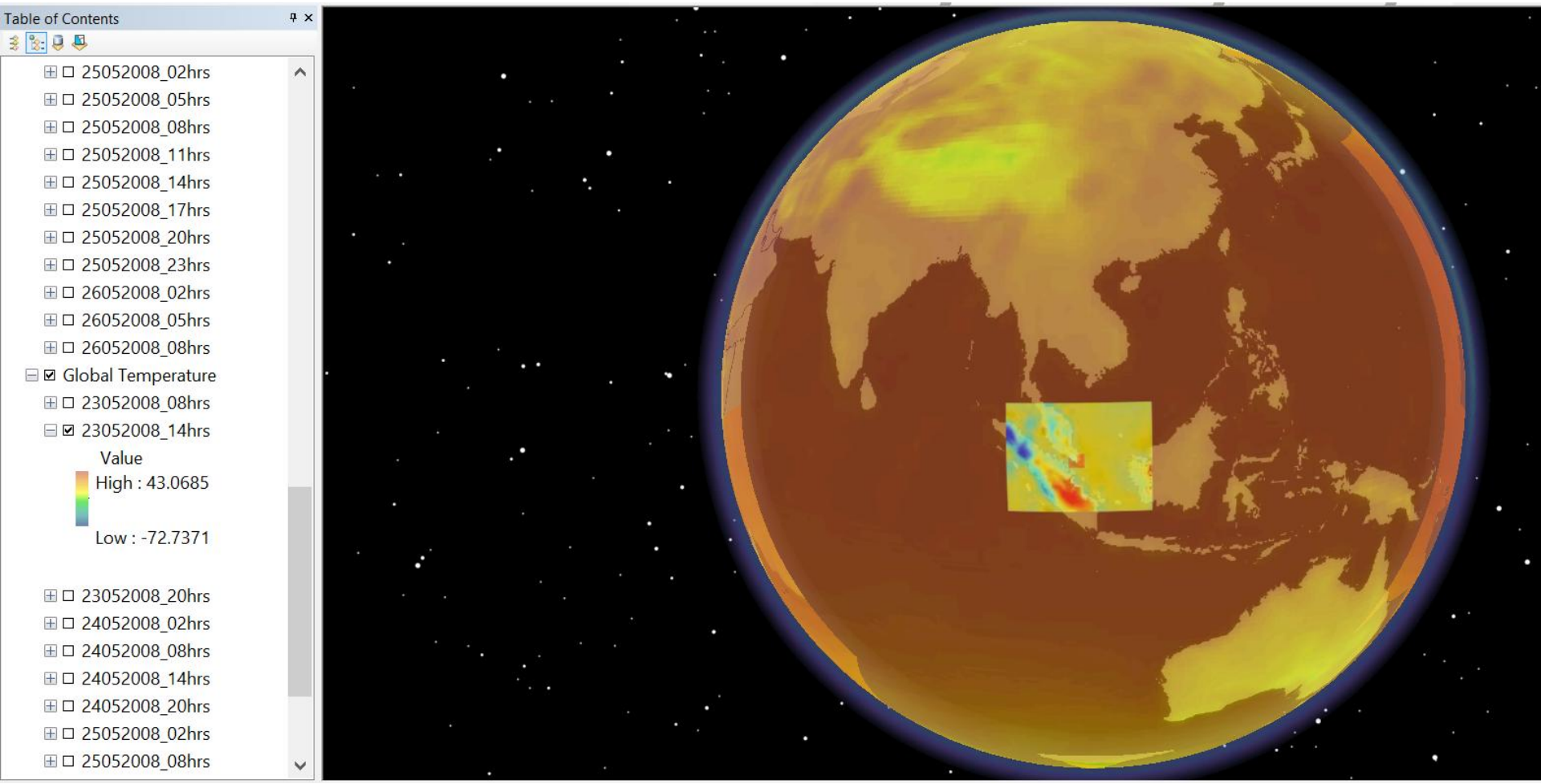
Sea breeze evolution in domain d04 at (a) 11:00 LT and (b) 17:00 LT. (Left) 10 m wind field.



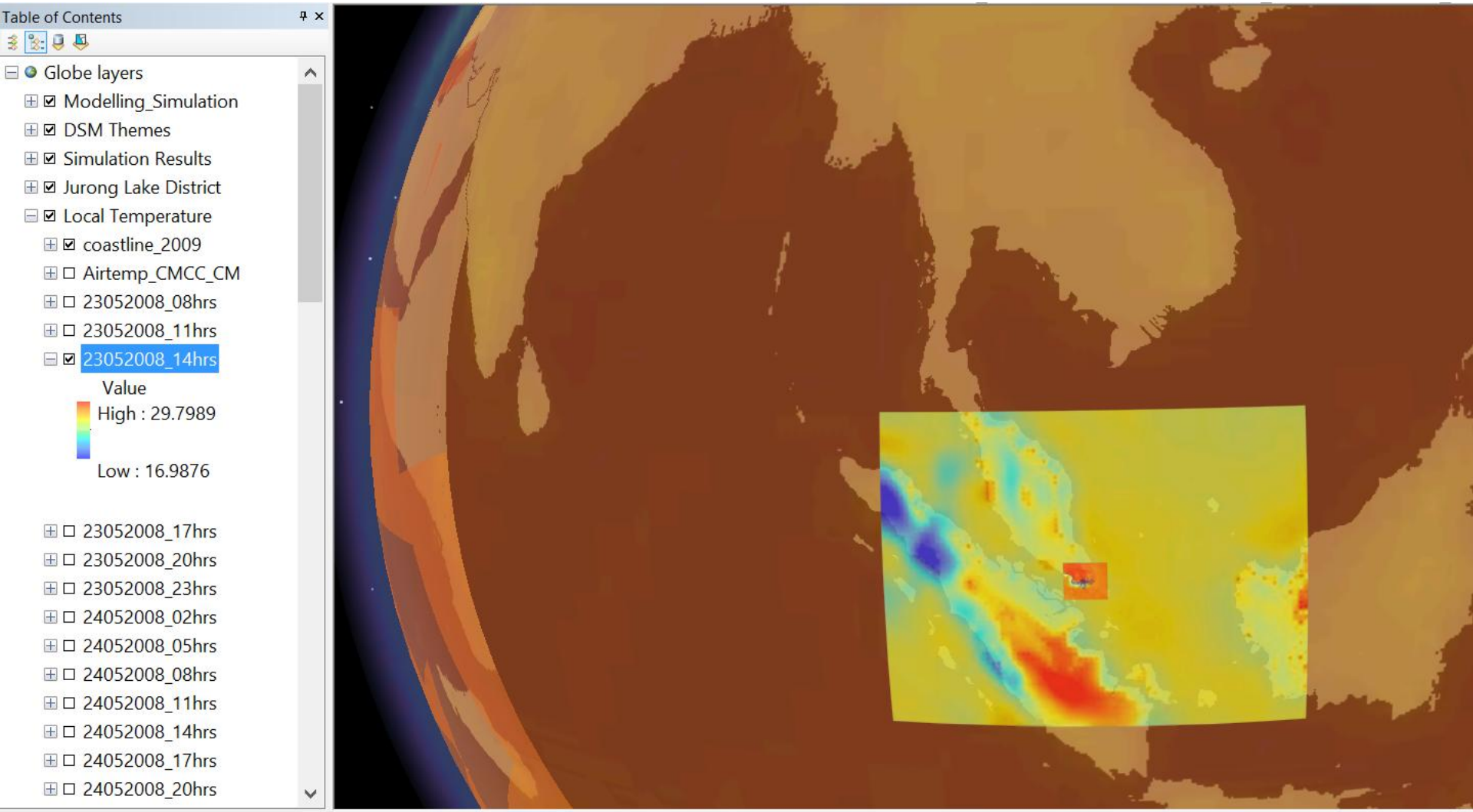
QUEST- Generate higher resolution of 40km Global temperatures (for baselines study) from the coarser resolution of 200km from NCEP Reanalysis.



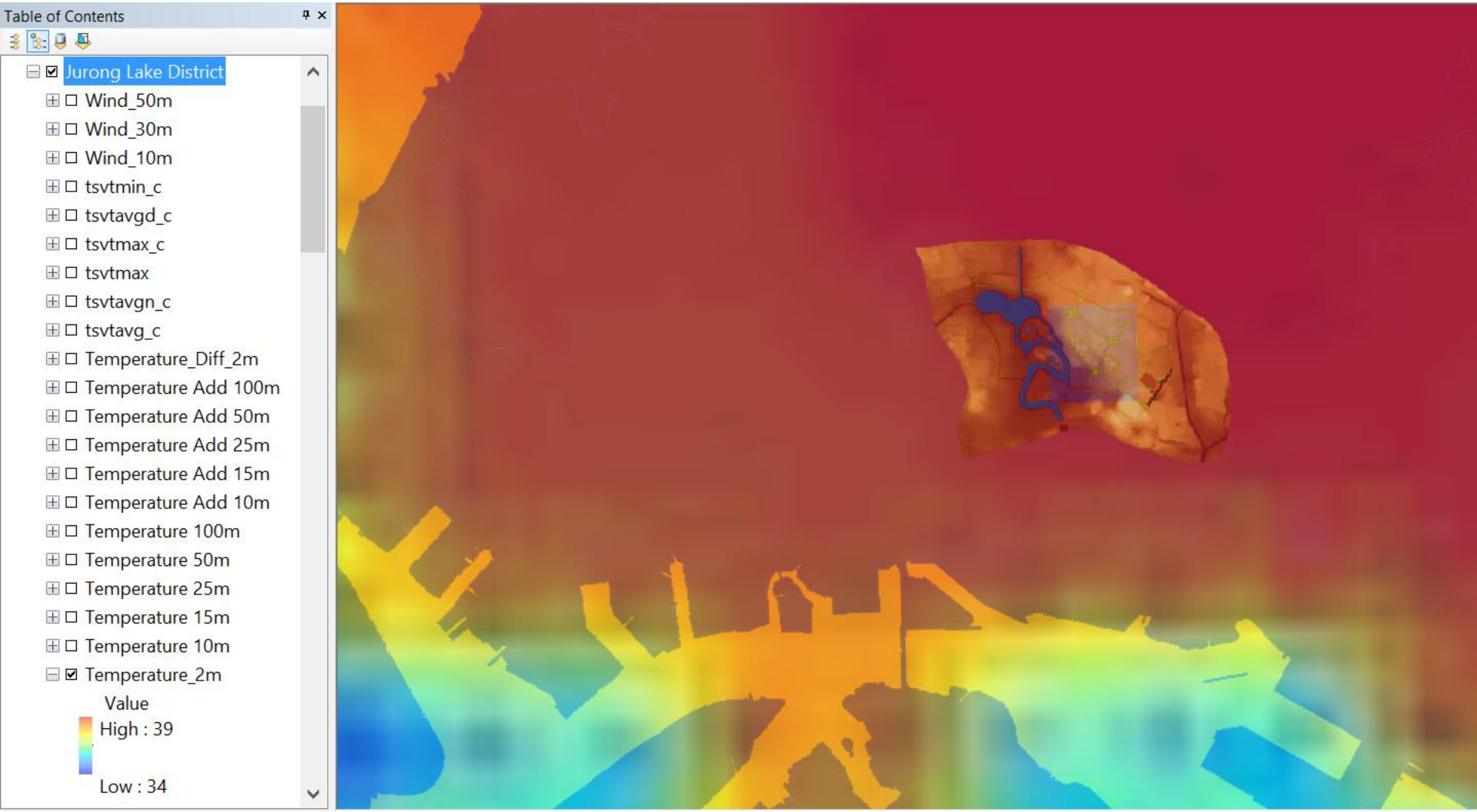
QUEST- Access to IPCC AR5 Global Climate Projections for the study of climate change impacts.



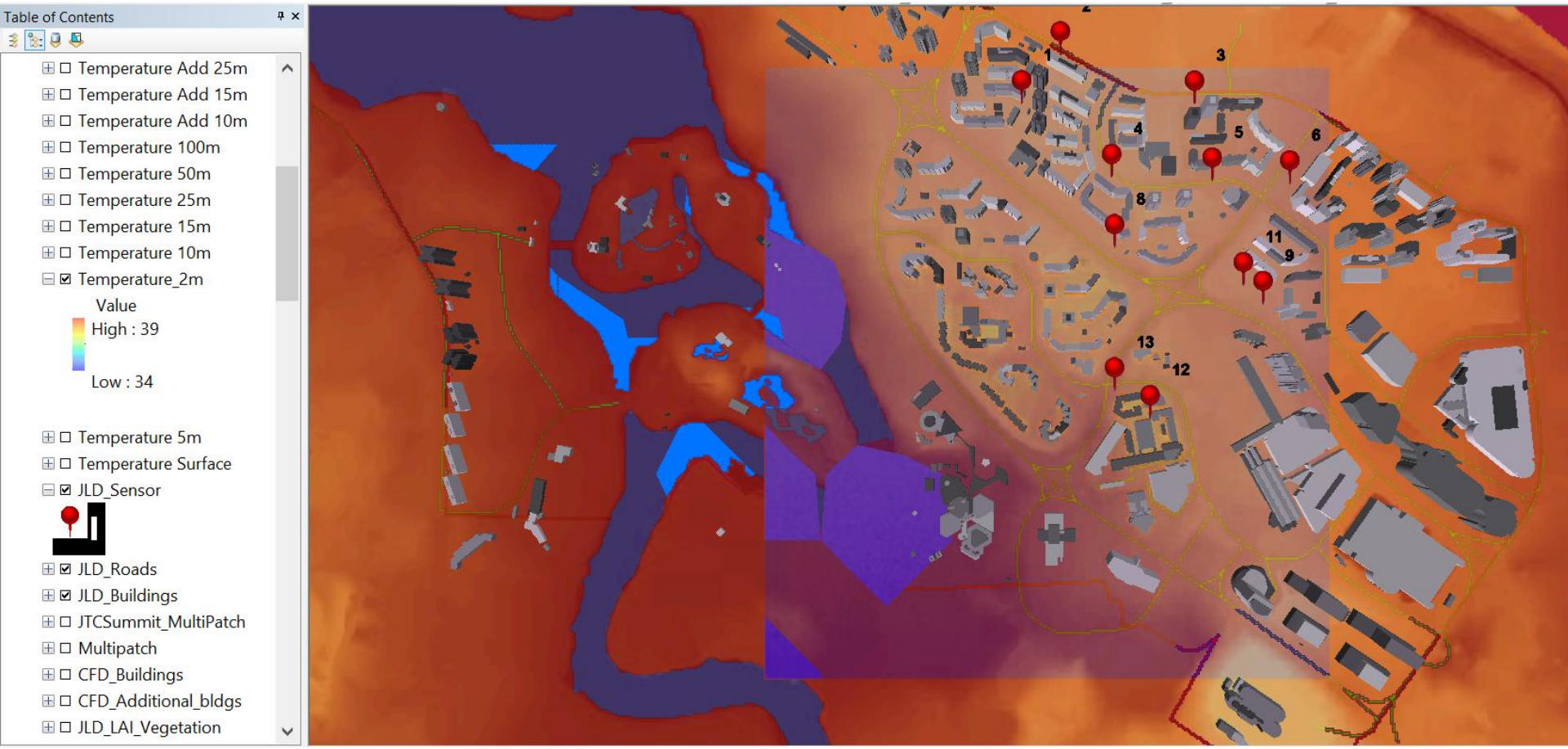
QUEST- Generate higher resolution of 10km regional temperatures (baseline study) over SE Asia from the coarser resolution 40km global model.



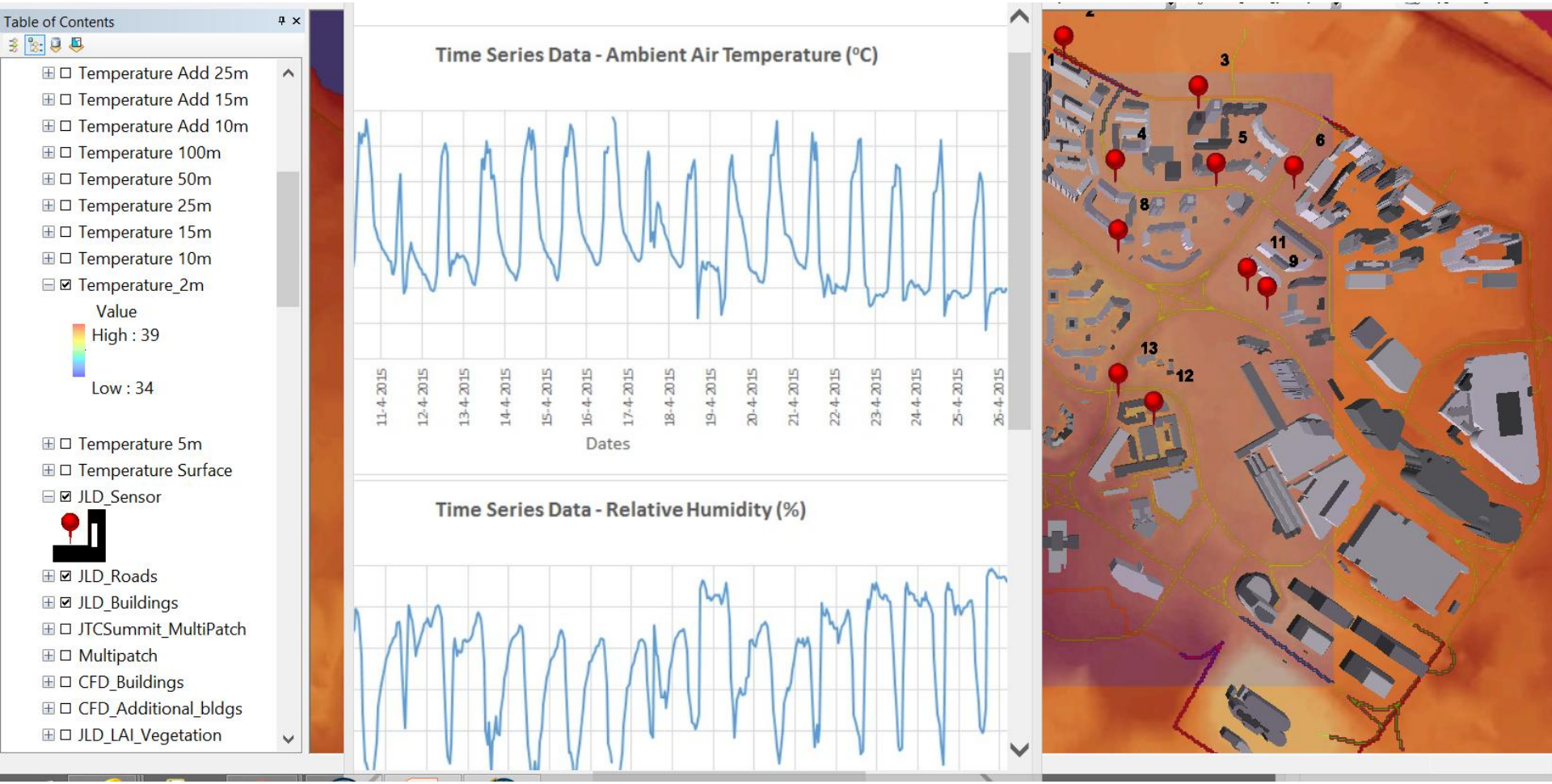
QUEST- Generate higher resolution of 1km local temperatures (baseline study) over Singapore and its surrounding region based on the coarser global and regional resolution with resolution of 40km and 10km respectively.



QUEST- Generate of 2m street-level temperatures (baseline study) over JLD from the coarser resolution 1km local model.



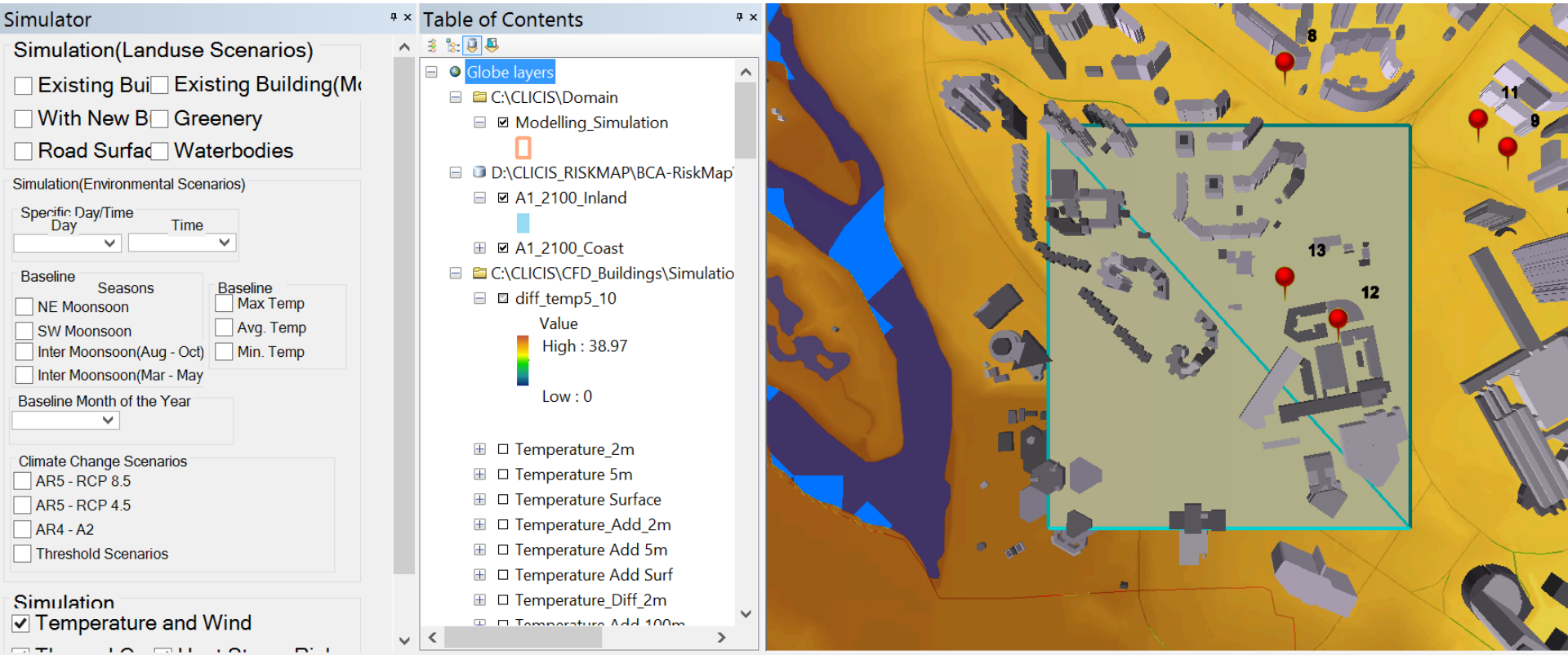
QUEST- Sensors installed over JLD for Calibration and Validation of the 2m street-level temperatures (baseline study) over JLD.



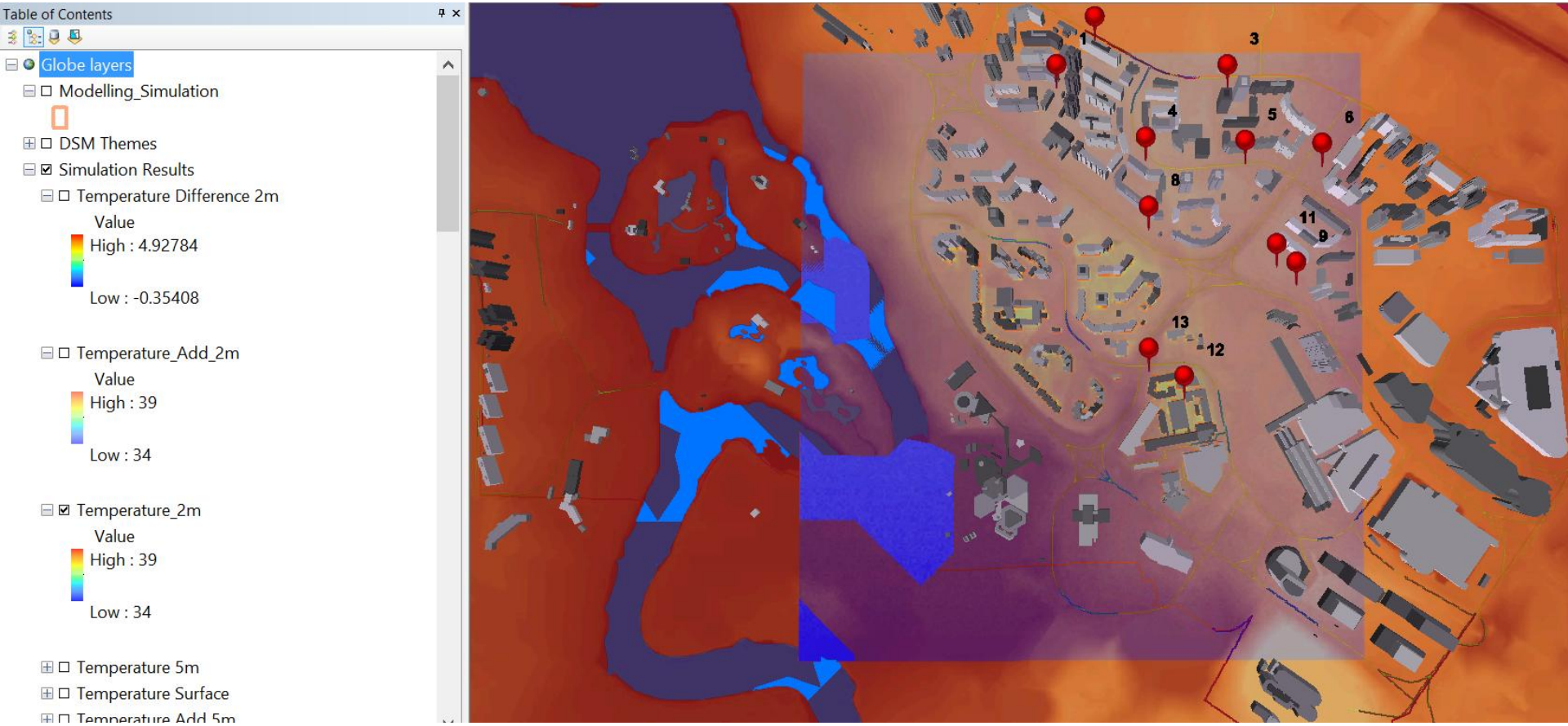
QUEST- Access to the observations from Sensors installed over JLD for Calibration and Validation of the 2m street-level temperatures (baseline study) over JLD.

Modelling & Simulation of UHI for Urban Planning & Design (Workflow)

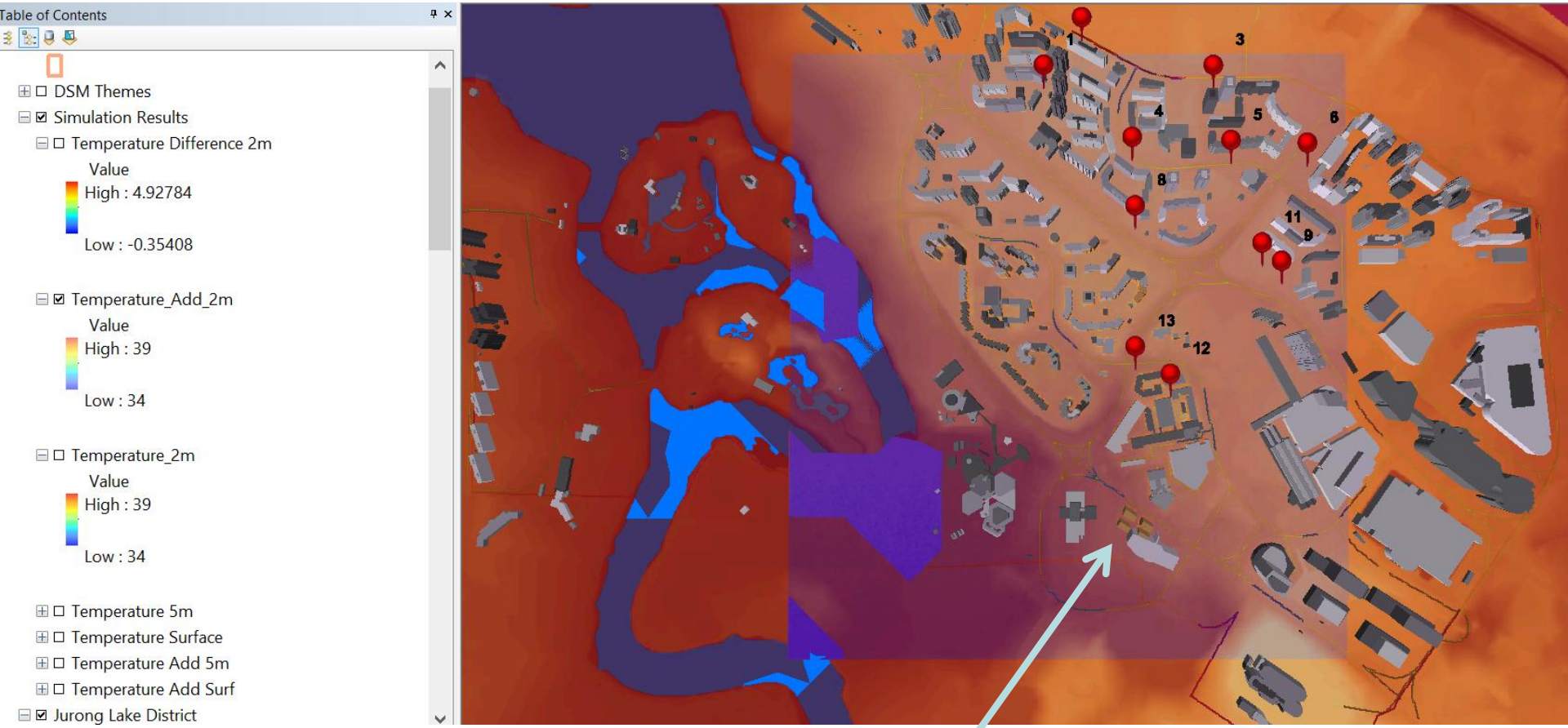
- Define Domain of Interest;
- Data Extraction;
- Setting up of scenarios for Simulation
  - Edit existing buildings/structures
  - Add new buildings/structures
  - Select the environmental conditions
  - Select the simulations to run
  - Select the outputs for the simulations



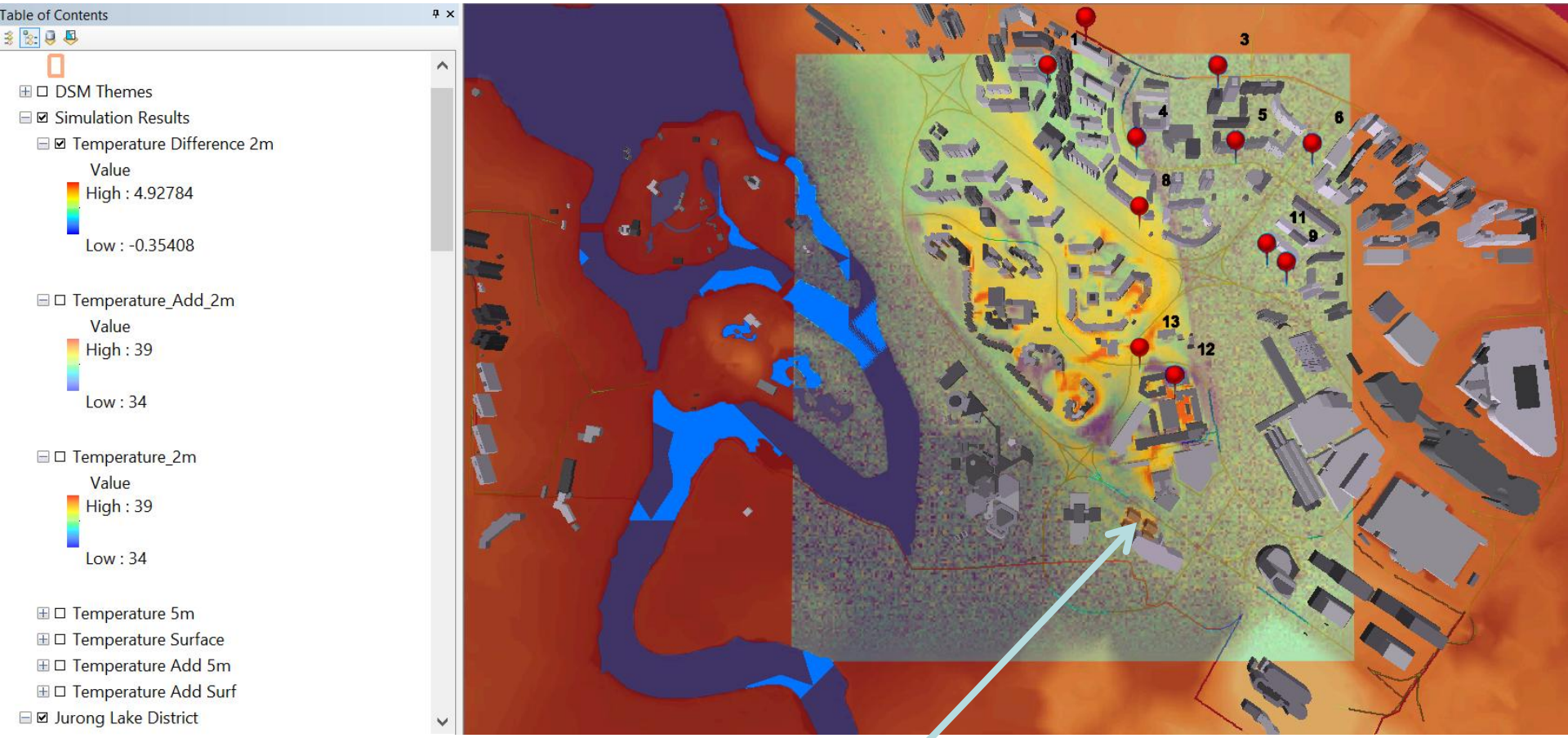
Select the environmental conditions
Select the simulations to run
Select the outputs for the simulations



Simulation Results: 2m Temperatures for Existing Buildings Scenario

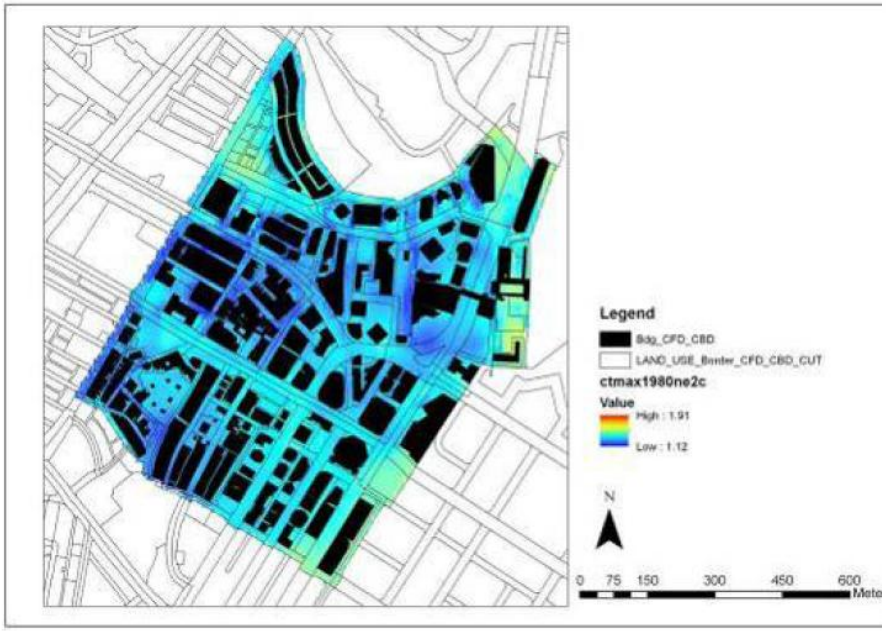


Simulation Results: 2m Temperatures with additional New Buildings Scenario

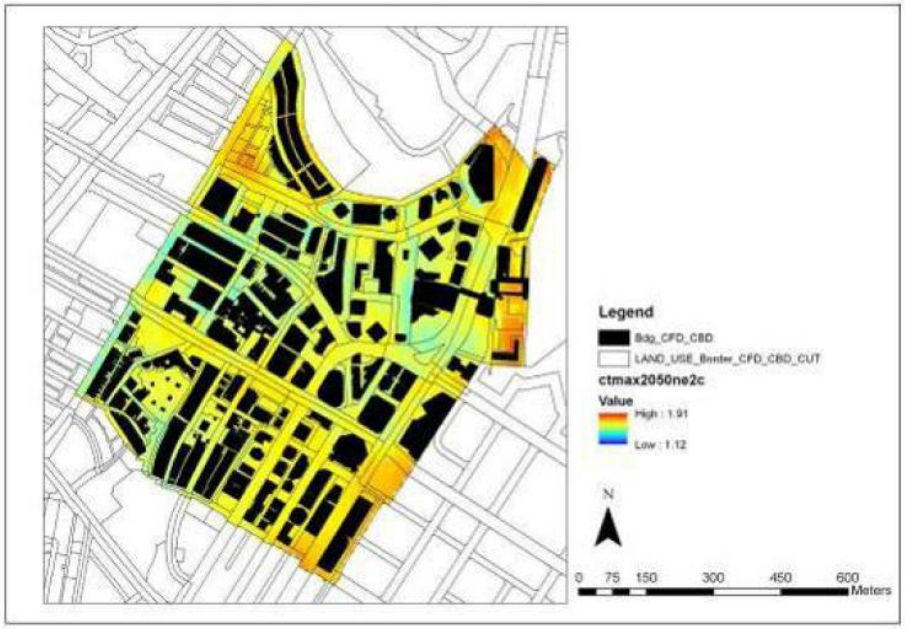


Simulation Results: Comparison of the 2m Temperatures for the two scenarios
(i) Existing Buildings Scenario; (ii) Adding New Buildings Scenario

Thermal Comfort Assessment/Simulation



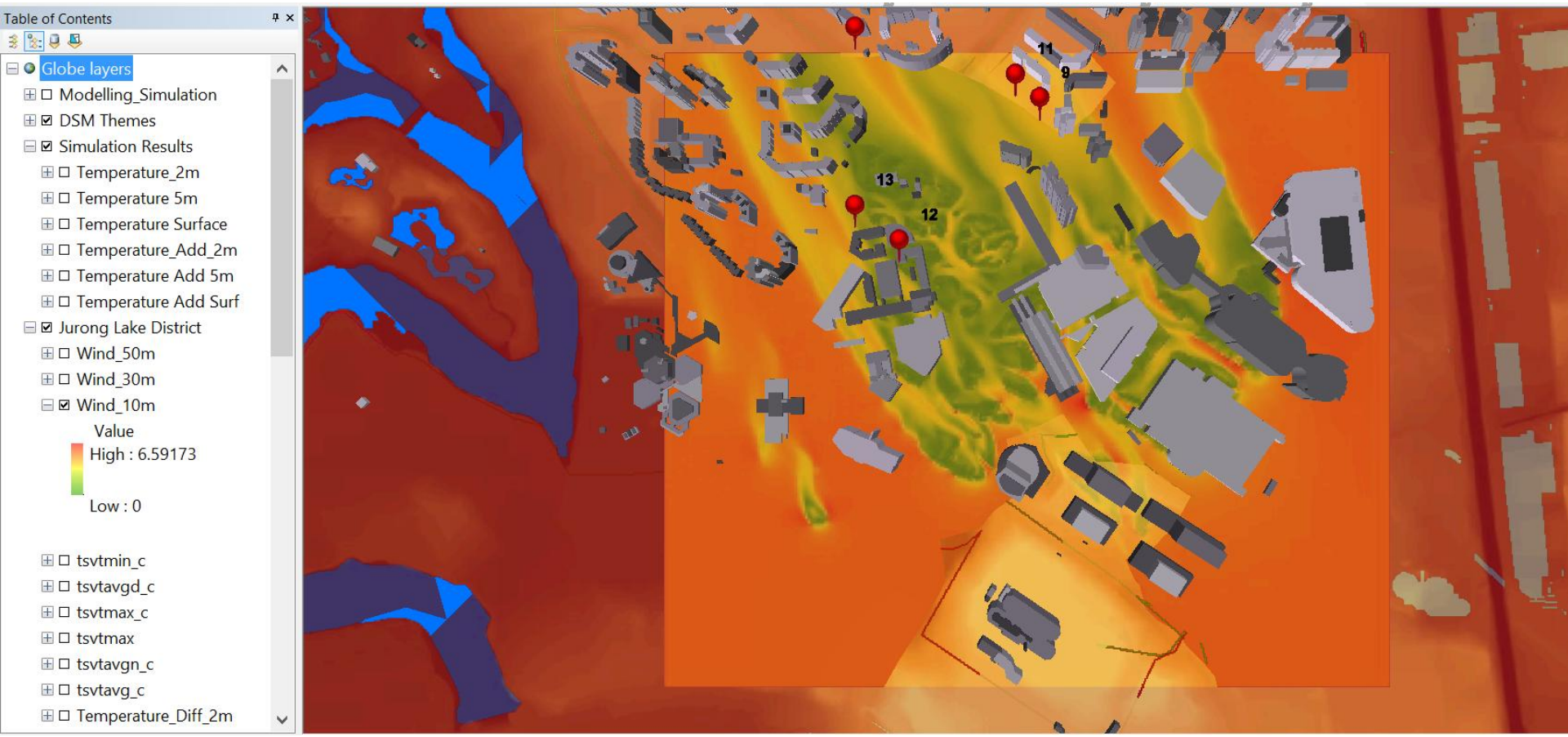
TSV map during daytime (Tmax) (Current)



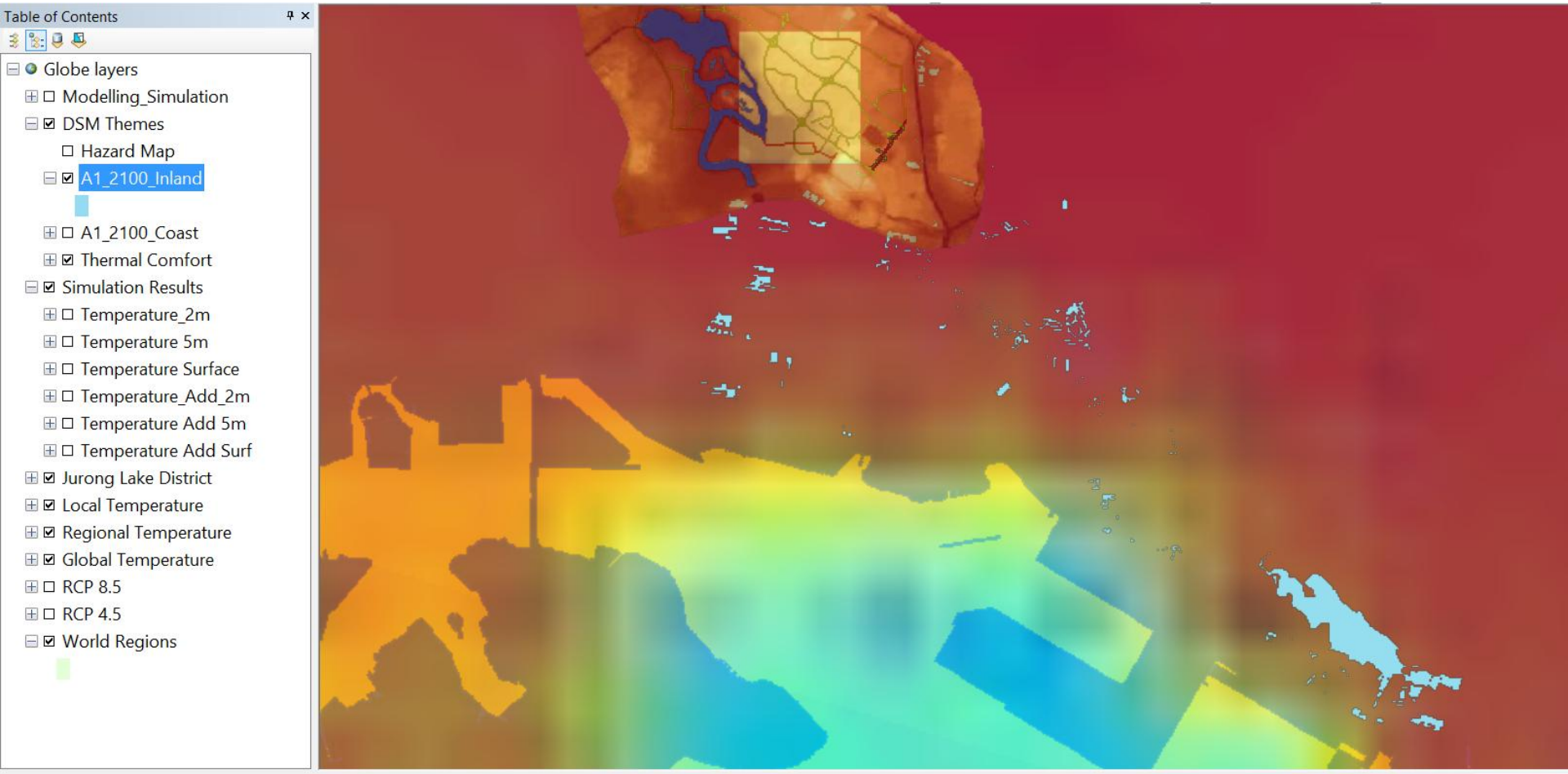
TSV map during daytime (Tmax) (2050, A2)

TSV range	Ta range (°C)	Perception (reference to ASHRAE 7-point scale)
-3～-2	Not applicable	cold to cool
-2～-1	22.4～25.4	cool to slightly cool
-1～0	25.4～28.5	slightly cool to neutral
0～1	28.5～31.6	neutral to slightly warm
1～2	31.6～34.7	slightly warm to warm
2～3	34.7-37.7	warm to hot

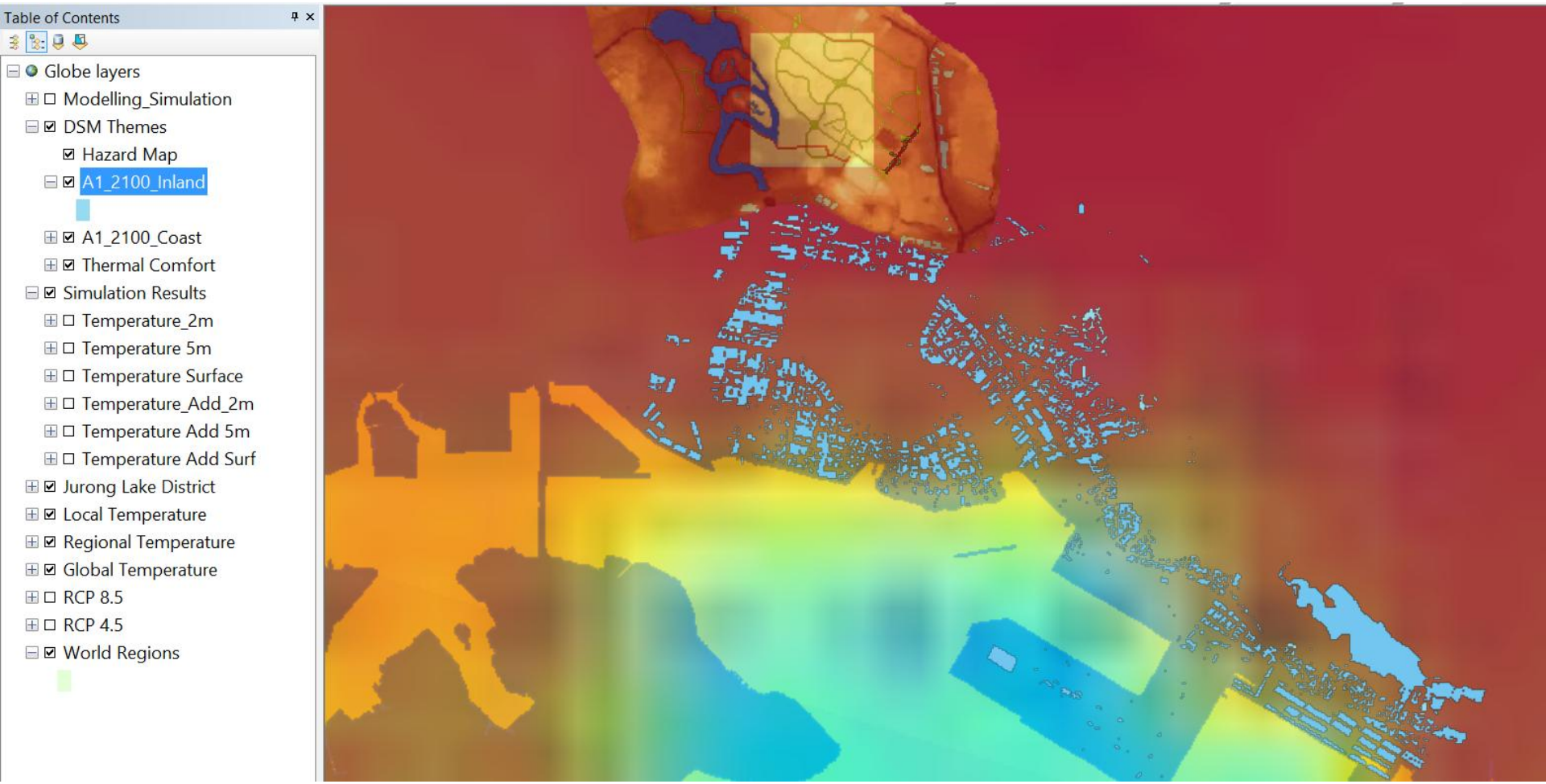
Examples of other factors for Urban Planning and Design



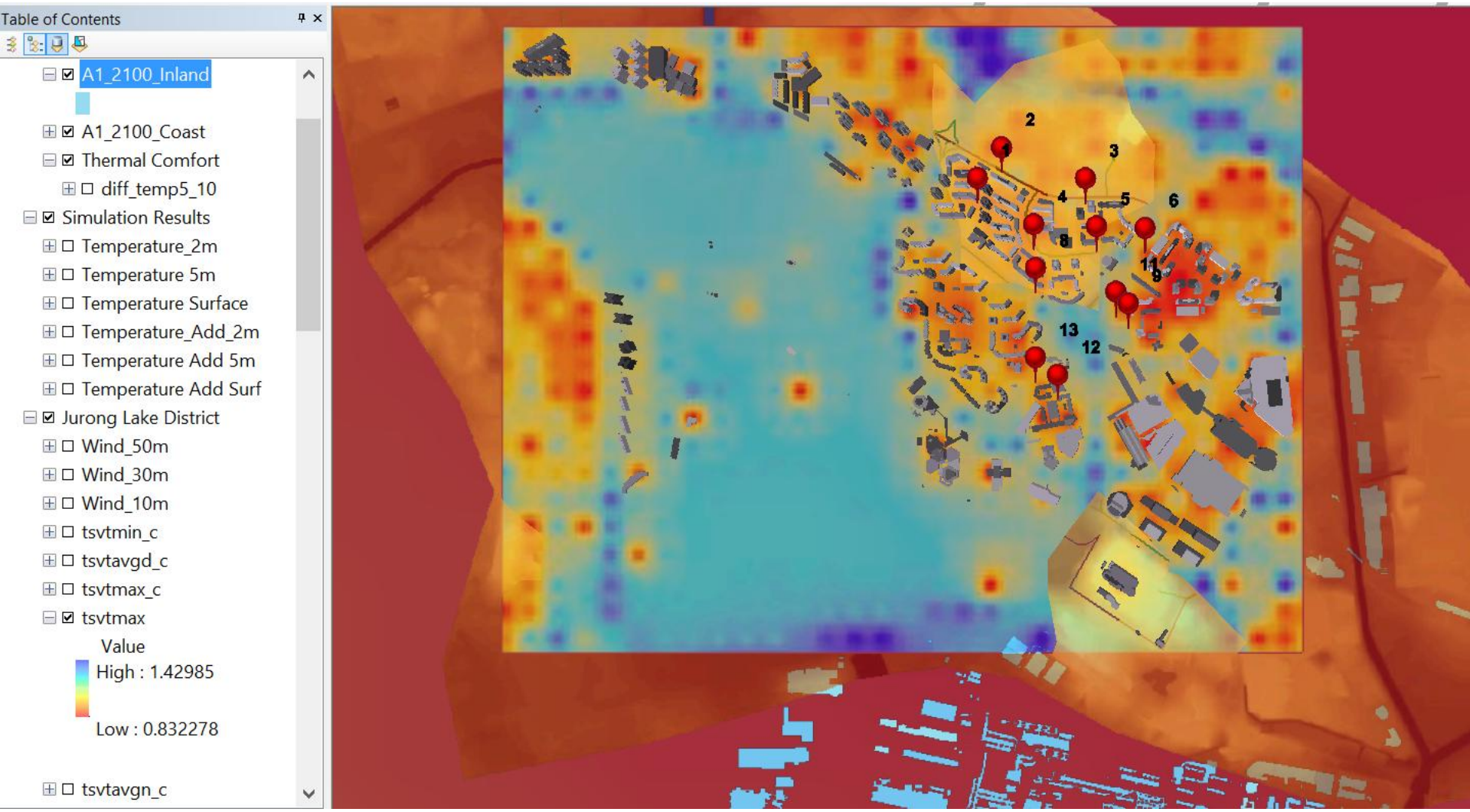
Various Information Layers such as wind at 10m height, etc., for Decision Support Module



Various Information ayers such as Inland Indundation A1_2100 ,for Decision Support Module



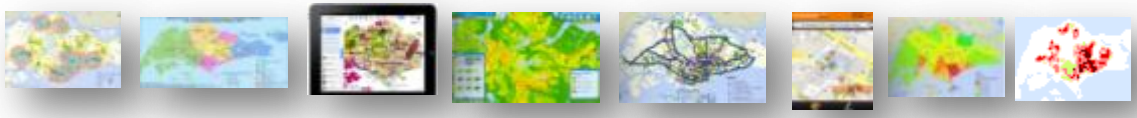
Various Information layers such as coastal Inland Indundation A1_2100 ,for Decision Support Module



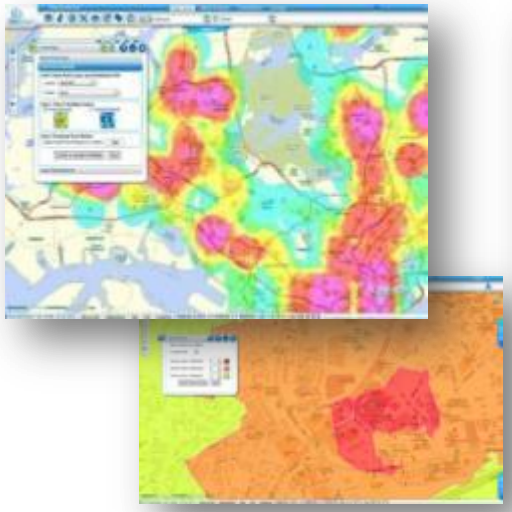
Combination of Various Information Layers such as Inland Indundation A1_2100 , Coastal, thermal comfort, etc. for Decision Support Module

COMMON GEOPLATFORMS FOR WOG DATA SHARING

AGENCY SPECIFIC SYSTEMS

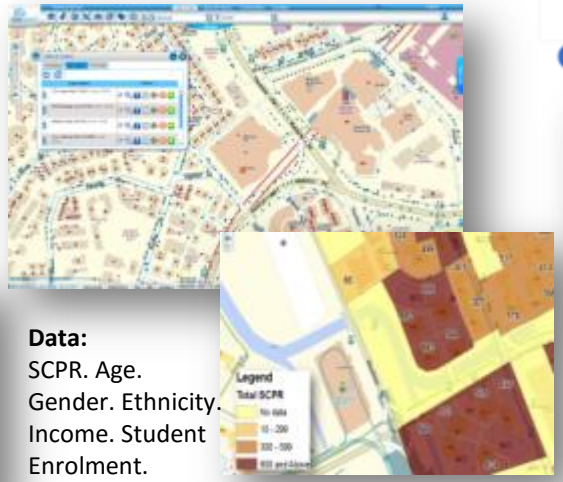


GEO ANALYTICS



Heatmap. Service Area. Routing. Proximity Search.

GEO DATA

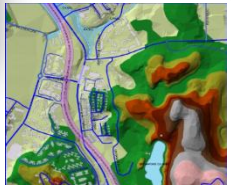


Data:
SCPR. Age. Gender. Ethnicity. Income. Student Enrolment. Household with Domestic Workers. Car Ownership. Construction Sites. Workers' Dorm

Fine grained data in Aggregated Data Zones (ADZ) for detailed analysis

GeoCommunity

Climate Change Comm (CLICIS)



SHARES

NGOs

RESTROOM ASSOCIATION (SINGAPORE)

Educational Institutions

cat welfare society

General Public

Businesses

Multi-Window Public Access

Common Platforms:

GeoSpace

OneMap Singapore

Summary

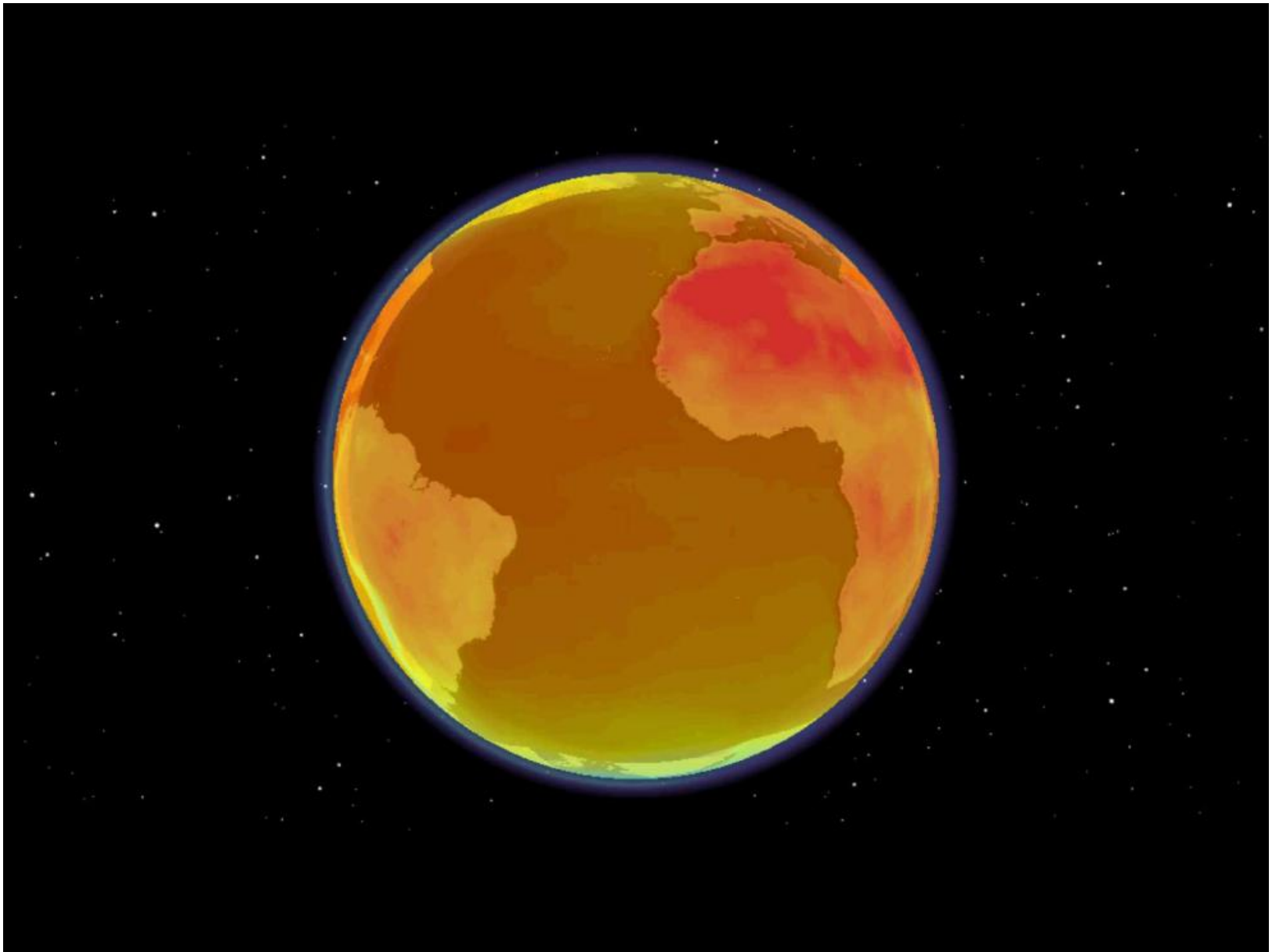
A GIS-based UHI/Thermal Comfort Assessment Framework (based on integrated coupled multi-scales atmospheric-urban-thermal comfort modelling) provides an effective platform to support climate-sensitive design and planning for Singapore with following key functionalities:

1) Data & Information Access & Retrieval

2) Planning, Design & Adaptation

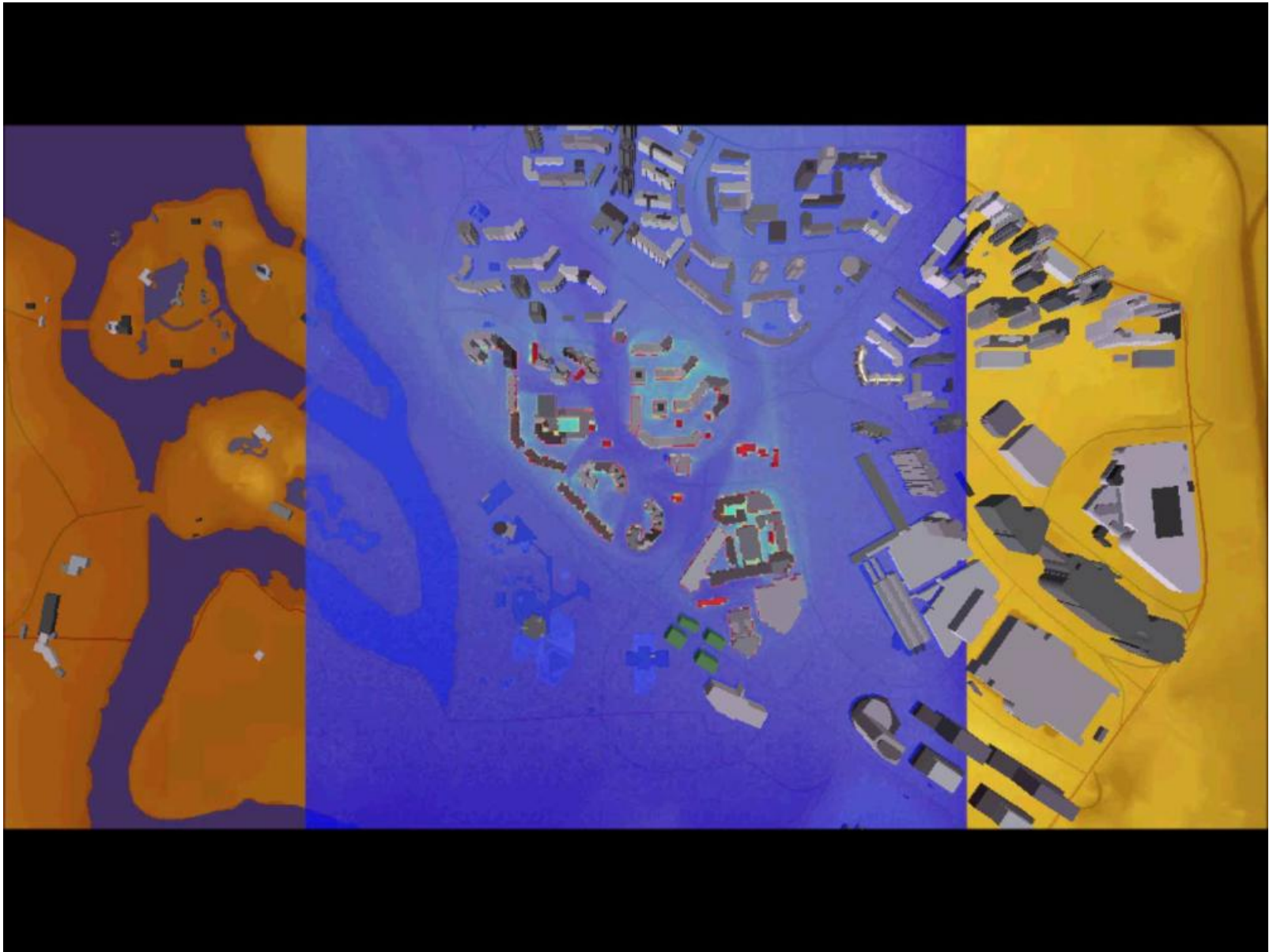
Summary

Data & Information Access & Retrieval



Summary

Planning, Design & Adaptation



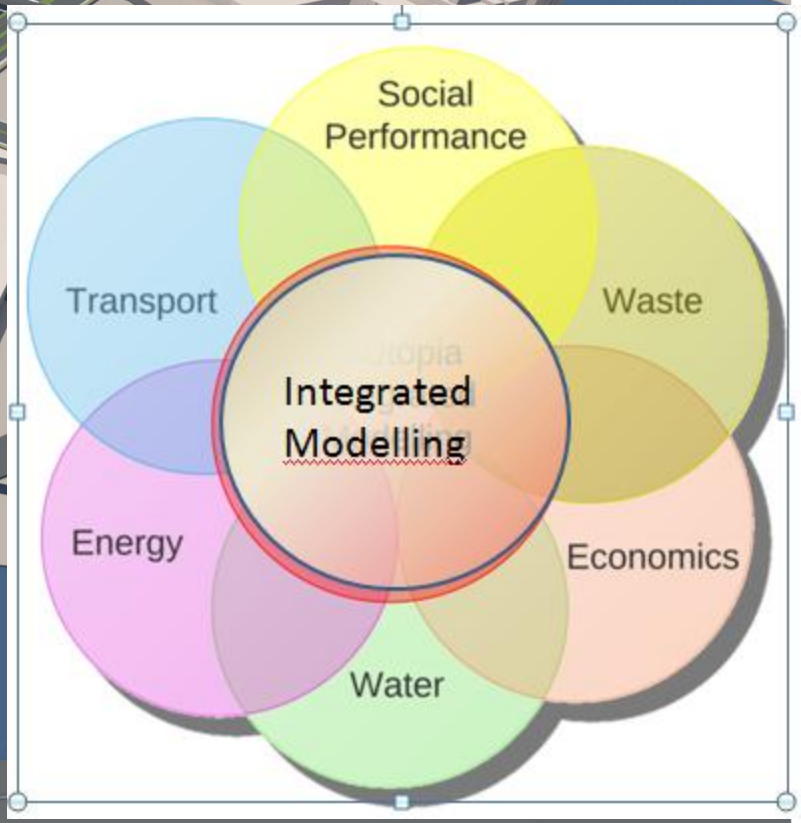
Areas for Development and Collaboration

A 3D GIS-based Modelling and Simulation Tool for Planning & Design of Sustainable Cities

Urban Planning

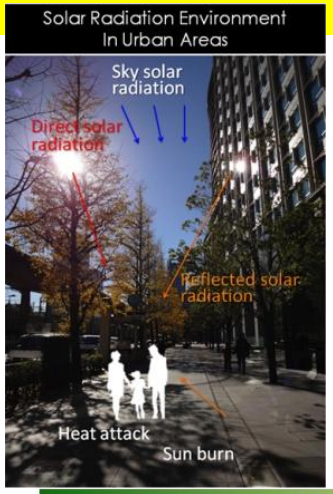
"driven by the vision of an **inclusive, highly liveable, economically vibrant and green home** for all Singaporeans"

What would a Low CO2 emission city look like?

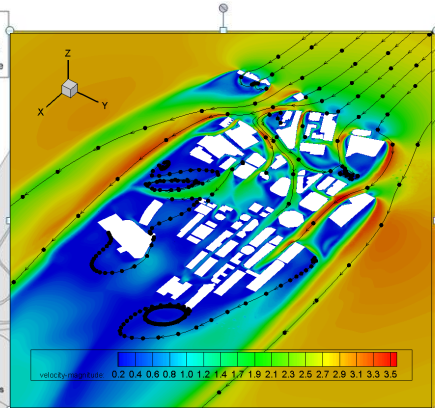


Integrated Modelling Platform

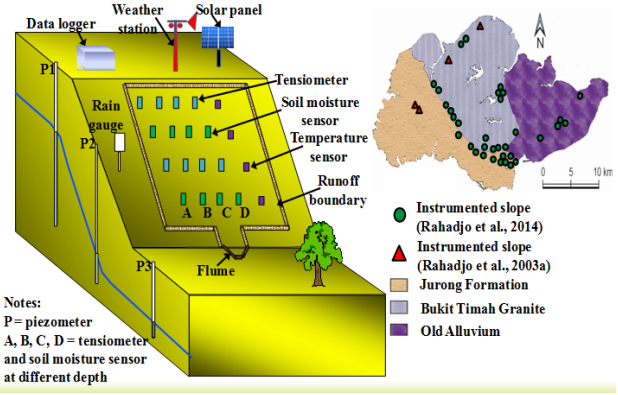
Modeling &Simulation (M&S) for Adaptation Planning (Biodiversity)



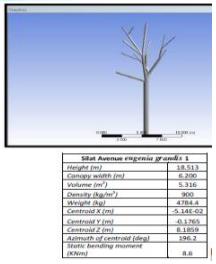
Tree failure was recorded near Marina Bay on 27 January 2000@1645



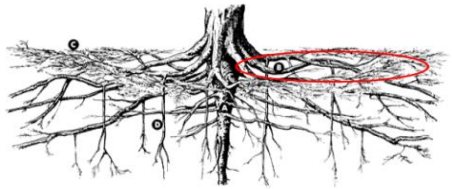
Field Instrumentation for Assessment of the Effect of Climatic Conditions on Slope Stability in Singapore



Trees above ground

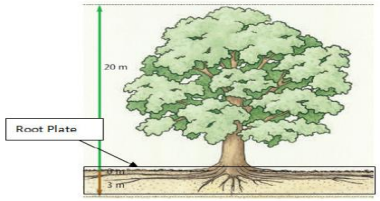


Trees below ground



Lateral Roots – Help support and anchor the tree, may extend far out beyond crown spread

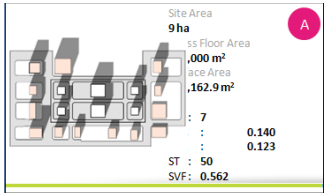
Uprooting modes– Flat Root



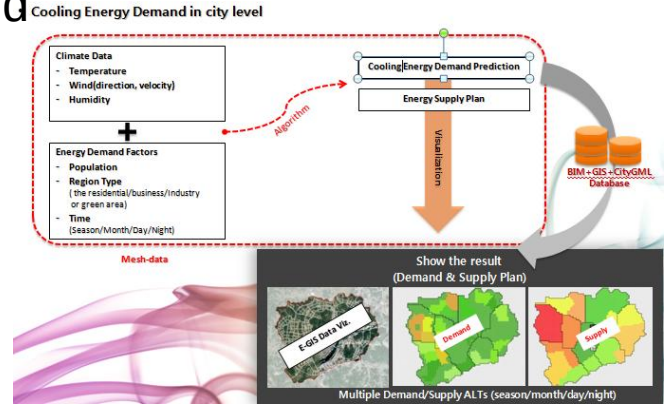
A flat root system is basically a "flattened" heart root (Dobson, 1995)

Cooling Energy Demand

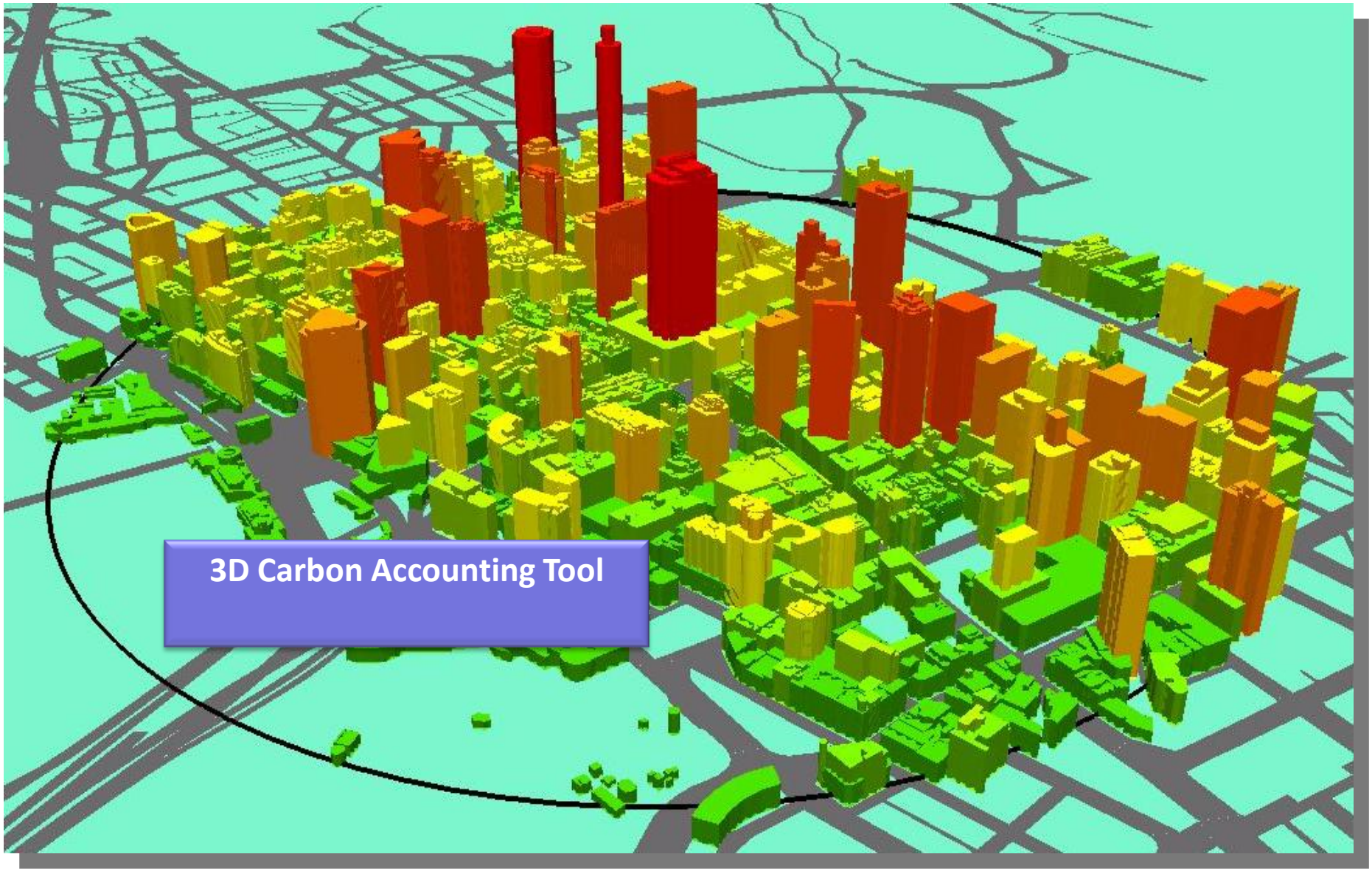
Precinct Area = 9 ha
Plot Ratio = 10
Max GFA = 630,000 m²



ECG_U	=	0.0435	Wh/m^{-4}
ECG	=	5,407.8	MWh/Yr
SG_U	=	0.1219	Wh/m^{-4}
SG	=	15,141.8	MWh/Yr
$FAIG_U$	=	0.1331	Wh/m^{-4}
FAIG	=	16,284.5	MWh/Yr
SCL_U	=	1.430	Wh/m^{-4}
SCL	=	**176,570.8**	MWh/Yr
	=	**280.71**	$KWh/m^2/yr$



An Assessment & Visualisation Tool



(I) Environmental Information

Study of climate change and climatic baselines on UHI/Thermal Comfort

(a) Access to oceanic, atmospheric, and geophysical data archives, which includes the a**rchive of Global Synoptic Observation Data from 1901-Present** of synoptic (hourly, 3-hourly, and 6-hourly climate data) from across the globe as well as global precipitation analyses (monthly, pentad, and daily) from surface and satellite measurements for 1979 onwards.

(NCEP/NCAR Reanalysis I: 1948-present (~200km); NCEP/DOE Reanalysis II: 1979-near present (~200km); NOAA-CIRES 20th Century Reanalysis version 2 (20CRv2): 1871-2012 (~200km); NCEP Climate Forecast System Reanalysis (CFSR) (~38km): 1979-present; Real-time NCEP Global Forecast System (GFS): 2015-present (~13km)

(b) Use of the datasets for the study of climate change and climatic baselines on UHI and thermal comfort; Sharing of research and studies on heat stress index.

(c) Customisation of the global/regional datasets and optimisation of integration of the downscaled global/regional climate data for the study of climate change and climatic baselines on UHI and thermal comfort for *ANY* typical city planning and design;

(d) Optimisation of GSM/RSM/MSM/Urban Model for urban planning and design.

(II) Modeling for Urban Environment

- NOAH (NOAH land surface model)
  - ✓ Developed in **N**CEP, **O**SU, **A**ir force, **H**ydrologic Research Lab
  - ✓ NOA1: maximum one-vegetation type considered in each cell

- Coupling of Land Surface Model to Urban Canopy Model – NCEP RSM/MSM

  The effects of land use type and anthropogenic heat (AH) and its diurnal variation on the thermal and wind environment such as coupling the Noah Land Surface Model (*Chen and Dudhia, 2001) to the Single-Layer Urban* Canopy Model (*Kusaka et al., 2001; Kusaka and Kimura, 2004) using a tile-approach (Tewari et al., 2006).*

(III) Use of Environmental Information for I*ntegrated* Planning & Design of Sustainable Cities

(a) Integration of Built and Natural Environment Datasets, incorporating environmental datasets, sensing and simulation such as urban materials; greenery types; scenario modelling (environment and climate) at various scales (island, precinct and building scales); 3D wind, temperature, thermal comfort;

(b) Analytical and 3D visualisation tools and services to support planners and managers in understanding the complex nature of urban development;

(c) Intelligent Disaster Decision Support System (IDDSS) for urban planning, integrating a smart geospatial information platform with an advanced optimisation and simulation engine to facilitate discovery and then integrate and analyse the data to develop simulation and optimisation models;

THANK YOU